UNIT 2

Chemistry in Living Systems

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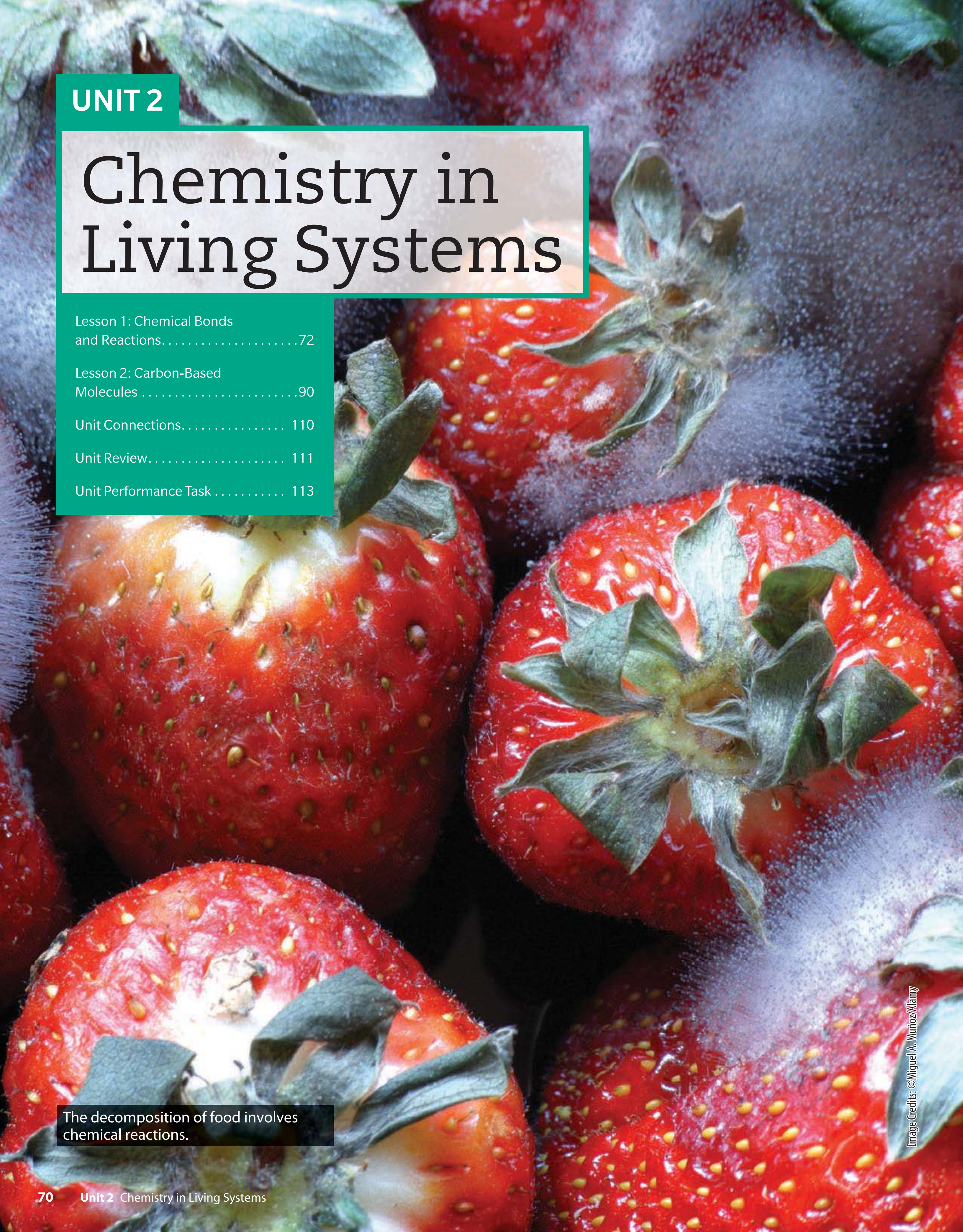


The decomposition of food involves chemical reactions.

FIGURE 1: This bombardier beetle is emitting a defensive spray.

Bombardier beetles store two chemicals in separate chambers in their abdomens. When the beetle is threatened, the chemicals quickly mix, producing a hot, noxious spray that deters most attackers. While the burning chemicals can harm or even kill insects or other animals threatening the beetle, the bombardier beetle itself is not harmed by the chemical blast.

Predict How do you think living things, such as the bombardier beetle, use chemistry to maintain homeostasis and survive in their environment?

DRIVING QUESTIONS

As you move through the unit, gather evidence to help you answer the following questions. In your Evidence Notebook, record what you already know about these topics and any questions you have about them.

1. Why is water crucial for life on Earth?
2. What properties of water make it important to organisms?
3. How is matter changed in chemical reactions?
4. How do organisms use chemistry to survive?
5. What materials are organisms made of?

UNIT PROJECT

Chemistry of Soap and Stains

What makes some stains harder to remove than others? Why do certain soaps and cleaners work on some types of stains but not others? Discover the chemical properties of different stains and how cleaners act on chemical bonds and structures to clean them. Can you predict which cleaners will wash away each stain?

Go online to download the Unit Project Worksheet to help plan your project.

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.

Explore Online

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.

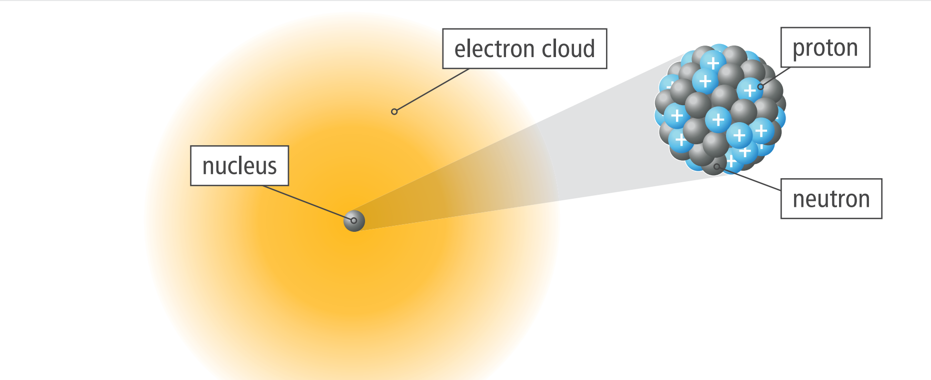
Atoms, Elements, and Compounds

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.



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.

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.

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.

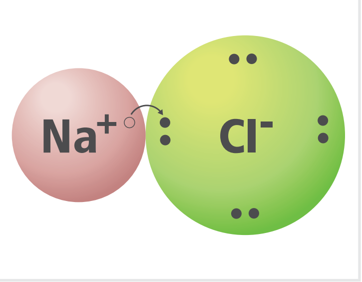
Image Credits: (b) ©Jupiterimages/Thinkstock/Alamy

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.

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.

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

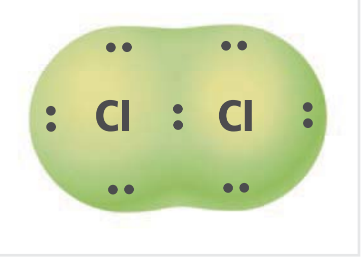


Covalent Bonds

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.

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.

FIGURE 5: Two chlorine atoms form a covalent bond.



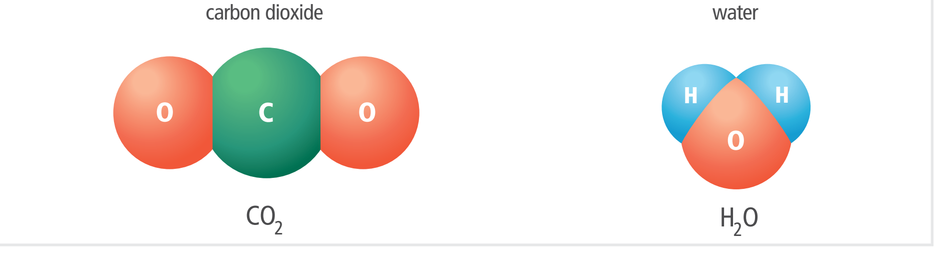
Analyze Create a Venn diagram to compare and contrast ionic and covalent bonds in terms of electrons and stability.

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?

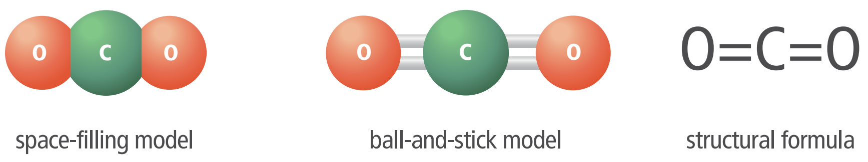
FIGURE 6: Carbon dioxide is made of two oxygen atoms each bonded to a carbon atom. Water is made of two hydrogen atoms each bonded to an oxygen atom.



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.

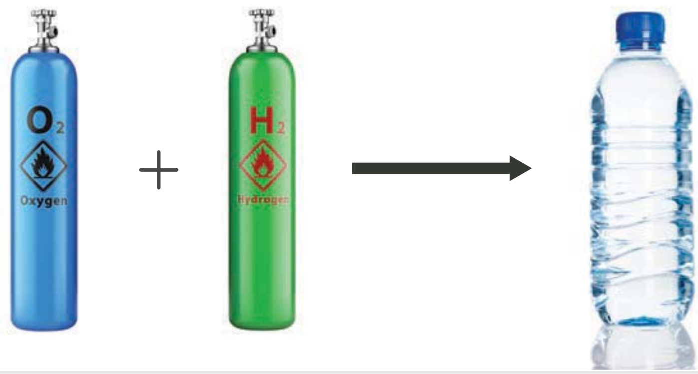
FIGURE 7: Types of Molecular Models



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?

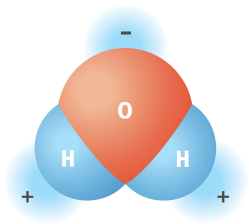
Properties of Water

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.



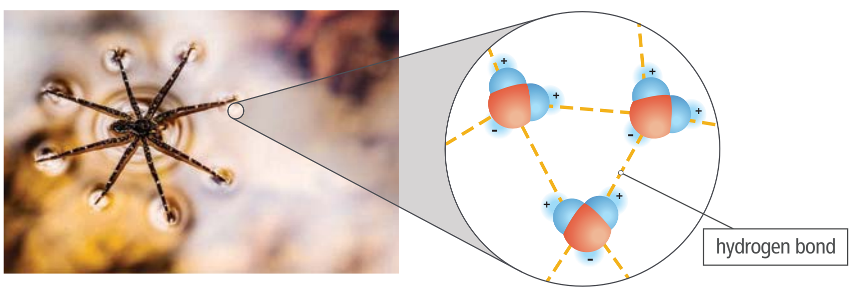
A water molecule has two covalent bonds. A water molecule is an example of a polar molecule. You can think about polar molecules similarly to how you think about the poles of a magnet. Just as magnets have a north and a south pole, polar molecules have a region with a slightly positive electric charge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

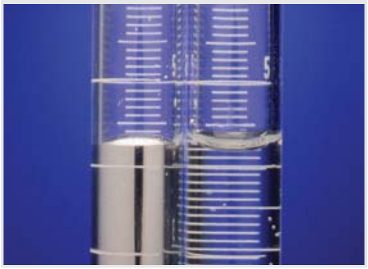
Individual hydrogen bonds are about 20 times weaker than typical covalent bonds, but they are strong enough to have an influence on water molecules. As a result, a large amount of energy is needed to overcome the interactions among water molecules. Water is a liquid at the temperatures that support most 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.

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.



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.

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.

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?

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.

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

Acids and Bases

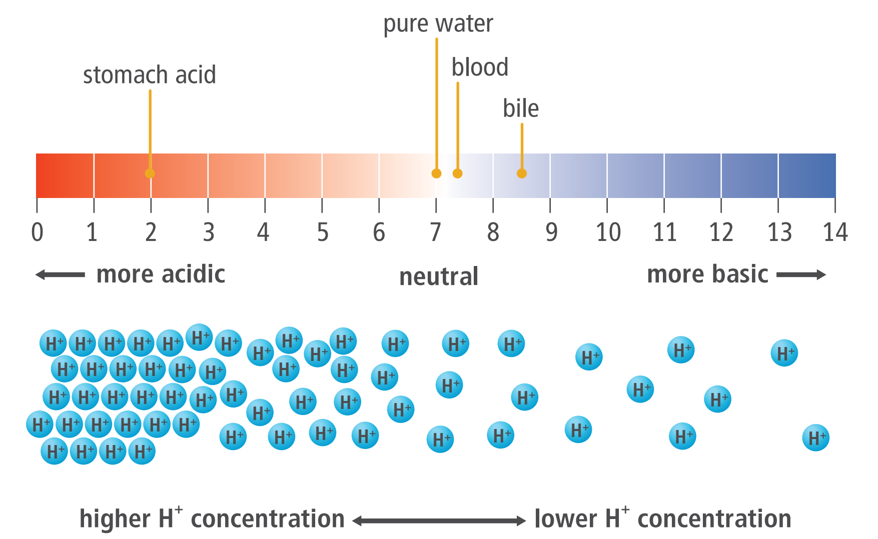
Some compounds separate into ions when they dissolve in water. An acid is a compound that releases a proton—a hydrogen ion (H^+)—when it dissolves in water. An acid increases the concentration of H^+ ions in a solution. Bases are compounds that remove H^+ ions from a solution. When a base dissolves in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

Explore Online

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

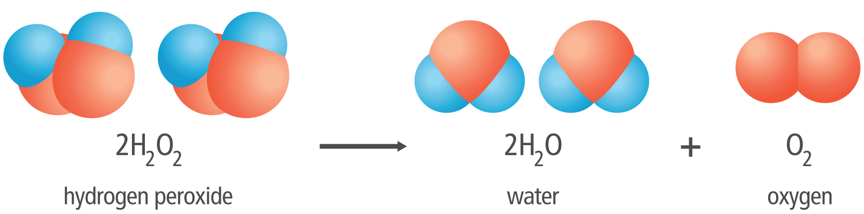
To understand chemical reactions, we need to know the inputs and outputs. Reactants are the initial substances in a chemical reaction. As the reaction proceeds, the bonds of the reactants are broken and rearranged to form the products of the reaction. The products of a chemical reaction are different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

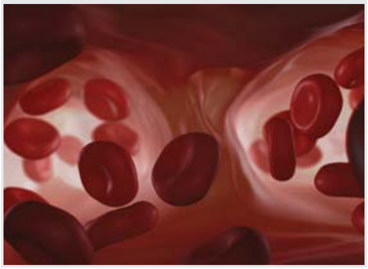


Analyze Answer these questions about the chemical reaction in Figure 13:

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.

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

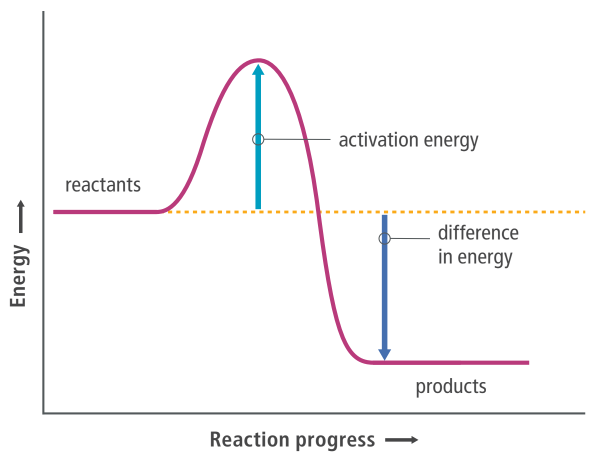
All chemical reactions involve changes in energy. The reactants must absorb energy in order to break their chemical bonds. When new bonds form to make the products, energy is released. During a chemical reaction, energy is both absorbed and released. Some chemical reactions absorb more energy than they 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.

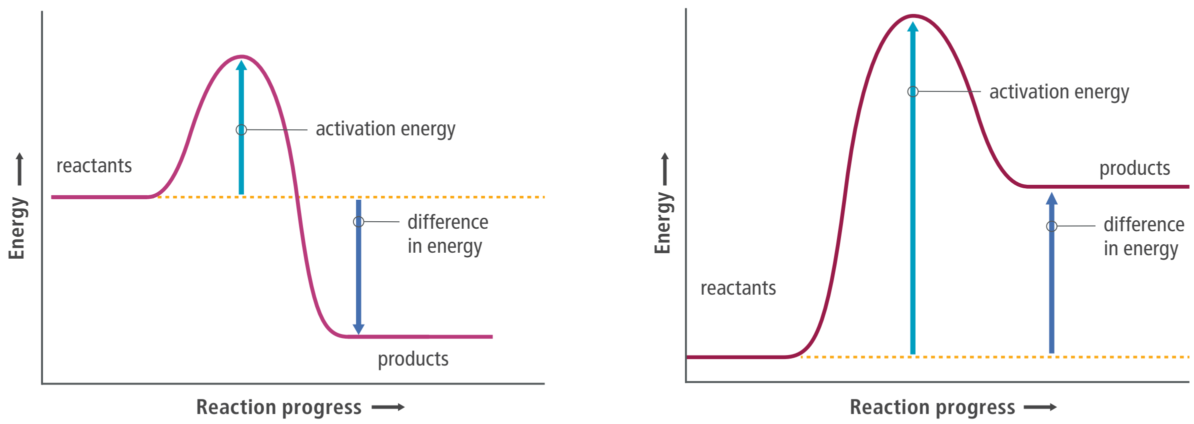
FIGURE 16: A chemical reaction in a firefly releases light energy.

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

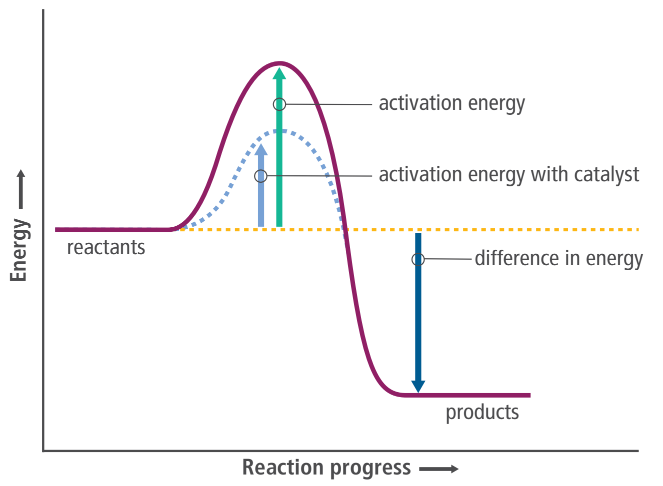
Chemical reactions in living things often need to happen quickly, but some have a high activation energy that makes this not possible. Remember that the activation energy is the amount of energy a chemical reaction needs to absorb before it can begin. Often, that activation energy comes from an increase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

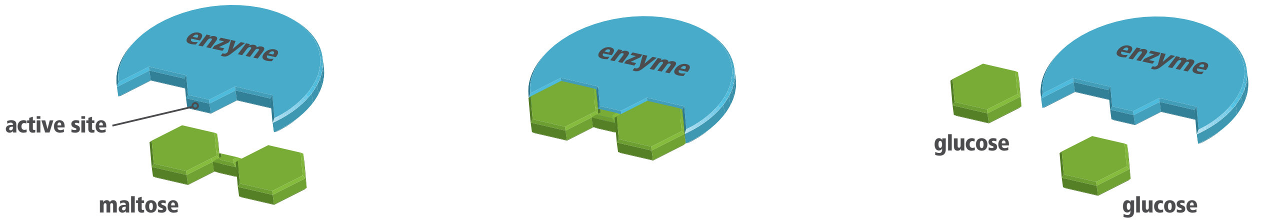
Enzymes

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.

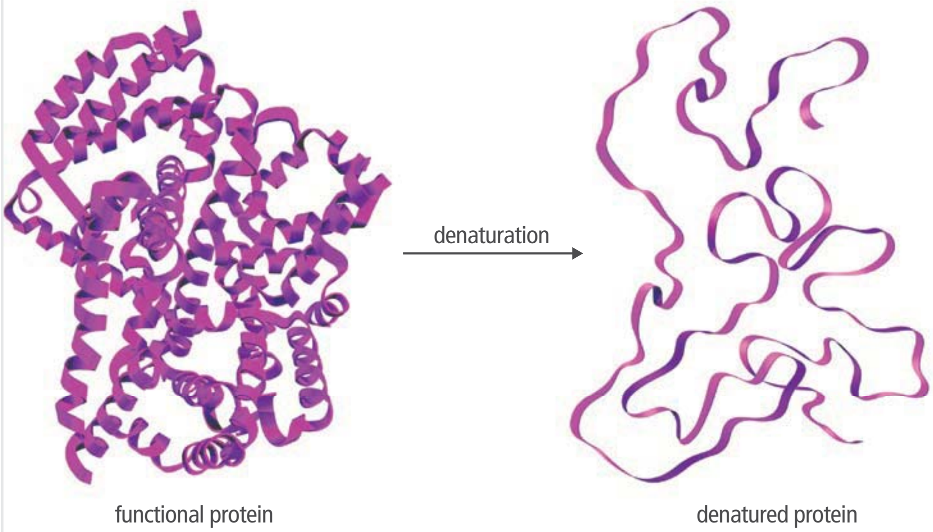
3 The enzyme allows a chemical reaction to occur that breaks the maltose molecule into two glucose molecules.

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?

Hands-On Lab

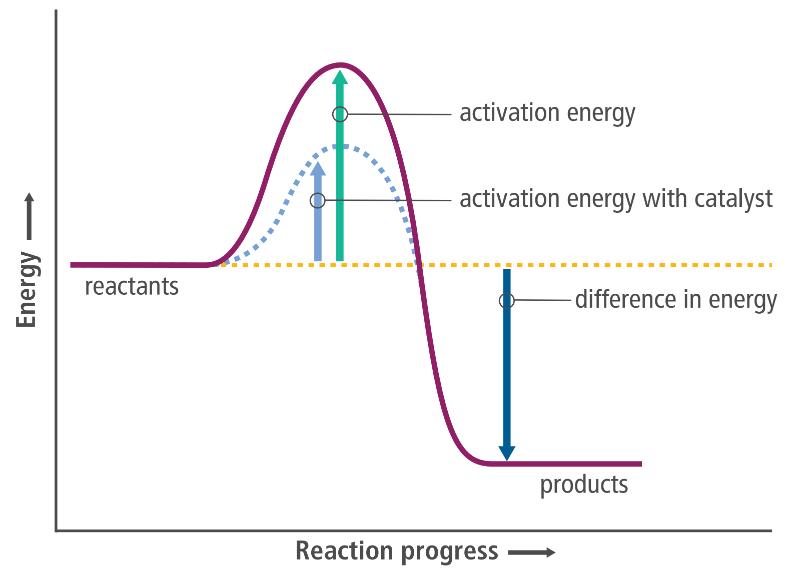
Experimenting with Catalase

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?

Image Credits: (l) (c) (r) ©Science Photo Library/Rhys Lewis & Minh Tan Pham, AHS/DECD/age fotostock

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

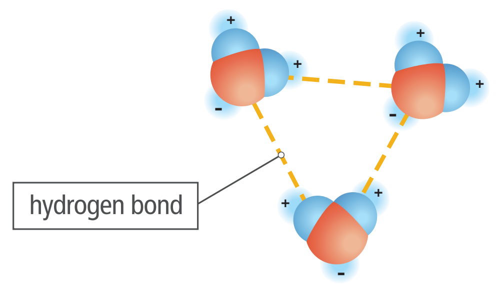
5. A chemical reaction proceeds until it reaches an equilibrium. Which statement is true when the reaction is at equilibrium?
   - **a.** All the reactants are used up.
   - **b.** The reaction is completed and will not change.
   - **c.** One reactant is used up, but one or more of the other reactants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

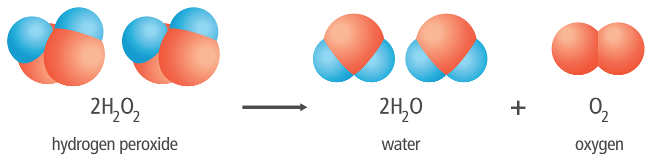


9. How does the structure of a water molecule result in hydrogen bonding? Use evidence from Figure 24 to support your answer.

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.

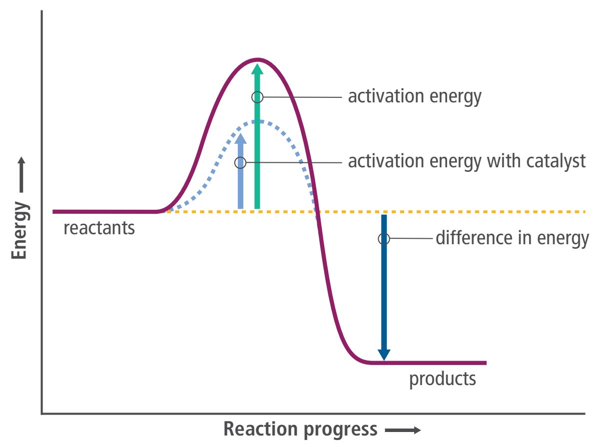


Use Figure 25 to answer questions 12–13.

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.

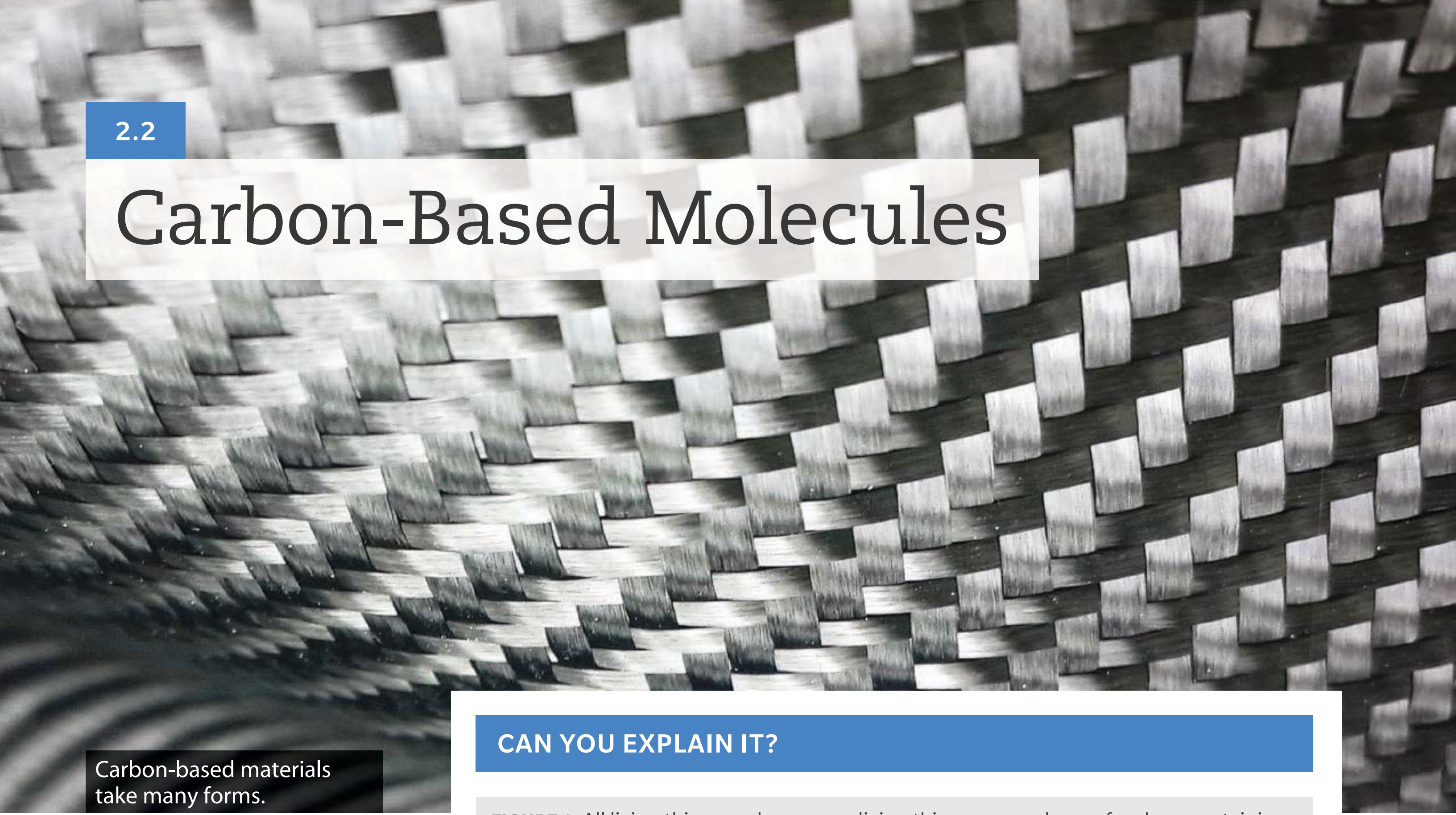
Remember to include the following information in your study guide:

- 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.

2.2

Carbon-Based Molecules



Carbon-based materials take many forms.

CAN YOU EXPLAIN IT?

FIGURE 1: All living things and many nonliving things are made up of carbon-containing compounds.

The universe is made up of many different elements, but one of the most important elements in living things is carbon. It is often called the element of life because carbon atoms are the basis of biomolecules, molecules that make up living things. Carbon is also found in a number of nonliving things. Its properties allow it to form millions of different compounds with vastly different properties. Carbon atoms can arrange themselves into the molecules that make up your food and your clothes. Carbon-based materials are also used for many technical applications, such as electronic, optics, and even the rubber in tires.

Gather Evidence As you explore the lesson, gather evidence for how the atoms in biomolecules are separated and rearranged to make new biomolecules.

Predict How can carbon be the central component of so many different types of molecules?

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Properties of Carbon

Organic chemistry refers to the chemistry of carbon-based molecules, because living organisms are responsible for the production of nearly all naturally occurring carbon compounds. It was once believed that carbon-based compounds were only able to be produced in living things. Now, organic chemists know how to synthesize many different types of carbon-based compounds to make foods, materials, medicines, and much more.

Predict Why do you think carbon has an entire branch of chemistry devoted to its study?

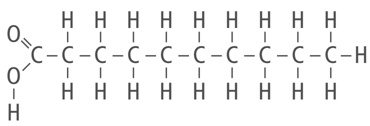
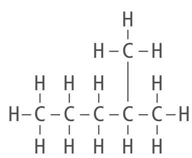
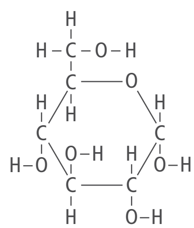
Despite the great number of carbon-based compounds that exist, those that compose all living things can be divided into four main groups: carbohydrates, lipids, proteins, and nucleic acids. Because of their relatively large size, these organic compounds are called macromolecules. Their structures and functions may differ in many ways, but they all share a common feature—they contain carbon.

Structure of Carbon-Based Molecules

Carbon atoms are the basis of most molecules that make up organisms and are involved in most processes that support life. The atomic structure of carbon gives it unique bonding properties. These properties allow it to form covalent bonds, or bonds that share pairs of electrons. Carbon has four available electrons to share with atoms of other elements to form covalent bonds. In organic molecules, carbon is most commonly bonded to the elements hydrogen, oxygen, nitrogen, and phosphorus.

Collaborate With a partner, compare the shapes of the molecules in Figure 2. What is similar? What differs?

FIGURE 2: Carbon-based molecules can have many different structures, including straight chains, branched chains, and rings.

Straight Chain	Branched Chain	Ring
		
CAPRIC ACID	**ISOHEXANE**	**GLUCOSE**
A fatty acid found in plant oils such as coconut oil and palm kernel oil, as well as in the milk of some mammals. This fatty acid has been shown to have antibacterial and anti-inflammatory properties.	A clear liquid used to make gasoline and glues, and as a solvent for extracting oils.	A simple sugar that is an important energy source for living organisms.

Analyze According to Figure 2, how many chemical bonds does carbon form? How is the number of bonds carbon can make related to its ability to form molecules with many different shapes?

In addition to forming single bonds, carbon atoms can also form double, or even triple, bonds. In structural formulas, double bonds are represented with two bars, and triple bonds are represented with three bars. As you can see in Figure 3, the carbon atom in carbon dioxide forms a double bond with each oxygen atom. In acetylene, each carbon forms one triple and one single bond. Both are carbon-based gases, but they have different chemical properties. For example, they have different densities, and carbon dioxide is odorless, while acetylene has a slight odor similar to garlic.

FIGURE 3: Carbon can form single, double, or triple bonds.

Carbon Dioxide (CO_2)	Acetylene (C_2H_2)
O=C=O	H–C≡C–H
A colorless, odorless gas that is naturally present in air (about 0.03 percent) and is used by plants in photosynthesis.	A colorless gas that burns with a bright flame and is used in welding. In its pure form, it has a sweet, garlic-like odor.

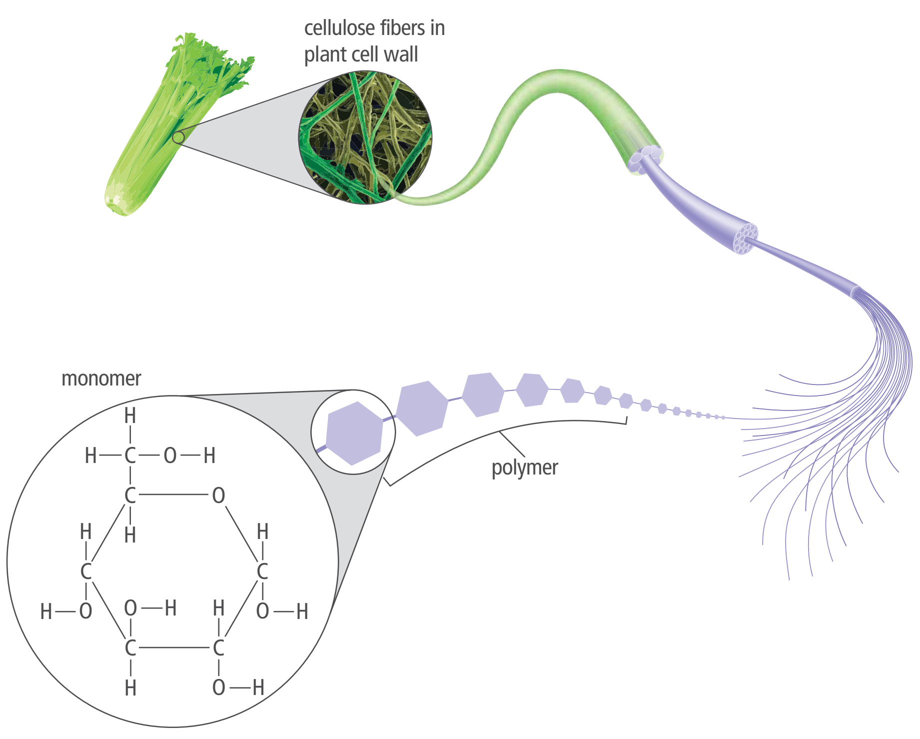
Predict Which do you think is the strongest type of covalent bond? A single, double, or triple bond? Explain your answer.

Monomers and Polymers

Looking back at Figure 2, you may note three characteristics of carbon atoms. One is that carbon can bond with itself or other atoms. The second is that the unique bonding in carbon molecules enables them to form a ring or a long-chain structure of repeating subunits. A polymer is a large molecule made of subunits called monomers. The monomers in a polymer may be the same, as they are in the cellulose molecule in Figure 4, or they may be different, as they are in proteins. The third characteristic of carbon atoms is they often bind to hydrogen atoms. In fact, many carbon compounds contain only carbon and hydrogen and are a class of compounds called hydrocarbons. The covalent bonds in hydrocarbons store a great amount of energy.

Language Arts Connection One polymer you may have heard of before is silk. Silk fibers, made by spiders and some worms, are very strong and durable. Now, researchers are trying to produce even stronger silk by feeding silkworms carbon-based materials such as carbon nanotubes. Scientists are hoping to use the enhanced silk for medical implants and wearable electronics. With a partner, research carbon-enhanced silk and discuss the ways this material might influence human society.

FIGURE 4: Cellulose is a polymer made of smaller subunits called glucose monomers.



Engineering

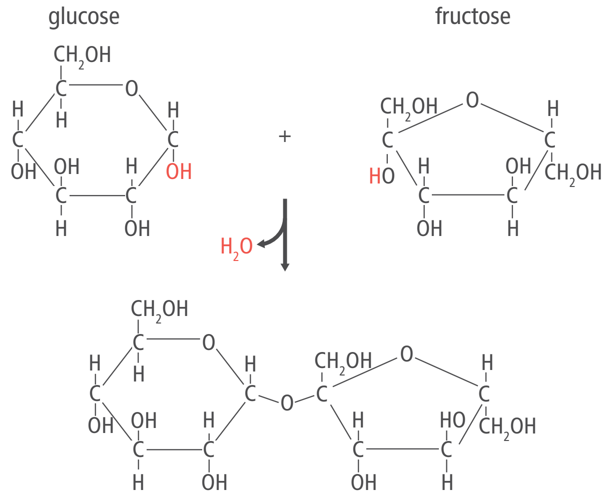
Making Polymers

Polymers may form through the process of dehydration synthesis. This process involves chemical reactions in which a molecule of water (H_2O) is released as one monomer bonds to another. One monomer provides a hydrogen ion (H^+) and the other provides a hydroxyl group (OH^-). Some polymers can be broken down in a reverse reaction, called hydrolysis. The bonds between the monomers are broken by the addition of water molecules.

In the human body, enzymes called hydrolases use hydrolysis to break apart polymers. In industry, dehydration synthesis can be used to make a wide variety of polymers, such as those in nylon and polyester fabrics.

Explain What might be some of the economic and environmental tradeoffs of producing clothes from human-made polymers, such as nylon and polyester, versus natural polymers, such as cotton?

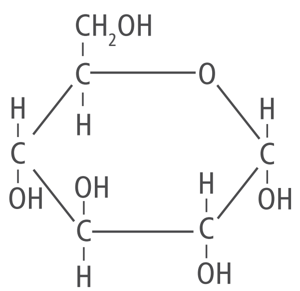
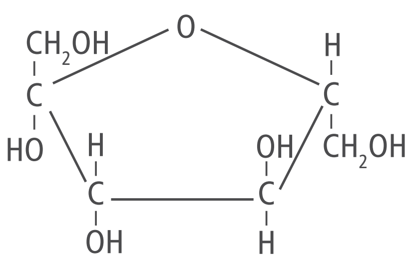
FIGURE 5: Glucose and fructose undergo dehydration to form sucrose, commonly known as table sugar.



Isomers

The molecular structures you've seen so far look flat, but molecules are actually three-dimensional (3D). The 3D placement of atoms and chemical bonds within organic molecules is central to understanding their chemistry. Molecules that share the same chemical formula but differ in the placement, or structure, of their atoms and/or chemical bonds are known as isomers. Because the atoms are connected in different ways, isomers have different physical and chemical properties. For example, glucose and fructose are energy sources for cell processes. However, fructose is not as easily metabolized as glucose. Isomers allow for greater variety of organic compounds with different properties.

FIGURE 6: The isomers glucose and fructose both have the chemical formula $C_6H_{12}O_6$.

Glucose	Fructose
	

Explain Compare and contrast the different types of carbon structures in terms of their structures, chemical formulas, and functions.

Structure and Function of Carbon-Based Molecules

The carbon-based macromolecules found in all organisms may be classified in four basic types: carbohydrates, lipids, proteins, and nucleic acids. These molecules, often called biomolecules, have different structures and functions, but all are formed around carbon chains and rings. Some organisms, like most green plants, make high-energy biomolecules through a process called photosynthesis. Other organisms obtain carbon-based molecules by eating food. All living things break down organic molecules and rearrange them to form new molecules necessary for life.

Carbohydrate Structure and Function

Analyze Which of the carbohydrates shown in Figure 7 are monomers, and which are polymers? Explain your answer.

Carbohydrates are composed of carbon, hydrogen, and oxygen. The most basic carbohydrates are simple sugars, or monosaccharides. Many simple sugars have either five or six carbon atoms. Glucose, one of the sugars made by plant cells during photosynthesis, is a six-carbon sugar. Simple sugars bind together to make larger carbohydrates called polysaccharides. A polysaccharide with two sugars joined together, such as sucrose, is called a disaccharide.

FIGURE 7: Glucose, sucrose, and cellulose are all carbohydrates.

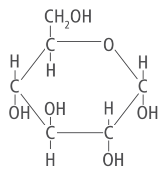
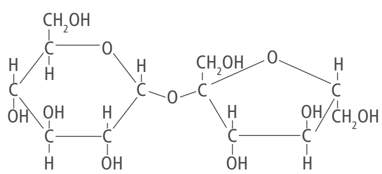
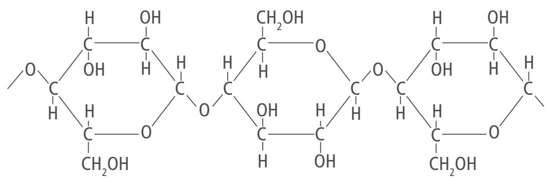
Monosaccharide	Disaccharide	Polysaccharide
		
GLUCOSE	**SUCROSE**	**CELLULOSE**
A simple sugar that is an important energy source in living organisms.	A simple sugar made of a glucose monomer bonded to a fructose monomer. Known as table sugar.	A complex carbohydrate with a straight, rigid structure that makes up the cell wall—a tough, outer layer of plant cells.

FIGURE 8: Carbohydrate-rich Foods

The energy contained in carbohydrate molecules can be released and used for essential cell processes. Carbohydrate-rich foods such as bread, pasta, vegetables, fruit, and sweeteners contain carbohydrate molecules that your body breaks down to release usable energy. Simple carbohydrates like glucose and sucrose can be quickly broken down and absorbed by your body. Complex carbohydrates are made up of longer chains of molecules and are broken down more slowly. Sources of complex carbohydrates include whole grains, potatoes, and vegetables. Complex carbohydrates are often rich in cellulose, or fiber, which is not broken down in your digestive system.

Predict Why does it take longer for your body to break down complex carbohydrates than simple carbohydrates? How is this related to their molecular structures?

Lipid Structure and Function

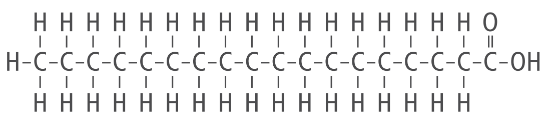
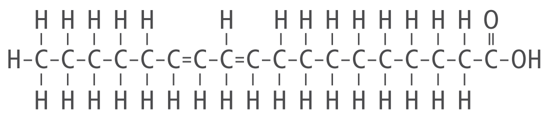
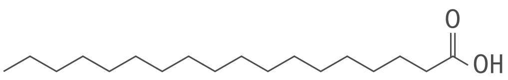
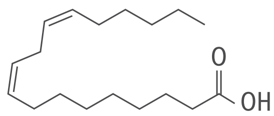
Lipids are similar to carbohydrates in that they contain many of the same elements. Unlike carbohydrates, lipids are nonpolar molecules. Thus, most lipids are insoluble in water because water molecules are polar. This is the origin of the phrase, "oil and water don't mix, " because lipids include many natural fats, oils, and waxes. Lipids also include phospholipids and steroids. Some lipids, such as fats and oils, are broken down as a source of usable energy for cells. Phospholipids are important for cell membrane structure. Waxes form protective coatings, and steroids act as chemical messengers.

The simplest lipids are fatty acids. More complex lipids often contain several fatty acids linked together. Fatty acids consist of long chain hydrocarbons containing two oxygen atoms at one end. Fatty acids are distinguished from one another by chain length and by the number of hydrogen atoms connected to each carbon atom. As shown in Figure 9, fatty acids are modeled in two different ways. The line drawings represent the same molecules as those above them, but the individual elements are not labeled. Each kink in the chain represents a carbon atom, including the ends.

FIGURE 9: Otters have a gland that secretes oil onto their fur.

Explain How does secreting oil onto their fur help otters maintain homeostasis?

FIGURE 10: Fatty acids can be saturated or unsaturated.

Saturated Fatty Acid	Unsaturated Fatty Acid
	
	
Saturated fatty acids are found mostly in foods from animals and some plants. They are usually solid at room temperature. There are no double bonds between the carbon atoms, so this molecule is "saturated" with hydrogen atoms. The saturated fatty acid shown here is stearic acid.	Unsaturated fatty acids are found mostly in oils from plants and are usually liquid at room temperature. There are double bonds between some carbon atoms, so this molecule is not saturated with hydrogen atoms, and it has a bent shape. The unsaturated fatty acid shown here is linoleic acid.

Collaborate With a partner, make a chart to compare and contrast these two sets of molecules: carbohydrates and lipids, and saturated and unsaturated fatty acids. Compare and contrast the elements that make them up, the arrangement of their atoms, and the types of bonds that hold the atoms together.

Fats and Oils

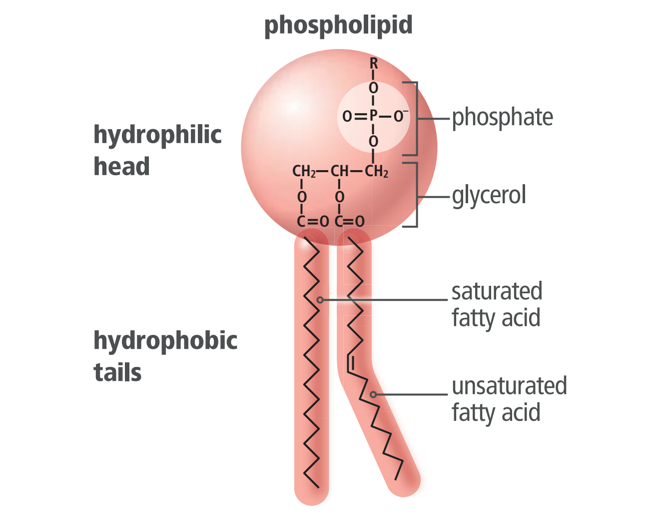
We often think of fats as something to avoid in our diets. However, fats and lipids serve many important roles in maintaining overall health. Fats contain 2.25 times as much energy per gram as carbohydrates, so fats are a major source of energy. They also play an important role in the absorption of some vitamins and minerals. Fats are needed to build and repair cell membranes and are an essential part of the myelin sheath that surrounds and protects nerves. Fats are also required for processes such as muscle movement, blood clotting, and inflammation.

FIGURE 11: Foods Containing Fats and Oils

Phospholipids

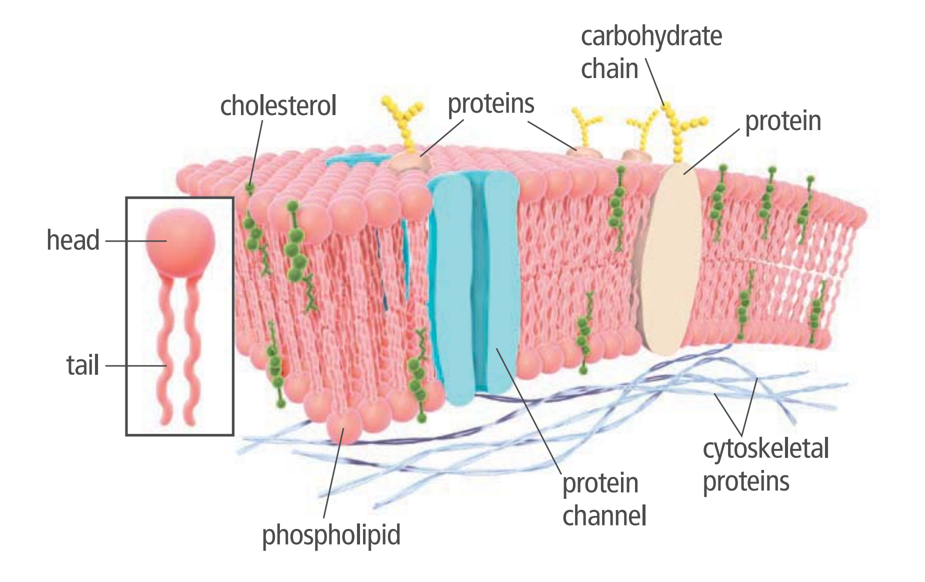
A phospholipid is a lipid that consists of glycerol, two fatty acids, and a phosphate group. The “head” of the phospholipid is made up of the glycerol backbone and the phosphate group. The fatty acids make up the “tails.” The polar head of a phospholipid is soluble in water, or hydrophilic, which means “water loving.” The nonpolar tails are insoluble in water, or hydrophobic, which means “water fearing.” When phospholipids are placed in a watery environment, they arrange themselves in two layers. The hydrophilic phosphate heads face outside, and the hydrophobic tails face the inside, away from the water.

FIGURE 12: A phospholipid is made up of a hydrophilic head and hydrophobic tails. The head contains glycerol and a phosphate group. The fatty acids in the tails may be saturated or unsaturated.



Cell membranes are made up of a double layer of phospholipids. The polar heads face the outside of the membrane, and the nonpolar tails face the inside of the membrane. Since some of the molecules that need to pass through the membrane are polar, the nonpolar tails of the phospholipids would normally repel them. Proteins in the membrane create “passageways” that allow both polar and nonpolar molecules to pass from one side to the other.

FIGURE 13: Phospholipids are responsible for the dynamic nature of the cell membrane. The membrane also contains carbohydrates, cholesterol, and proteins.



Predict The hydrophobic tails of phospholipids keep water from passing directly through the cell membrane. How might this be beneficial for the maintenance of homeostasis in a cell?

Waxes

Waxes are distinguished from other lipids by very long carbon chains that are very hydrophobic. They resist water and are solid at a range of temperatures. Waxes form protective coatings for many living things, including plants, animals, fungi, and bacteria. Their properties also make waxes valuable commodities. Many products contain waxes, including makeup and foods.

FIGURE 14: Waxes form protective coatings on leaves.

Worker honey bees make wax out of carbohydrate molecules in honey. Bees consume the honey, and special glands in their abdomens convert the sugars in the honey into wax molecules. The wax then oozes out of the bee through small pores and forms flakes on the outside of the bee's body. Worker bees then chew the wax to make it soft and pliable, and finally incorporate it into the beehive structure. These bees are breaking down carbon-based molecules to make different molecules.

Analyze Waxes are a main component of the cuticle found on the upper surface of some plant leaves. Why might the leaves of these plants have a waxy cuticle?

Steroids

So far, the lipids you have examined have a mostly linear structure. Steroids, however, are a class of lipid that has a fused ring structure. All steroids have four linked carbon rings, and several of them have a short tail. Steroids contain both hydrophobic and hydrophilic regions, and they are insoluble in water.

Cholesterol is an example of a lipid with a fused ring structure. Your body needs a certain amount of cholesterol to function properly. Not all of the cholesterol in your body comes from your diet; your cells can make cholesterol from fatty acids. The ability to make cholesterol is important because it is an important part of cell membranes. Cholesterol is also the starting compound for steroid hormone production. Cholesterol-based steroids have many functions. Some regulate your body's response to stress. Others, such as testosterone and estrogen, control sexual development and the reproductive system.

FIGURE 15: A nutrition label shows how many milligrams of cholesterol are present in your food. Nutrition labels also show how many grams of carbohydrates, fats, and proteins are present.

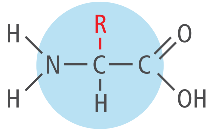
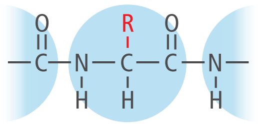
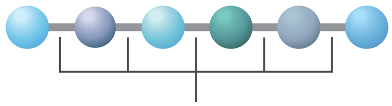
Explain Excess cholesterol has been linked to heart disease, so the labels on some food products contain wording such as "cholesterol-free." Is it necessary to eat a completely cholesterol-free diet? Explain your answer.

Protein Structure and Function

Analyze How do the terms polymer and monomer apply to the structure of protein molecules?

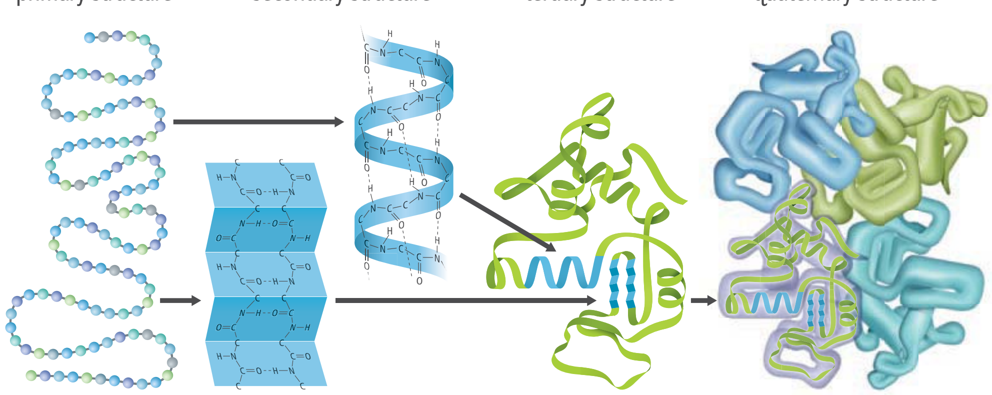
Proteins are often described as the building blocks of life. They play many essential roles in organisms. Many proteins function as enzymes, which help regulate chemical reactions within our bodies. The building blocks for proteins are amino acids. There are a number of different amino acids, but organisms use only 20 to build proteins. Our bodies can make 12 of these standard amino acids. The others come from foods you eat, such as meats, beans, and nuts.

FIGURE 16: Proteins are made up of amino acids linked together in a chain called a polypeptide.

		
Amino acids have a carbon atom bonded to a hydrogen atom, an amino group (NH_2), and a carboxyl group (COOH). Different amino acids have different side groups (R).	Peptide bonds form between the amino group of one amino acid and the carboxyl group of another amino acid.	A polypeptide is a chain of precisely ordered amino acids linked by peptide bonds. A protein is made of one or more polypeptides.

Proteins differ in the number and order of amino acids. The specific sequence of amino acids determines a protein's structure and function. Proteins may have three, and sometimes four, levels of structure: primary, secondary, tertiary, and quaternary.

FIGURE 17: There are four possible levels of protein structure.



Predict Which would probably have the greatest effect on a protein's function—a change to the primary, secondary, or tertiary structure? Explain your answer.

The primary structure of a protein is the sequence of amino acids in the polypeptide. Hydrogen bonds between amino acids cause the chain to fold into zig-zag-shaped sheets and spirals, which make up the secondary structure. The tertiary structure is the 3D shape of the protein. Many proteins contain multiple polypeptide chains, or subunits, which combine to form the quaternary structure.

Remember that enzymes and other proteins are particularly sensitive to environmental changes. If pH or temperature exceed the normal ranges for a cell, the shape of its proteins may change, and their function may be disrupted. This process, called denaturation, only disrupts secondary, tertiary, and quaternary structures—the sequence of the protein remains unaffected.

Nucleic Acid Structure and Function

The unique sequence of amino acids in a protein is determined by the sequence of monomers in another biological polymer: nucleic acid. Nucleic acid polymers are made up of monomers called nucleotides. A nucleotide is composed of a sugar, a phosphate group, and a nitrogen-containing molecule, called a base. The sugar and phosphate nucleotides form the backbone of the DNA double helix. The nitrogenous bases form matching pairs held together by hydrogen bonds.

There are two general types of nucleic acids: DNA and RNA. Figure 19 shows the structure of each of these nucleotides and their nitrogenous bases. The names of the nitrogenous base also refer to the nucleotides that contain the bases.

FIGURE 18: Nucleotide Model

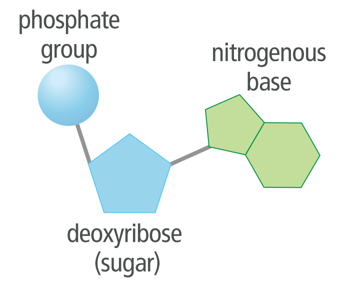
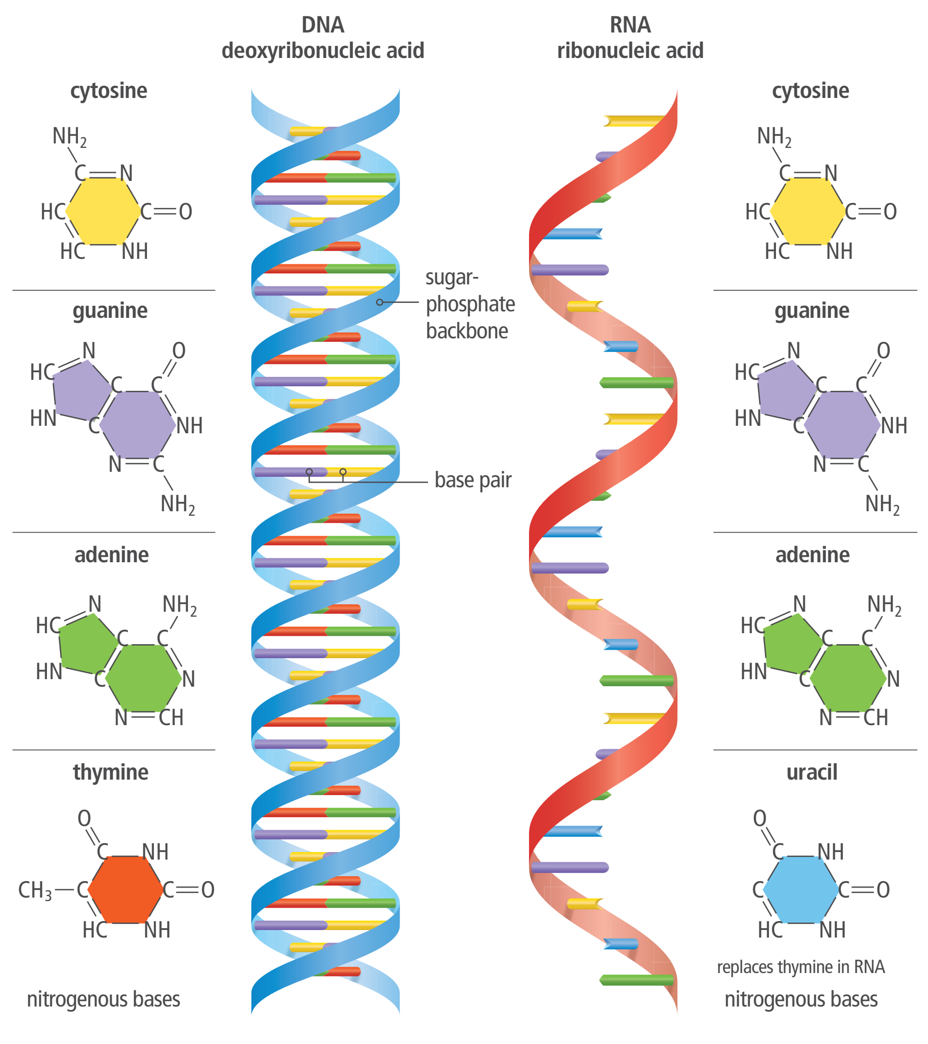


FIGURE 19: DNA and RNA are both nucleic acids.



Collaborate With a partner, compare and contrast RNA and DNA in terms of structure and nitrogenous bases.

Explore Online

Hands-On Lab

Modeling Biochemical Compounds Model a variety of biomolecules to better understand how atoms are arranged in these large molecules.

Explain Use evidence you have gathered to support or refute the claim that living things break down and rearrange carbon-based molecules. To organize your thoughts, make a graphic organizer to compare and contrast the four main types of biomolecules in these aspects: elemental makeup, overall structure, and main functions.

Chemical Energy

FIGURE 20: When an elk eats plants, energy in the plant molecules is released through a series of chemical reactions.

Model Draw a simple flow chart to show how energy is transferred from the sun to the elk's cells.

Your cells need energy to perform essential cell processes. This energy comes from food, but not directly. First, the food must be digested. Digestion breaks food into individual molecules, and some of these molecules store energy in their bonds. This chemical energy is only usable after biomolecules are broken down by a series of chemical reactions known as cellular respiration.

Chemical Energy and ATP

Cellular respiration transfers energy from organic molecules such as glucose to a molecule called ATP, or adenosine triphosphate. ATP is known as the energy currency of the cell. It provides the energy necessary for cell processes such as pumping molecules across the cell membrane and driving chemical reactions. ATP also provides energy for mechanical processes, such as the contraction of muscle cells.

Cellular respiration is complementary to another process called photosynthesis. In this process, organisms such as plants and algae absorb energy from sunlight and use it to help make high-energy sugars. When an animal such as an elk eats a plant, the plant matter is digested, and individual molecules are transported to cells. Cellular respiration converts energy from some of these molecules to a form cells can use.

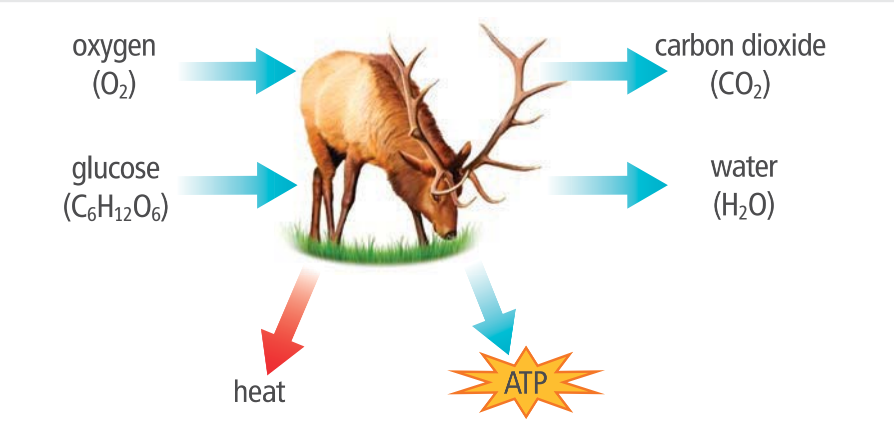
Energy and Matter

Cellular respiration is a multistep process that transfers chemical energy from glucose to ATP, which provides energy for cell processes. In addition to glucose, cellular respiration requires oxygen as a reactant. The products are ATP, carbon dioxide, and water. Heat is also released as a product of cellular respiration.

Collaborate With a partner, answer the following questions.

1. What is the energy input for cellular respiration, and what are the energy outputs?
2. According to this model, is cellular respiration an endothermic or exothermic process? Explain your answer.

FIGURE 21: Cellular Respiration



ATP is a molecule made up of subunits called adenine and ribose, as well as three phosphate groups. The bonds between the phosphate groups are high-energy bonds that store chemical energy in a form that cells can use.

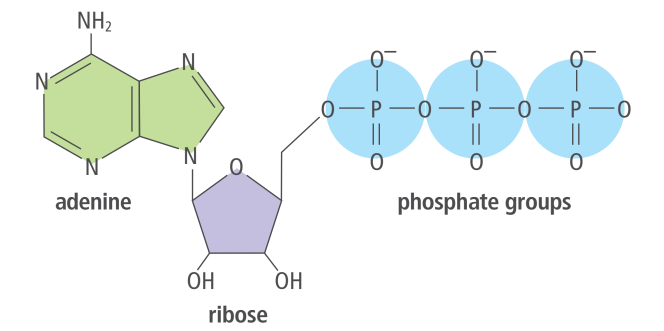


FIGURE 22: ATP is made up of adenine, ribose, and three phosphate groups. The "tri" in triphosphate signifies that there are three phosphate groups in this molecule.

ATP is generated when cells carry out cellular respiration. In this process, energy from the breakdown of biomolecules is used to add a phosphate group to adenosine diphosphate, or ADP. The energy carried by ATP is released when a bond between two phosphate groups is broken. A phosphate group is released, and ATP becomes ADP, a lower-energy molecule. The energy released can be used to power cell processes such as transporting materials, carrying out reactions, and producing new molecules.

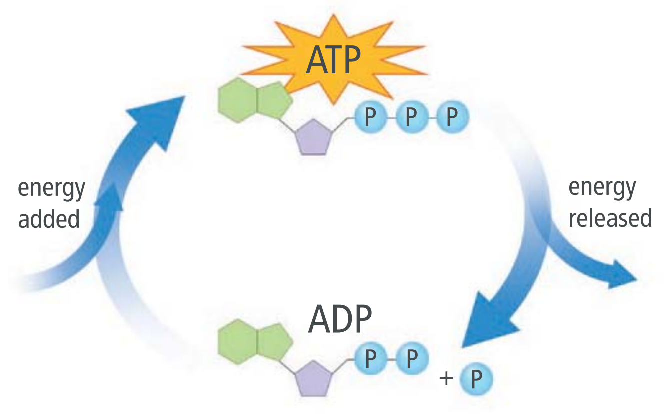


FIGURE 23: Cells use energy from the breakdown of carbon-based molecules to add a phosphate group to ADP. This forms ATP, a higher-energy molecule. When a phosphate group is removed from ATP, energy is released for cell processes.

Language Arts Connection Make an analogy to explain the role of ATP in storing energy and releasing energy for cell processes.

Analyzing Energy Content in Food

The energy in food is measured in Calories. One Calorie from food equals one kilocalorie, or 1000 calories. Proteins and carbohydrates have 4 Calories per gram, and fats have 9 Calories per gram. The number of Calories in food is indirectly related to the amount of ATP that can be produced from the food. The number of ATP molecules produced depends on the type of molecule that is broken down—carbohydrate, lipid, or protein.

Carbohydrates are the molecules most commonly broken down to make ATP, but they are not stored in large amounts in your body. The body uses fat for energy storage instead because it is more Calorie-dense and can yield greater amounts of ATP per unit mass. Proteins store about the same amount of energy as carbohydrates, but they are less likely to be broken down to make ATP. The amino acids in proteins are needed to build new proteins more than they are needed for energy.

Explain A common misconception is that proteins are a good source of energy. Explain which types of foods are the best energy sources and how this relates to the amount of ATP made by your cells.

The Cell Membrane

Collaborate Think about another system that controls inputs and outputs. Why is it necessary to control inputs and outputs in this system?

To maintain homeostasis, cells need to take in some substances while expelling others. But how do cells manage the import and export of materials? The cell membrane, or plasma membrane, has a specialized structure that allows the cell to control the passage of materials into and out of the cell. Different types of carbon-based molecules, including lipids, proteins, and carbohydrates, make up the cell membrane.

Cell Membrane Structure

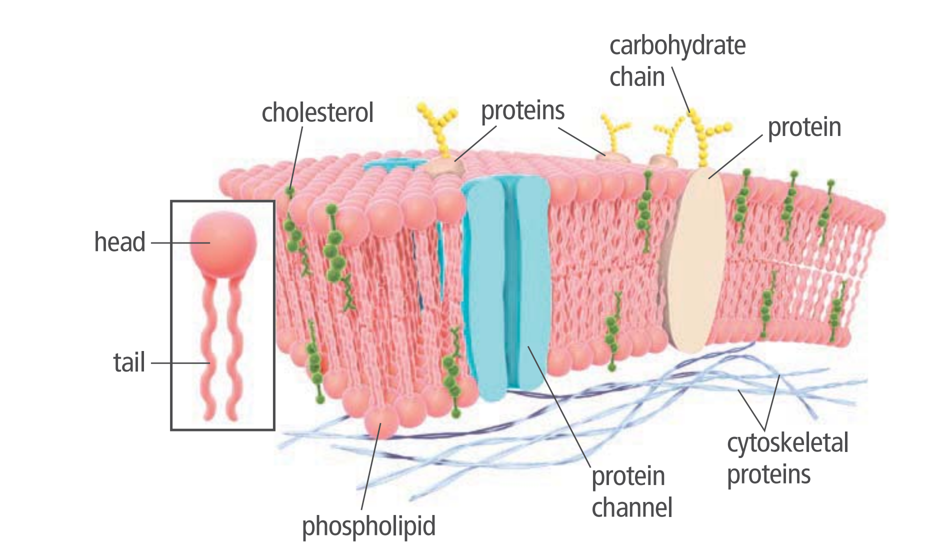
The cell membrane consists of a double layer of phospholipids. The hydrophilic heads of the phospholipids face the watery environment outside the membrane, and the hydrophobic tails face the inside of the membrane. However, the types of substances that could pass through the membrane, and their rates of passage, would be quite limited if the membrane was only composed of phospholipids. To solve this problem, the cell membrane also contains carbohydrates, proteins, and cholesterol.

Explore Online

Hands-On Lab

Modeling the Cell Membrane Make a model to investigate the properties of the cell membrane.

FIGURE 24: The cell membrane is made of two phospholipid layers embedded with other molecules, such as proteins, carbohydrates, and cholesterol.



A cell membrane needs multiple passageways for substances to enter and exit the cell. This task is accomplished by proteins. Some proteins embedded in the phospholipid bilayer transport materials across the membrane. Others, in the form of enzymes, speed up chemical reactions that take place on the membrane. Still others act as receptors for specific molecules, such as hormones.

Explain How do the structures within the cell membrane help the cell function within a larger system?

Carbohydrates on the cell membrane serve as identification tags, which allow cells to distinguish one type of cell from another. They also enable neighboring cells to adhere to each other. Cholesterol gives strength to the cell membrane by limiting the movement of the phospholipids, preventing the membrane from becoming too fluid. Cholesterol also protects the cell membrane at low temperatures by preventing it from becoming solid if the cell is exposed to cooler than normal temperatures.

The structure of the cell membrane gives it the property of selective permeability. This means it allows some, but not all, materials to cross. Selective permeability enables a cell to maintain stable conditions in spite of unpredictable, changing conditions outside the cell. Molecules and other materials cross the membrane in several ways. Some of these methods require the cell to expend energy; others do not. How a particular molecule crosses the membrane depends on the molecule's size, polarity, and concentration inside versus outside the cell.

Model Draw a model to illustrate the concept of a semipermeable membrane.

Passive Transport

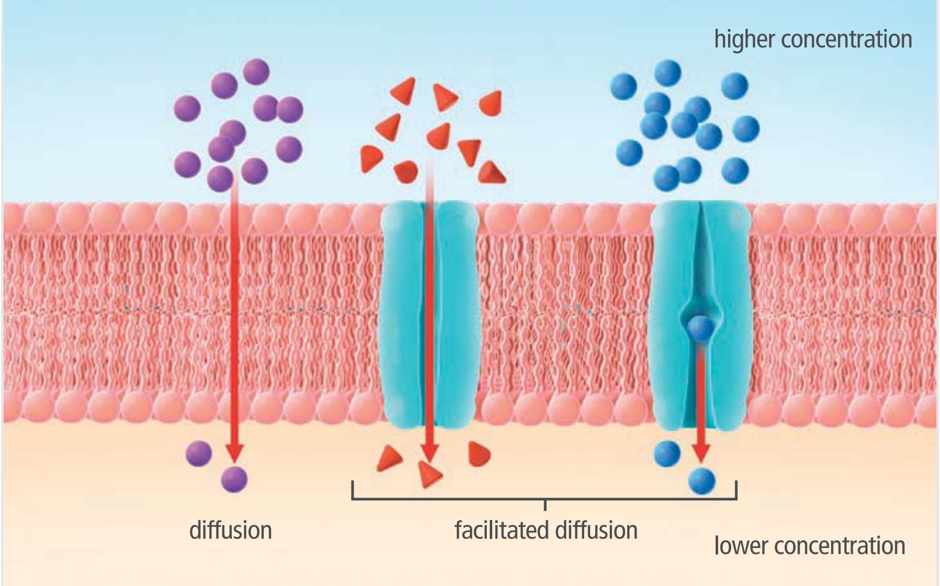
Cells almost continually import and export substances across the cell membrane. If they had to expend energy to move every molecule, cells would require an enormous amount of energy to stay alive. Fortunately, some molecules enter and exit a cell without energy input from the cell in a process called passive transport. This type of transport results from the diffusion of molecules across a membrane.

Diffusion

Diffusion is the movement of molecules in a fluid or gas from a region of higher concentration to a region of lower concentration. It results from the natural motion of particles, which causes molecules to collide and scatter. Concentration is the number of molecules of a substance in a given volume. A concentration gradient is the difference in the concentration of a substance from one location to another. Molecules diffuse down their concentration gradient—that is, from a region of higher concentration to a region of lower concentration.

FIGURE 25: Passive Transport

Explore Online



Analyze Compare and contrast the way molecules move in diffusion and facilitated diffusion. Discuss concentration and mode of transport across the membrane.

Some molecules cannot simply diffuse across a membrane. Facilitated diffusion is the diffusion of molecules across a membrane through transport proteins. Some proteins form openings, or pores, through which molecules can move. Other proteins bind to specific molecules to be transported on one side of the membrane. When the correct molecule binds, these proteins change their shape, and this allows the molecule to pass through the membrane to the other side. Each protein in the membrane is specific to a certain type of molecule or particle.

Hands-On Lab

MATERIALS

- beaker, medium (3)
- food coloring
- hot plate
- ice
- timer
- water

Heat and Diffusion

You can see diffusion in action when you add food coloring to water. In this lab, you will measure the rate of diffusion in water at three different temperatures.

Predict Which solution will have the greatest rate of diffusion: a hot, cold, or room-temperature one? Explain your answer.

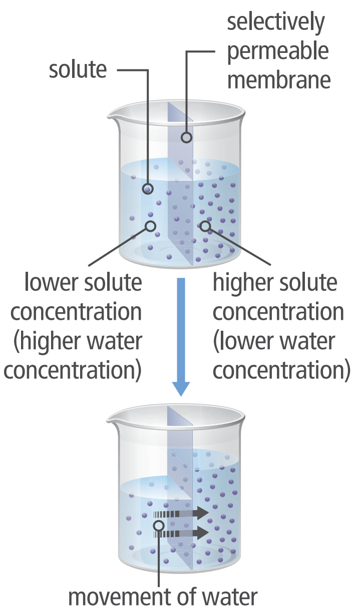
PROCEDURE

1. Place the same amount of water in three beakers.
2. Place Beaker 1 on the hot plate until it is warm, but not boiling. Place Beaker 2 in an ice bath or refrigerator. Leave Beaker 3 at room temperature.
3. With the timer ready, add one drop of food coloring in the room-temperature water. Record how long it takes the food coloring to evenly disperse throughout the solution. Repeat for the other two solutions.
4. Record your data in a data table.

ANALYZE

1. How could you tell that molecules were diffusing in this lab?
2. In which solution did diffusion occur most rapidly?
3. Explain your results in terms of the movement of water and food coloring molecules in each beaker. How did temperature affect this movement?

FIGURE 26: Osmosis is the movement of water toward areas of higher solute concentration.



Osmosis

Water molecules, of course, also diffuse. They move across a semipermeable membrane from an area of higher water concentration to an area of lower water concentration. They are also moving from an area of lower solution concentration to an area of higher solution concentration. This process is called osmosis. It is important to recognize that the higher the concentration of dissolved particles (solutes) in a solution, the lower the concentration of water molecules in the same solution. The membrane is only permeable to some solutes, so water must cross the membrane to equalize the concentrations of the two solutions.

Plants use osmosis to move water into the cells of their roots. Proteins in the cell membranes of root cells transport certain molecules into the cell. These molecules become more highly concentrated on the inside of the root cells than outside, and water follows the molecules into the cells. Water is always drawn toward areas of higher solute concentration.

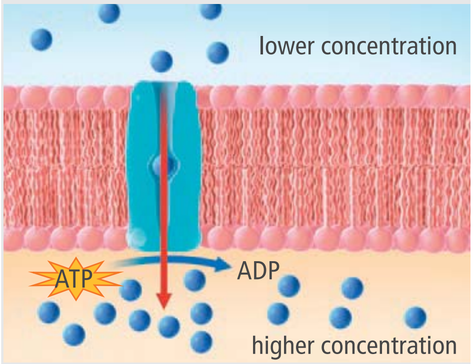
Model Red blood cells burst when placed in pure water. Draw a model explaining this phenomenon. Label semipermeable membrane, solute concentration, and movement of water on your model.

Active Transport

Sometimes a cell must move a substance against a concentration gradient in order to maintain homeostasis. Then it must use a process called active transport. Active transport drives molecules across a membrane from a region of lower concentration to a region of higher concentration using transport proteins. Unlike facilitated diffusion, the activity of transport proteins must be powered by chemical energy. An input of energy is necessary because the transport proteins have to overcome the natural tendency of substances to move with a concentration gradient. ATP often provides the energy for active transport.

Explore Online

FIGURE 27: Active Transport

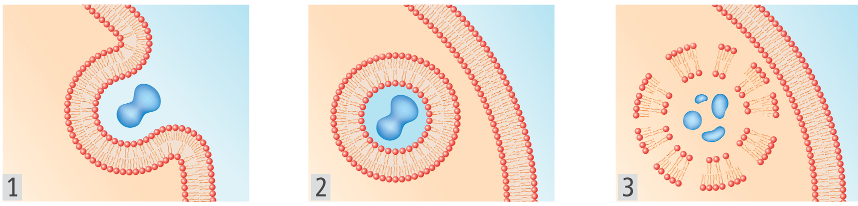


Analyze Make a table to compare passive and active transport in terms of energy, concentration, and the role of proteins in the membrane.

Endocytosis

A cell may also use energy to move large substances across the cell membrane using vesicles. Endocytosis is the process of taking liquids or fairly large molecules into a cell by engulfing them in a membrane. The cell membrane folds inward around the substance and pinches off inside the cell, forming a vesicle. The vesicle then fuses with a lysosome or similar vesicle. The vesicle membrane and content are broken down (if necessary) and released into the cell.

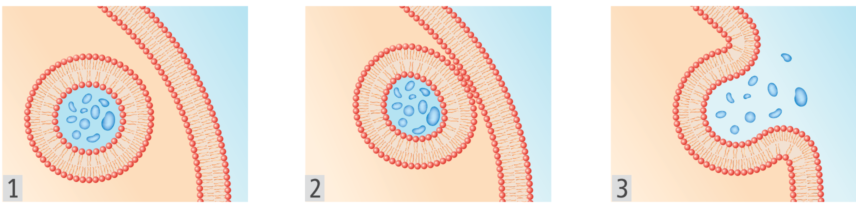
FIGURE 28: Endocytosis allows cells to take in materials.



Exocytosis

Exocytosis is the release of substances out of a cell by the fusion of a vesicle with the membrane. A vesicle forms around materials to be sent out of the cell. The vesicle then moves toward the cell's surface, where it fuses with the membrane and releases its contents.

FIGURE 29: Exocytosis allows cells to expel materials.



Predict Which would be more likely to carry out endocytosis: a white blood cell engulfing foreign materials or a cell that excretes hormones? Explain.

Explain Cystic fibrosis is a disease that occurs when a protein that normally transports ions across the cell membrane does not function properly. A change to the tertiary structure of the protein prevents it from transporting chloride ions out of cells. This leads to a lack of water outside the cells, which causes a sticky mucus to form in the lungs. Explain how diffusion and osmosis are related to the symptoms of cystic fibrosis.

Data Analysis

Food and Energy

Have you ever heard the saying, “You are what you eat?” In many ways, this is true! Living things are made up of different types of organic, or carbon-based, molecules. When we eat food, our digestive system breaks down the food into smaller molecules that can be used by the body. When digestion is complete, nutrients are absorbed by the body and transported by the circulatory system and lymphatic system to all the cells.

Once food enters the body, it can be broken down further to harness energy and form new types of molecules. For example, sugar molecules contain the elements necessary to produce many other types of organic molecules. These elements can be rearranged and combined with other elements through chemical reactions to form new products such as proteins, fats, and DNA.

The information on a food label, such as the one in Figure 30, can help you make good choices and compare the values of different foods. The label shown here is for cereal.

Serving size and number This measurement varies from one product to another. In this case, one serving equals $\frac{3}{4}$ of a cup of cereal.

Calories The numbers listed on the label are for one serving only. If you eat your cereal with milk, you will have a different number of Calories.

Nutrients to limit Americans usually consume too much saturated fat, trans fat, cholesterol, and sodium. Trans fat is a type of fat that can cause cell damage. A diet high in these nutrients is linked to obesity, which affects more and more Americans of all ages. Too much sodium can raise blood pressure by causing the body to retain water.

Nutrients to target Americans need to consume enough fiber, vitamins, and other nutrients each day. Notice that this product is low in Vitamin A and Vitamin C, but high in iron.

FIGURE 30: Nutrition labels contain information about the biomolecules in your food.

ANALYZE

Use the nutrition label shown in Figure 30 to complete the calculations necessary for Questions 1-6.

1. The label shows the calories in one serving of this food. If you were to eat two servings of this food, how many total calories would you consume?
2. If you were to eat two servings of this food, how many grams of carbohydrates would you consume?
3. Total carbohydrates is the sum of the simple sugars, starches, and dietary fiber in a product. Based on the label, what percentage of the total carbohydrates are in the form of fiber?
4. Carbohydrates contain 4 Calories per gram, fats contain 9 Calories per gram, and proteins contain 4 Calories per gram. Calculate the amount of caloric energy provided by each group of biomolecules in one serving of this food.
5. The label indicates that there are 0.3 grams of saturated fat in this product. What percentage of total fats is made up of unsaturated fats?
6. If a serving of this food is 29 grams, what percentage of the food is made up of carbohydrates?

The guidelines for what makes up a healthy diet have changed over time. You may have seen the food pyramid, which has carbohydrates at the base of the pyramid, and fats, oils, and sweetened foods at the top of the pyramid. More recently, a plate with four main sections for vegetables, proteins, grains, and fruits has been used as a model of a balanced diet. This is an example of how different fields of science work together to gather new information and update guidelines accordingly.

Language Arts Connection Research current nutritional guidelines using scientific and government sources. Consider the following when conducting your research:

- What is a balanced diet?
- How is a balanced diet modeled?
- How have nutritional guidelines changed over time?

Develop an informational pamphlet to share with your peers. Your pamphlet should contain the information you researched.

Informative/explanatory writing is a well-organized analysis of a topic. This type of writing tells how or why. Be sure to:

- Provide an introduction that clearly states the topic and engages readers.
- Organize your ideas to make important connections and distinctions.
- Include details that support your ideas.
- Provide a conclusion that supports your explanation.

FIGURE 31: Food has energy and nutrients your body can use.

PRACTICE

Track Your Nutrients

Record the foods you eat over the course of a week. Record the amount of carbohydrates, lipids, and proteins contained in the foods you eat for each meal. Are there any patterns in your eating habits?

MODELING BIOCHEMICAL COMPOUNDS | BUILDING BLOCKS OF PLANTS | INVESTIGATING OSMOSIS | **Go online to choose one of these other paths.**

Lesson Self-Check

CAN YOU EXPLAIN IT?

FIGURE 32: Carbon is essential to life on Earth.

Carbon is often called the building block of life because carbon atoms are the central component of most molecules that make up living things. These molecules form the structure of living things and carry out most of the processes that keep organisms alive. Carbon is so important because its atomic structure gives it bonding properties that are unique among elements.

Carbon atoms can arrange themselves into the molecules that make up your food and your clothes. Carbon-based materials are also used for many technical applications, such as electronics, optics, and even the rubber in tires.

Explain How can carbon be the central component of so many different types of molecules? Write an explanation that answers these questions:

1. How do the properties of carbon allow it to form a variety of different molecules?
2. What evidence is there that chemical reactions in organisms' cells break apart and rearrange carbon-based molecules?
3. How is energy from biomolecules transferred to cell processes in living things?

CHECKPOINTS

Check Your Understanding

1. Suppose you are going to draw models of the four main biomolecules. Which statement describes how the models will be similar?
   - **a.** They will all be formed around carbon chains and rings.
   - **b.** They will all include a chain of amino acids.
   - **c.** They will all have hydrocarbon chains connected only by double bonds.
   - **d.** They will all include a sugar, a phosphate group, and a base.

2. Which of these evidence statements should you include in an explanation of the relationship among carbon, amino acids, and proteins? Select all correct answers.
   - **a.** Amino acids are polymers made up of proteins.
   - **b.** Proteins are polymers made up of amino acids.
   - **c.** Proteins and amino acids are polymers because they contain multiple carbon atoms.
   - **d.** Amino acids are monomers made up mostly of carbon, hydrogen, nitrogen, and oxygen.

3. Use these terms to complete the statement explaining how living things obtain and use the molecules necessary for life:

   ATP, glucose, cell processes, cellular respiration, photosynthesis

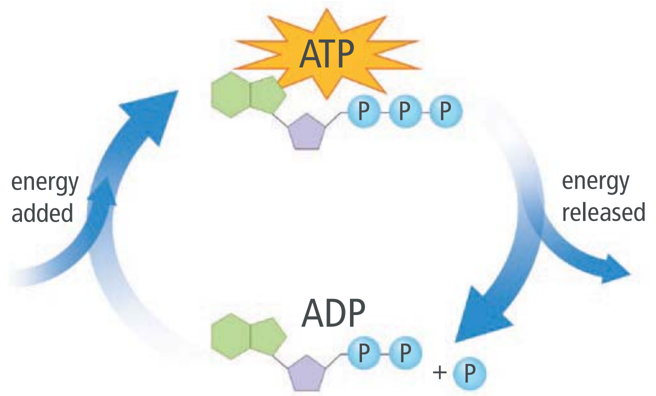
   Some living things, such as plants and algae, transfer energy from sunlight to _____ molecules. This process is known as _____. Virtually all living things transfer energy from these molecules to another molecule called _____, which provides the energy for _____. The process that produces this molecule is called _____.

4. Use these terms to complete the statement explaining how enzymes carry out chemical reactions in living things:

   bonds, shape, proteins, temperature

   Enzymes are _____ that help break chemical _____, as well as form new ones. Enzymes require specific environmental conditions related to _____ and pH to properly function. If these conditions are not met, the _____ of the enzyme may change. This could result in a nonfunctional enzyme that cannot carry out chemical reactions.

FIGURE 33: Formation and Breakdown of ATP



5. Use the model in Figure 33 to write an explanation for how ATP stores energy and how this energy is released for cell processes.

6. Which type of transport across the membrane requires ATP—facilitated diffusion or active transport? Explain your answer.

7. Draw a Venn diagram to compare and contrast carbohydrates and lipids. Include terms related to the molecular structures, functions, and energy content of these molecules.

MAKE YOUR OWN STUDY GUIDE

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

Organisms are made up of carbon-based molecules.

Carbon-based molecules are broken down and rearranged in organisms' cells to form new molecules and obtain energy.

Remember to include the following information to 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.

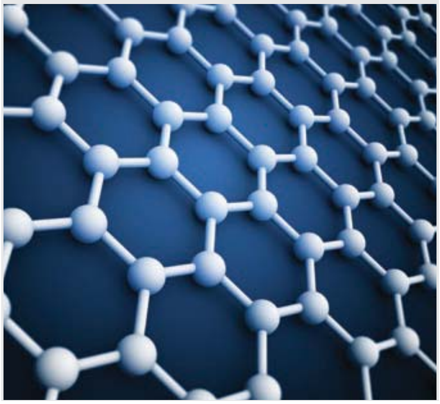
Consider how the models in this lesson can be used to compare and contrast different types of carbon-based molecules.

Physical Science Connection

Graphene The unique chemistry of carbon molecules has many uses in nonliving systems. For example, graphene is a substance composed of a honeycomb lattice of carbon, just one atom thick. Graphene was first characterized in 2004 and is an excellent conductor, extremely flexible, and 100 times stronger than steel. Scientists and engineers are just beginning to tap into the many possible uses for graphene and products made with it.

Using library and Internet resources, research current and potential applications of graphene. Write a blog entry explaining the applications you think would have the greatest benefits. Use evidence from your research to support your claims.

FIGURE 1: Schematic View of Graphene



Art Connection

Chemistry of Pigments Pigments are colored substances that can be used to color other materials. Pigments have been used for thousands of years to add color to artwork, clothing, skin, textiles, decorations, and other materials. Each pigment, whether organic or inorganic, natural or synthetic, has unique chemical properties that determine the pigment's color, durability, binding and other attributes. People using pigments and dyes carefully select those with the characteristics most appropriate and useful for the application at hand.

Using library and Internet resources, research the chemical properties and historical uses of pigments. Using your favorite pigments, produce your own work of art—a painting, a print, or another format. Prepare a report describing the chemistry and history of the pigments you chose to accompany your artistic work.

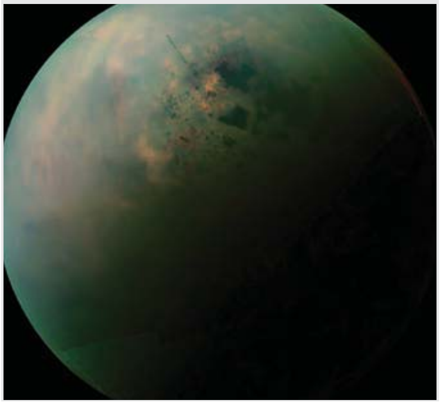
FIGURE 2: A Collection of Pigments

Life Science Connection

Silicon-Based Life All known life forms on Earth depend on the chemistry of carbon biomolecules. Carbon may not be the only possible basis for life, however. The element silicon (Si) shares several important chemical properties with carbon, including the ability to form four bonds per atom. Some scientists have theorized that silicon-based life—perhaps on other planets, with conditions unlike those found on Earth—might be possible. For example, some scientists think other planetary bodies, like Titan, may be able to sustain silicon-based life.

Using library and Internet resources, research the case for silicon as a basis for the chemistry of living things. Construct an explanation using evidence stating whether you think silicon-based life could exist. In your argument, discuss the specific chemical properties of silicon compared to carbon that could make life possible or not. Cite specific text evidence to support your claims.

FIGURE 3: Titan, one of Saturn's moons, has conditions that some think may be able to support silicon-based life.



SYNTHESIZE THE UNIT

In your Evidence Notebook, make a concept map, graphic organizer, or outline using the Study Guides you made for each lesson in this unit. Be sure to use evidence to support your claims.

When synthesizing individual information, remember to follow these general steps:

- Find the central idea of each piece of information.
- Think about the relationships between the central ideas.
- Combine the ideas to come up with a new understanding.

DRIVING QUESTIONS

Look back to the Driving Questions from the opening section of this unit. In your Evidence Notebook, review and revise your previous answers to those questions. Use the evidence you gathered and other observations you made throughout the unit to support your claims.

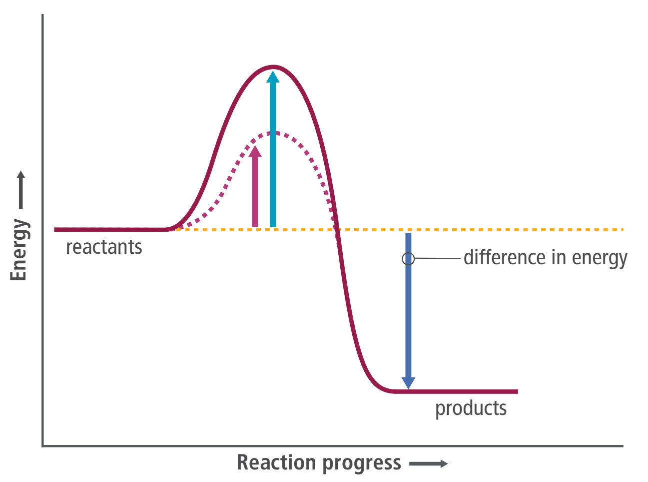
PRACTICE AND REVIEW

Use the information in from Figure 4 to answer question 1.

1. In the graph shown in Figure 4, the solid red line represents the energy of a chemical reaction. The dotted red line represents the energy of the same reaction, in the presence of a catalyst. Which statement best describes the role played by the catalyst?
   - **a.** The catalyst is used up in the reaction.
   - **b.** The catalyst makes the reaction more endothermic.
   - **c.** The catalyst increases the concentration of reactants.
   - **d.** The catalyst lowers the activation energy of the reaction.

Activation Energy with a Catalyst

FIGURE 4: The Effect of a Catalyst on a Chemical Reaction



2. Hydrogen bonding is an important factor contributing to many properties of water, including boiling point, specific heat, and adhesion. Which of the following would be true if hydrogen bonds between water molecules did not form? Select all correct answers.
   - **a.** Water would have less mass per volume.
   - **b.** Plants would be less efficient in transporting water from roots to leaves.
   - **c.** Heat produced by biochemical processes would be more difficult to regulate.
   - **d.** Less water would exist in liquid form on the surface of Earth.

3. In large hydrocarbon molecules such as fatty acids, the component atoms are held together by covalent bonds. Can similar stable molecules be formed with hydrogen bonds? Explain your reasoning.

4. In our bodies, the enzyme amylase is present in saliva and breaks down starch molecules into maltose. In our intestines, the enzyme maltase breaks down maltose into two glucose molecules. In your Evidence Notebook, develop a model demonstrating what effect an amylase enzyme deficiency would have on a person.

5. You learn that two sugar compounds are isomers, meaning they have the same chemical formula but differ in the placement of atoms and/or bonds. Would you expect the two sugars to have the same physical and chemical properties? Explain why or why not.

6. A phospholipid bilayer is the central component of cell membranes, which water molecules cannot freely pass through. What characteristics of the phospholipid bilayer prevent water from crossing freely?

a. The exterior and interior regions of the membrane are hydrophobic, keeping water outside.

b. The exterior and interior regions of the membrane are hydrophilic, trapping water inside the membrane.

c. The exterior of the membrane is hydrophobic, keeping water away, though the interior is hydrophilic.

d. The exterior of the membrane is hydrophilic, but the interior is hydrophobic, keeping water from passing.

7. Is it more difficult for your body to break down simple carbohydrates or complex carbohydrates?

a. Simple carbohydrates are easier to break down because they consist of only one or two sugar molecules.

b. Complex carbohydrates are easier to break down because they consist of many sugars chained together.

c. Simple carbohydrates are easier to break down because they consist of many sugars chained together.

d. Complex carbohydrates are easier to break down because they consist of only one or two sugar molecules.

8. What would be likely to happen if the hydrogen bonds in DNA were broken?

a. The loss of bonds would cause a DNA mutation.

b. The hydrogen bonds would be replaced with covalent bonds.

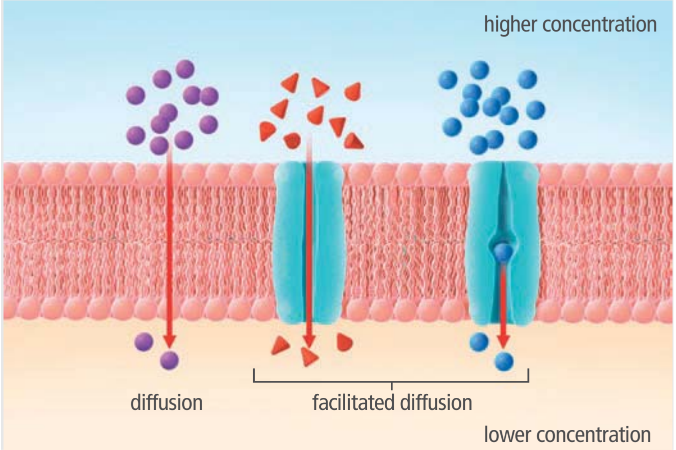
c. The loss of bonds would tear the DNA strands apart.

d. The loss of bonds could cause the DNA strands to fuse.

9. Insulin is a protein made up of two polypeptide chains. If a mutation caused a change in one of the amino acids in the primary structure of one of the insulin subunits, could that change affect the secondary, tertiary, or quaternary structure of the protein as well? In your Evidence Notebook, create a model to show how each level of protein structure might be affected by a primary structural change.

Use the information from Figure 5 to answer question 10.

FIGURE 5: Modes of passive transport include diffusion and facilitated diffusion.



10. In the image in Figure 5, molecules are entering a cell via forms of passive transport. If the molecules reach a higher concentration inside the cell than outside, which of these forms, if any, can still be used to transport molecules into the cell? Are other methods of transport more suitable in this scenario? Explain your reasoning.

UNIT PROJECT

Return to your unit project. Prepare your research and materials into a presentation to share with the class. In your final presentation, evaluate the strength of your hypothesis, data, analysis, and conclusions.

Remember these tips while evaluating:

- Consider the chemical properties of the stains, and how those properties affect the effectiveness of the soaps.
- Do your predictions match closely with your observations in the experiments? Why or why not?
- Think of ways you could apply your findings to predict properties of other substances.

How Do Enzymes Help with Lactose Intolerance?

Lactose intolerance is an inability to digest lactose, a sugar found in milk and other dairy products. More than two-thirds of adults suffer from lactose intolerance, which can cause symptoms including abdominal pain, gas, nausea, and diarrhea after dairy products are consumed. Supplements have been developed to assist those with lactose intolerance—but how do these supplements work?

1. ASK A QUESTION

With your team, define the specific question to be answered. Identify all of the factors you will explore to answer the question and the characteristics a complete answer should have.

2. PLAN AND CARRY OUT AN INVESTIGATION

With your team, design and carry out an experiment to determine the effect of lactose intolerance supplement tablets on milk.

Hands-On Lab

Explore Online

Digesting Milk

Use glucose test strips to determine the presence and amount of glucose in the milk. What differences do you expect to see between milk alone and milk treated with the tablets?

3. ANALYZE DATA

On your own, analyze the question you've defined along with your research. Can you characterize the effect the tablets have on the milk? How does this relate to the condition of lactose intolerance in humans? What might be the connection?

4. CONDUCT RESEARCH

On your own, research the structure of lactose, how it breaks down in the body, how lactose intolerance arises, and what the supplement tablets have in common with the normal digestive process. How does this information correlate with your experimental findings?

5. COMMUNICATE

Write a report explaining how the lactose intolerance supplement tablets work, why some people require these or similar pills, and how lactose is broken down. Present your report and relate your findings to what you have learned about chemical reactions, rearrangement of atoms, breaking of chemical bonds, and the formation of new products.

CHECK YOUR WORK

A complete presentation should include the following information:

- a clearly defined problem with supporting questions that are answered in the final presentation
- a summary of experimental results, based on observations
- a solution describing the mechanism of lactose breakdown, the specific deficiency in lactose intolerance, and the way in which the supplement tablets counteract symptoms in lactose-intolerant people