THEME FOCUS **Energy and Matter**
In every chemical reaction, there is a change in energy.

BIG Idea Atoms are the foundation of biological chemistry and the building blocks of all living organisms.

Section 1

Reading Preview

Essential Questions

- What are atoms?
- How are the particles that make up atoms diagrammed?
- What are the similarities between covalent and ionic bonds?
- How are van der Waals forces described?

Review Vocabulary

substance: a form of matter that has a uniform and unchanging composition

New Vocabulary

atom
nucleus
proton
neutron
electron
element
isotope
compound
covalent bond
molecule
ion
ionic bond
van der Waals force

Multilingual eGlossary

BrainPOP

Atoms, Elements, and Compounds

MAIN Idea **Matter is composed of tiny particles called atoms.**

Real-World Reading Link Many scientists think that the universe began with a sudden, rapid expansion billions of years ago. They think that the building blocks that make up the amazing diversity of life we see today are a result of that expansion. The study of those building blocks is the science of chemistry.

Atoms

Chemistry is the study of matter, its composition, and properties. Matter is anything that has mass and takes up space. All of the organisms that you study in biology are made up of matter. **Atoms** are the building blocks of matter.

Connection to History In the fifth century B.C., Greek philosophers Leucippus and Democritus first proposed the idea that all matter is made up of tiny, indivisible particles. It wasn't until the 1800s that scientists began to collect experimental evidence to support the existence of atoms. As technology improved over the next two centuries, scientists proved not only that atoms exist but also that they are made up of even smaller particles.

The structure of an atom An atom is so small that billions of them could fit on the head of a pin. Yet, atoms are made up of even smaller particles called neutrons, protons, and electrons, as illustrated in **Figure 1.** Neutrons and protons are located at the center of the atom, which is called the **nucleus. Protons** are positively charged particles (p^+), and **neutrons** are particles that have no charge (n^0). **Electrons** are negatively charged particles (e^-) that are located outside the nucleus. Electrons constantly move around an atom's nucleus in energy levels. The basic structure of an atom is the result of the attraction between protons and electrons. Atoms contain an equal number of protons and electrons, so the overall charge of an atom is zero.

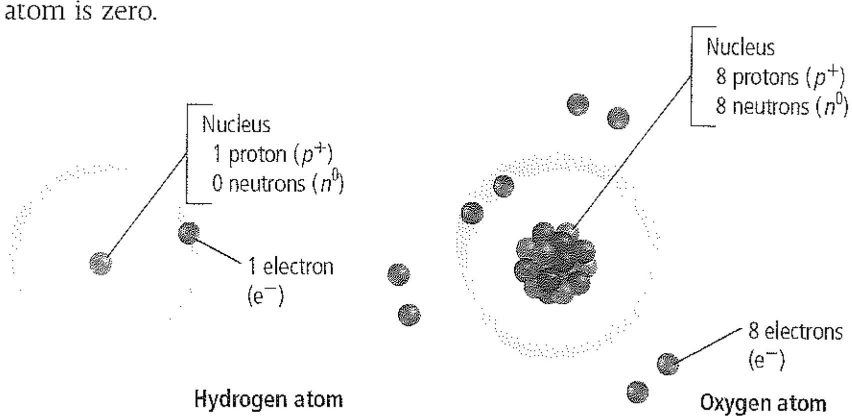


Figure 1 Hydrogen has only one proton and one electron. Oxygen has eight protons, eight neutrons, and eight electrons. The electrons move around the nucleus in two energy levels (shown as the darker shaded rings).
Infer *the charge of an atom if it contained more electrons than protons.*

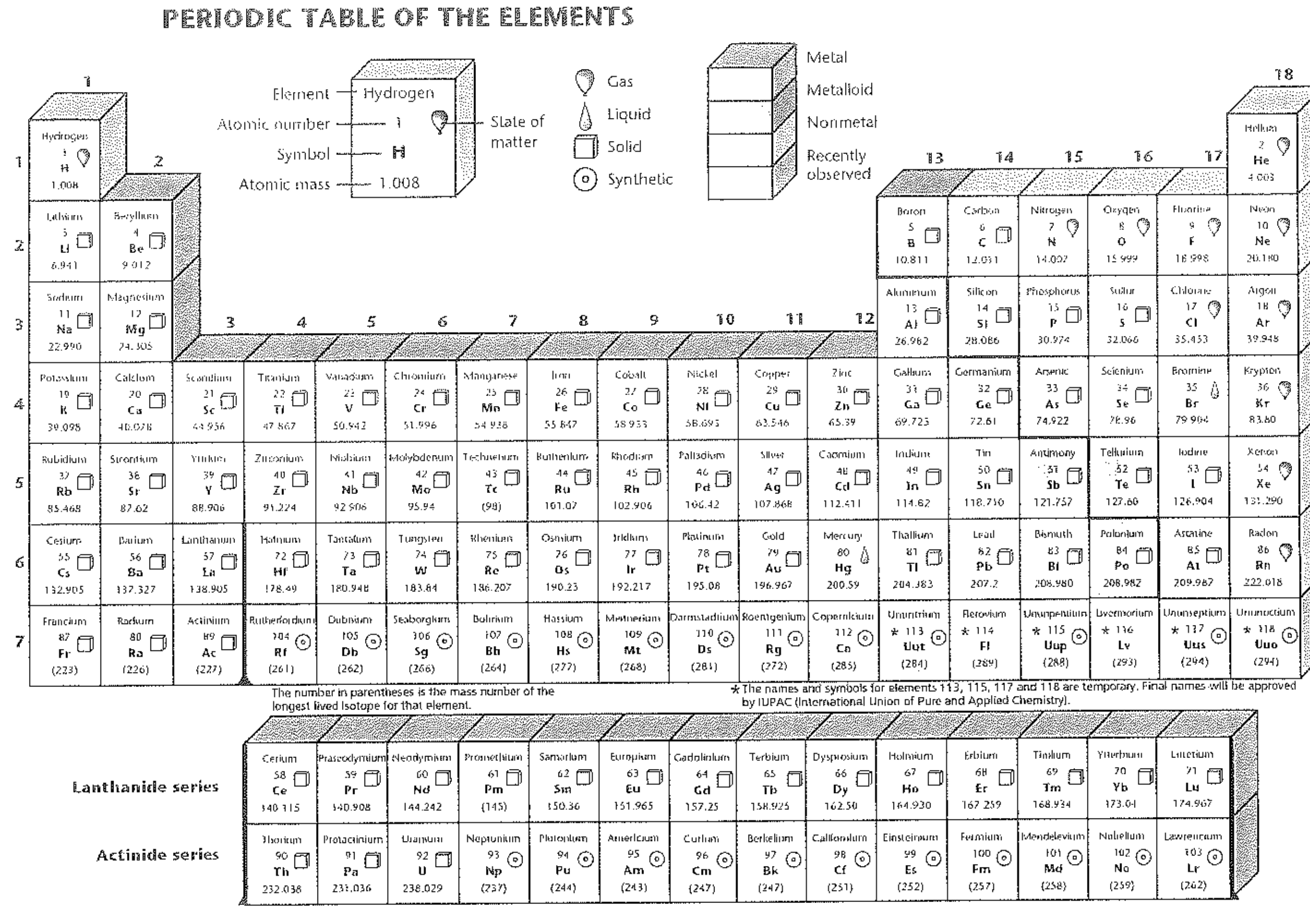


Figure 2 The periodic table of the elements organizes all of the known elements. Examine the biologists' guide to the periodic table on the back cover of this book.

Elements

An **element** is a pure substance that cannot be broken down into other substances by physical or chemical means. Elements are made of only one type of atom. There are over 100 known elements, 92 of which occur naturally. Scientists have collected a large amount of information about the elements, such as the number of protons and electrons each element has and the atomic mass of each element. Also, each element has a unique name and symbol. All of these data, and more, are collected in an organized table called the periodic table of the elements.

The periodic table of the elements As shown in **Figure 2,** the periodic table is organized into horizontal rows, called periods, and vertical columns, called groups. Each individual block in the grid represents an element. The table is called periodic because elements in the same group have similar chemical and physical properties. This organization even allows scientists to predict elements that have not yet been discovered or isolated. As shown in **Figure 3,** elements found in living organisms also are found in Earth's crust.

Figure 3 The elements in Earth's crust and living organisms vary in their abundance. Living things are composed primarily of three elements: carbon, hydrogen, and oxygen.
Interpret ***what the most abundant element is that exists in living things.***

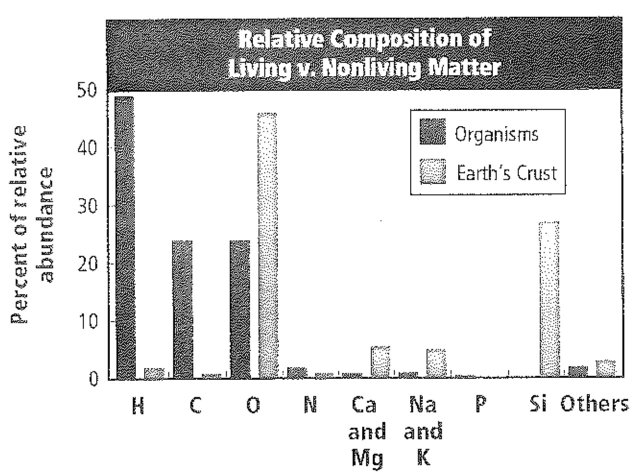
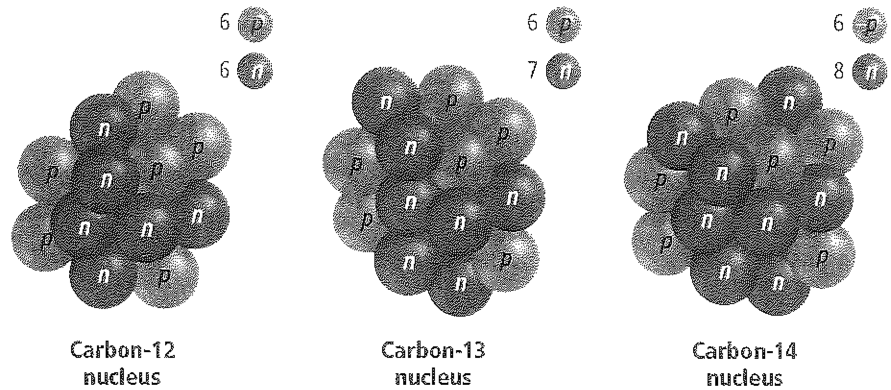


Figure 4 Carbon-12 and carbon-13 occur naturally in living and nonliving things. All living things also contain a small amount of carbon-14.
Compare *the similarities and differences of isotopes.*



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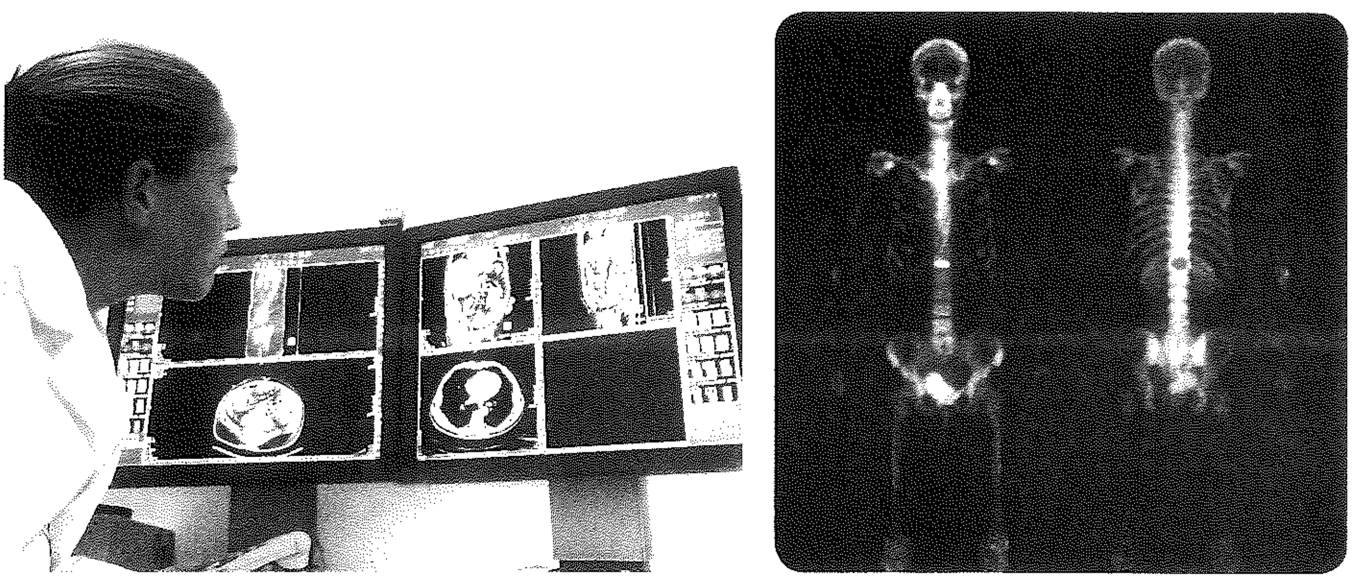
Isotopes Although atoms of the same element have the same number of protons and electrons, atoms of an element can have different numbers of neutrons, as shown in **Figure 4.** Atoms of the same element that have different numbers of neutrons are called **isotopes.** Isotopes of an element are identified by adding the number of protons and neutrons in the nucleus. For example, the most abundant form of carbon, carbon-12, has six protons and six neutrons in its nucleus. One carbon isotope—carbon-14—has six protons and eight neutrons. Isotopes of elements have the same chemical characteristics.

Radioactive isotopes Changing the number of neutrons in an atom does not change the overall charge of the atom. However, changing the number of neutrons can affect the stability of the nucleus, in some cases causing the nucleus to decay, or break apart. When a nucleus breaks apart, it gives off radiation that can be detected. Isotopes that give off radiation are called radioactive isotopes.

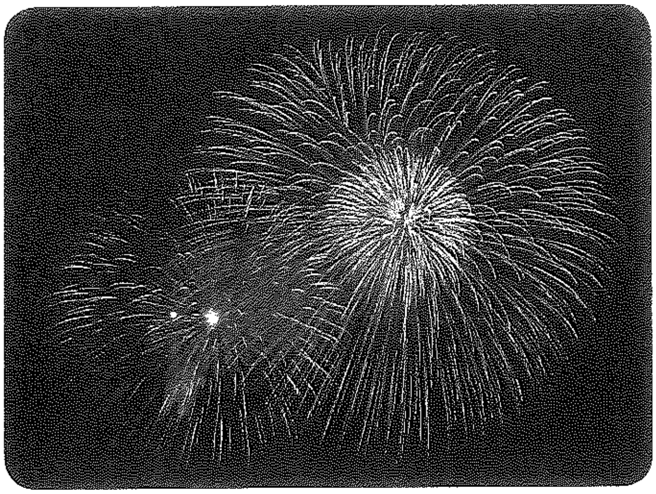
Carbon-14 is a radioactive isotope that is found in all living things. Scientists know the half-life, or the amount of time it takes for half of carbon-14 to decay, so they can calculate the age of an object by finding how much carbon-14 remains in the sample. Other radioactive isotopes have medical uses, as shown in **Figure 5.**

Reading Check **State** the difference between an isotope and a radioactive isotope.

Figure 5 Radioactive isotopes are used to help doctors diagnose disease, and locate and treat certain types of cancer.



(l)Sigrid Gombert/Getty Images; (r)Neil Borden/Photo Researchers



Brilliant fireworks displays depend on compounds such as the metal strontium.

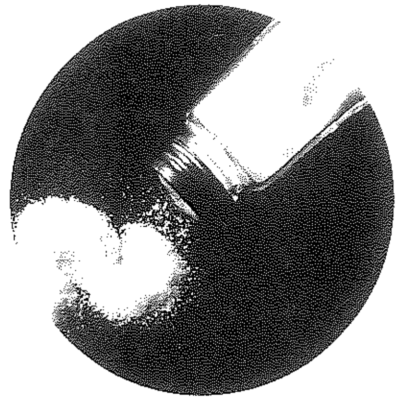


Table salt is the compound NaCl.

Wetlands are sources of living things made of complex compounds and the simple compound methane (CH_4).

Compounds

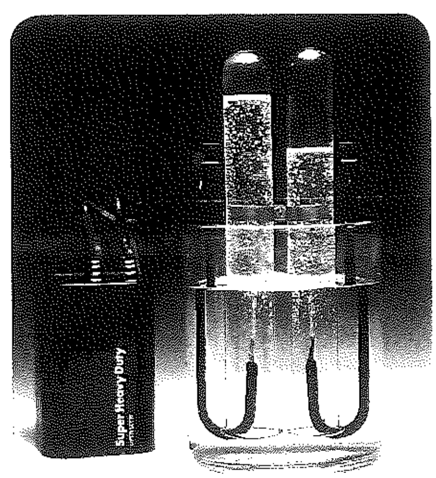
Elements can combine to form more complex substances. A **compound** is a pure substance formed when two or more different elements combine. There are millions of known compounds and thousands more discovered each year. **Figure 6** shows a few of them. Each compound has a chemical formula made up of the chemical symbols from the periodic table. You might know that water is the compound H_2O. Sodium chloride (NaCl) is the compound commonly called table salt. The fuel people use in cars is a mixture of hydrocarbon compounds. Hydrocarbons have only hydrogen and carbon atoms. Methane (CH_4) is the simplest hydrocarbon. Bacteria in areas such as the wetlands shown in **Figure 6** release 76 percent of global methane from natural sources by decomposing plants and other organisms. They are made of compounds, too.

Compounds have several unique characteristics. First, compounds are always formed from a specific combination of elements in a fixed ratio. Water always is formed in a ratio of two hydrogen atoms and one oxygen atom, and each water molecule has the same structure. Second, compounds are chemically and physically different from the elements that comprise them. For example, water has different properties than hydrogen and oxygen.

Another characteristic of compounds is that they cannot be broken down into simpler compounds or elements by physical means, such as tearing or crushing. Compounds, however, can be broken down by chemical means into simpler compounds or into their original elements. Consider again the example of water. You cannot pass water through a filter and separate the hydrogen from the oxygen, but a process called electrolysis, illustrated in **Figure 7**, can break water down into hydrogen gas and oxygen gas.

Figure 6 You and your world are made of compounds.

Figure 7 Electrolysis of water produces hydrogen gas that can be used for hydrogen fuel cells.



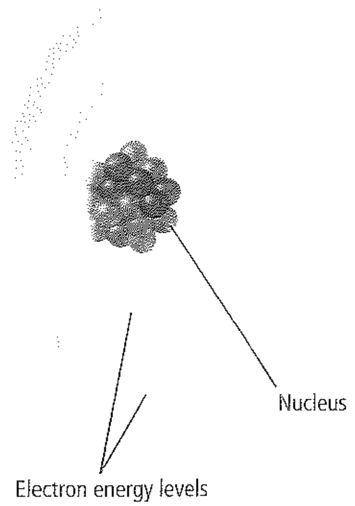


Figure 8 Electrons are moving constantly within the energy levels surrounding the nucleus.

Chemical Bonds

Compounds such as water, salt, and methane are formed when two or more substances combine. The force that holds the substances together is called a chemical bond. Think back to the protons, neutrons, and electrons that make up an atom. The nucleus determines the chemical identity of an atom, and the electrons are involved directly in forming chemical bonds. Electrons travel around the nucleus of an atom in areas called energy levels, as illustrated in **Figure 8.** Each energy level has a specific number of electrons that it can hold at any time. The first energy level, which is the level closest to the nucleus, can hold up to two electrons. The second can hold up to eight electrons.

A partially filled energy level is not as stable as an energy level that is empty or completely filled. Atoms become more stable by losing electrons or attracting electrons from other atoms. This results in the formation of chemical bonds between atoms. It is the forming of chemical bonds that stores energy and the breaking of chemical bonds that provides energy for processes of growth, development, adaptation, and reproduction in living things. There are two main types of chemical bonds—covalent bonds and ionic bonds.

Covalent bonds When you were younger, you probably learned to share. If you had a book that your friend wanted to read as well, you could enjoy the story together. In this way, you both benefited from the book. Similarly, one type of chemical bond forms when atoms share electrons in their outer energy levels.

The chemical bond that forms when electrons are shared is called a **covalent bond. Figure 9** illustrates the covalent bonds between oxygen and hydrogen that form water. Each hydrogen (H) atom has one electron in its outermost energy level, and oxygen (O) has six. Because the outermost energy level of oxygen is the second level, which can hold up to eight electrons, oxygen has a strong tendency to fill the energy level by sharing the electrons from the two nearby hydrogen atoms. Hydrogen does not completely give up the electrons; it also has a strong tendency to share electrons with oxygen to fill its outermost energy level. Two covalent bonds form, which creates water.

Most compounds in living organisms have covalent bonds holding them together. Water and other substances with covalent bonds are called molecules. A **molecule** is a compound in which the atoms are held together by covalent bonds. Depending on the number of pairs of electrons that are shared, covalent bonds can be single, double, or triple, as shown in **Figure 10.**

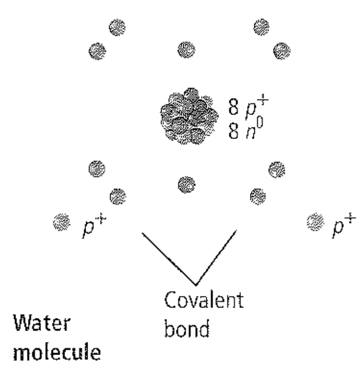
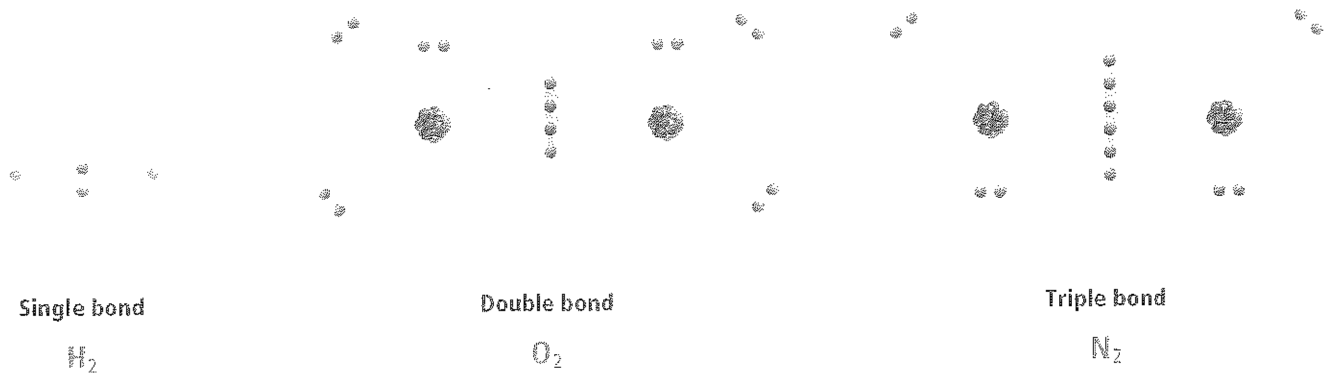


Figure 9 In water (H_2O), two hydrogen atoms each share one electron with one oxygen atom. Because the oxygen atom needs two electrons to fill its outer energy level, it forms two covalent bonds, one with each hydrogen atom.



Ionic bonds Recall that atoms are neutral; they do not have an electric charge. Also recall that for an atom to be most stable, the outermost energy level should be either empty or completely filled. Some atoms tend to give up (donate) or obtain (accept) electrons to empty or fill the outer energy level to be stable. An atom that has lost or gained one or more electrons becomes an **ion** and carries an electric charge. For example, sodium has one electron in its outermost energy level. Sodium can become more stable if it gives up this one electron, leaving its outer energy level empty. When it gives away this one negative charge, the neutral sodium atom becomes a positively charged sodium ion (Na^+). Similarly, chlorine has seven electrons in its outer energy level and needs just one electron to fill it. When chlorine accepts an electron from a donor atom, such as sodium, chlorine becomes a negatively charged ion (Cl^-).

An **ionic bond** is an electrical attraction between two oppositely charged atoms or groups of atoms called ions. **Figure 11** shows how an ionic bond forms as a result of the electrical attraction between Na^+ and Cl^- to produce NaCl (sodium chloride). Substances formed by ionic bonds are called ionic compounds.

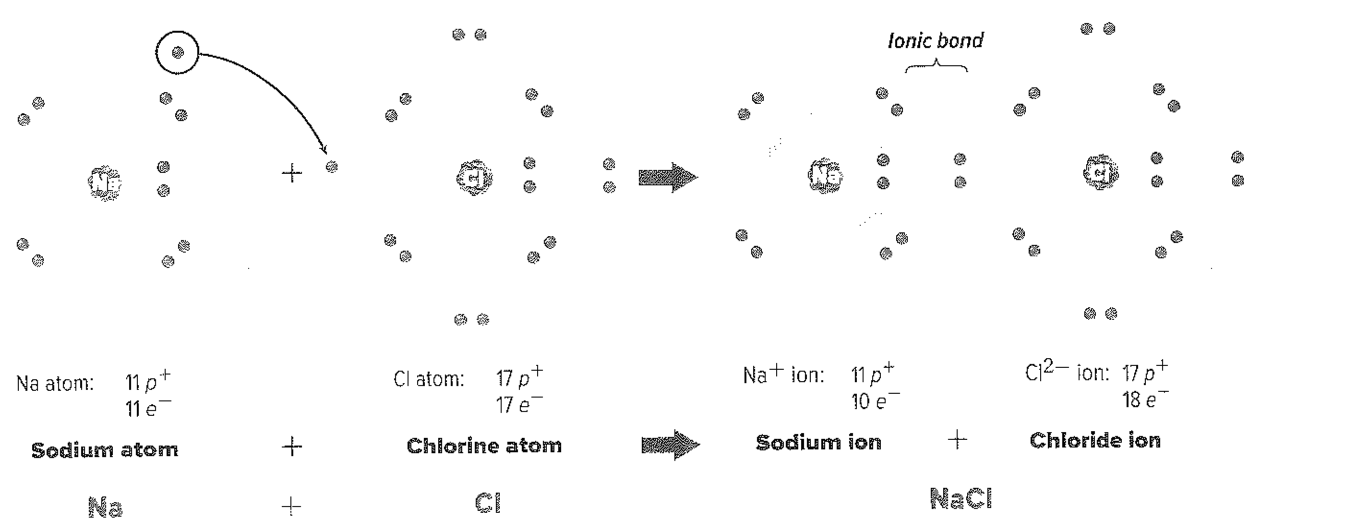
Ions in living things include sodium, potassium, calcium, chloride, and carbonate ions. They help maintain homeostasis as they travel in and out of cells. In addition, ions help transmit signals among cells that allow you to see, taste, hear, feel, and smell.

Figure 10 A single bond has one pair of shared electrons, a double bond has two pairs, and a triple bond has three pairs.

Personal Tutor

Figure 11 To form ions, sodium donates an electron and chlorine gains an electron. An ionic bond forms when the oppositely charged ions come close together.

Animation



VOCABULARY
WORD ORIGIN
Atom
comes from the Greek word *atomos,* meaning *not divisible*

Some atoms tend to donate or accept electrons more easily than other atoms do. Look at the periodic table of elements inside the back cover of this textbook. The elements identified as metals tend to donate electrons, and the elements identified as nonmetals tend to accept electrons. The resulting ionic compounds have some unique characteristics. For example, most dissolve in water. When dissolved in solution, ionic compounds break down into ions and these ions can carry an electric current. Most ionic compounds, such as sodium chloride (table salt), are crystalline at room temperature. Ionic compounds generally have higher melting points than do molecular compounds formed by covalent bonds.

Connection to Earth Science Although most ionic compounds are solid at room temperature, other ionic compounds are liquid at room temperature. Like their solid counterparts, ionic liquids are made up of positively and negatively charged ions. Ionic liquids have important potential in real-world applications as safe and environmentally friendly solvents that can possibly replace other harmful solvents. The key characteristic of ionic liquid solvents is that they typically do not evaporate and release chemicals into the atmosphere. Most ionic liquids are safe to handle and store, and they can be recycled after use. For these reasons, ionic liquids are attractive to industries that are dedicated to environmental responsibility.

Reading Check **Compare** ionic solids and liquids.

MiniLab 1

Test for Simple Sugars

MiniLab

What common foods contain glucose? Glucose is a simple sugar that provides energy for cells. In this lab, you will use a reagent called Benedict's solution, which indicates the presence of –CHO (carbon, hydrogen, oxygen) groups. A color change determines the presence of glucose and other simple sugars in common foods.

Procedure

1. Read and complete the lab safety form.
2. Create a data table with columns labeled *Food Substance, Sugar Prediction, Observations,* and *Results.*
3. Choose four **food substances** from those provided by your teacher. Read the food labels and predict the presence of simple sugar in each food. Record your prediction.
4. Prepare a **hot water bath** with a temperature between 40°–50°C using a **hot plate** and **1000-mL beaker.**
5. Label four **test tubes.** Obtain a **graduated cylinder.** Add 10 mL of a different food substance to each test tube. Then add 10 mL of **distilled water.** Swirl gently to mix.
6. Add 5 mL of **Benedict's solution** to each tube. Use a clean **stirring rod** to mix the contents.
7. Using **test-tube holders,** warm the test tubes in the hot water bath for 2–3 min. Record your observations and results.

Analysis

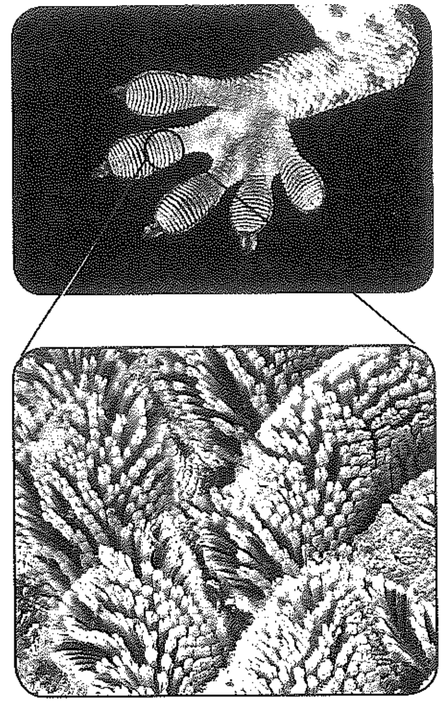
1. **Interpret Data** Did any of the foods contain simple sugars? Explain.
2. **Think Critically** Could a food labeled "sugar-free" test positive using Benedict's solution as an indicator? Explain.

van der Waals Forces

You have learned that positive ions and negative ions form based on the ability of an atom to attract electrons. If the nucleus of the atom has a weak attraction for the electron, it will donate the electron to an atom with a stronger attraction. Similarly, elements in a covalent bond do not always attract electrons equally. Recall also that the electrons in a molecule are in random motion around the nuclei. This movement of electrons can cause an unequal distribution of the electron cloud around the molecule, creating temporary areas of slightly positive and negative charges.

When molecules come close together, the attractive forces between these positive and negative regions pull on the molecules and hold them together. These attractions between the molecules are called **van der Waals forces,** named for Dutch physicist Johannes van der Waals, who first described the phenomenon. The strength of the attraction depends on the size of the molecule, its shape, and its ability to attract electrons. Although van der Waals forces are not as strong as covalent and ionic bonds, they play a key role in biological processes.

Scientists have determined that geckos can climb smooth surfaces because of van der Waals forces between the atoms in the hairlike structures on their toes, shown in **Figure 12,** and the atoms on the surface they are climbing.



SEM Magnification: 240 ×

Figure 12 Geckos have millions of microscopic hairs on the bottoms of their feet that are about as long as two widths of a human hair. Each spreads into 1000 smaller pads.

van der Waals forces in water Consider how van der Waals forces work in a common substance–water. The areas of slight positive and negative charges around the water molecule are attracted to the opposite charge of other nearby water molecules. These forces hold the water molecules together. Without van der Waals forces, water molecules would not form droplets, and droplets would not form a surface of water. It is important to understand that van der Waals forces are the attractive forces between the water molecules, not the forces between the atoms that make up water.

Section 1 Assessment

Section Summary

- Elements are pure substances made up of only one kind of atom.
- Isotopes are forms of the same element that have a different number of neutrons.
- Compounds are substances with unique properties that are formed when elements combine.
- Elements can form covalent and ionic bonds.

Understand Main Ideas

1. MAIN Idea **Diagram** Sodium has 11 protons and 11 neutrons in its nucleus. Draw a sodium atom. Be sure to label the particles.
2. **Explain** why carbon monoxide (CO) is or is not an atom.
3. **Explain** Are all compounds molecules? Why or why not?
4. **Compare** van der Waals forces, ionic bonds, and covalent bonds.

Think Critically

5. **Explain** how the number of electrons in an energy level affects bond formation.

MATH in Biology

6. Beryllium has four protons in its nucleus. How many neutrons are in beryllium-9? Explain how you calculated your answer.

Reading Preview

Essential Questions

- What are the parts of a chemical reaction?
- How can energy changes be related to chemical reactions?
- What is the importance of enzymes in living organisms?

Review Vocabulary

process: a series of steps or actions that produce an end product

New Vocabulary

chemical reaction
reactant
product
activation energy
catalyst
enzyme
substrate
active site

Multilingual eGlossary

Chemical Reactions

Main Idea **Chemical reactions allow living things to grow, develop, reproduce, and adapt.**

Real-World Reading Link When you lie down for the night, you might think that your body is completely at rest. In fact, you are still digesting the food that you ate that day, the scrape on your elbow is healing, and your muscles and bones are growing and developing. All the things that happen inside your body are the result of chemical reactions.

Reactants and Products

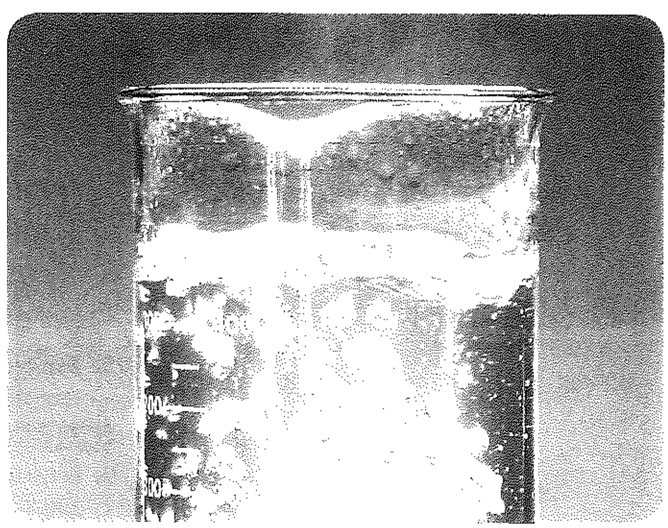
A new car with shining chrome and a clean appearance is appealing to many drivers. Over time, however, the car might get rusty and lose some of its appeal. Rust is a result of a chemical change called a chemical reaction. A **chemical reaction** is the process by which atoms or groups of atoms in substances are reorganized into different substances. Chemical bonds are broken and formed during chemical reactions. The rust on the chain in **Figure 13** is a compound called iron oxide (Fe_2O_3), and it was formed when oxygen (O_2) in the air reacted with iron (Fe).

It is important to know that substances can undergo changes that do not involve chemical reactions. For example, consider the water in **Figure 13.** The water is undergoing a physical change. A physical change alters a substance's appearance but not its composition. The water is water before and after the change.

How do you know when a chemical reaction has taken place? Although you might not be aware of all the reactions taking place inside your body, you know that the surface of the chain in **Figure 13** has changed. What was once silver and shiny is now dull and orange-brown. Other clues that a chemical reaction has taken place include the production of heat or light, and the formation of a new gas, liquid, or solid.

Figure 13 After a chemical change, such as rusting, a new substance is formed. During a physical change, such as ice melting or water boiling, the chemical makeup of the water is not altered.

Chemical change



Physical change

Chemical equations When scientists write chemical reactions, they express each component of the reaction in a chemical equation. In written chemical equations, chemical formulas describe the substances in the reaction with arrows indicating the process of change.

Reactants and products A chemical equation shows the **reactants,** the starting substances, on the left side of the arrow. The **products,** the substances formed during the reaction, are on the right side of the arrow. The arrow can be read as "yields" or "react to form."

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

The following chemical equation can be written to describe the reaction that provides energy to the volleyball players in **Figure 14.**

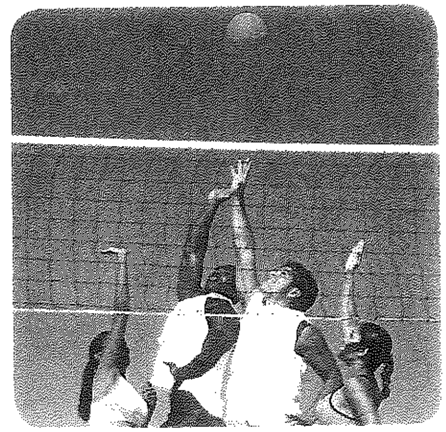


Figure 14 The process that provides your body with energy involves the reaction of glucose with oxygen to form carbon dioxide and water.

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

Glucose and oxygen react to form carbon dioxide and water.

Balanced equations In chemical reactions, matter cannot be created or destroyed. This principle is called the law of conservation of mass. Accordingly, all chemical equations must show this balance of mass. This means that the number of atoms of each element on the reactant side must equal the number of atoms of the same element on the product side. Coefficients are used to make the number of atoms on each side of the arrow equal.

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

Multiply the coefficient by the subscript for each element. You can see in this example that there are six carbon atoms, twelve hydrogen atoms, and eighteen oxygen atoms on each side of the arrow. The equation confirms that the number of atoms on each side is equal, and therefore the equation is balanced.

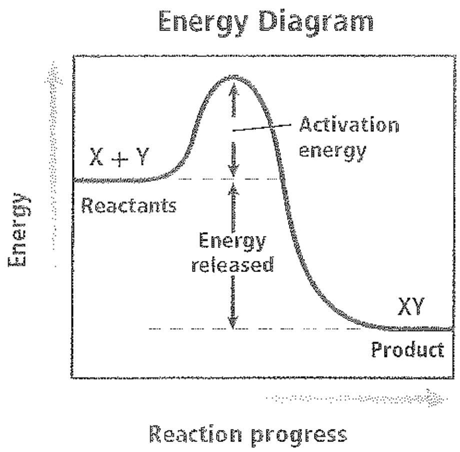
Vocabulary

Coefficient
in a chemical equation, the number written in front of a reactant or a product
The number 6 in $6Fe_2O_3$ is a coefficient.

Reading Check Explain why chemical equations must be balanced.

Energy of Reactions

Connection to Physics A sugar cookie is made with flour, sugar, and other ingredients mixed together, but it is not a cookie until it is baked. Something must start the change from dough to cookie. The key to starting a chemical reaction is energy. For the chemical reactions that transform the dough to a cookie, energy in the form of heat is needed. Similarly, most compounds in living things cannot undergo chemical reactions without energy.



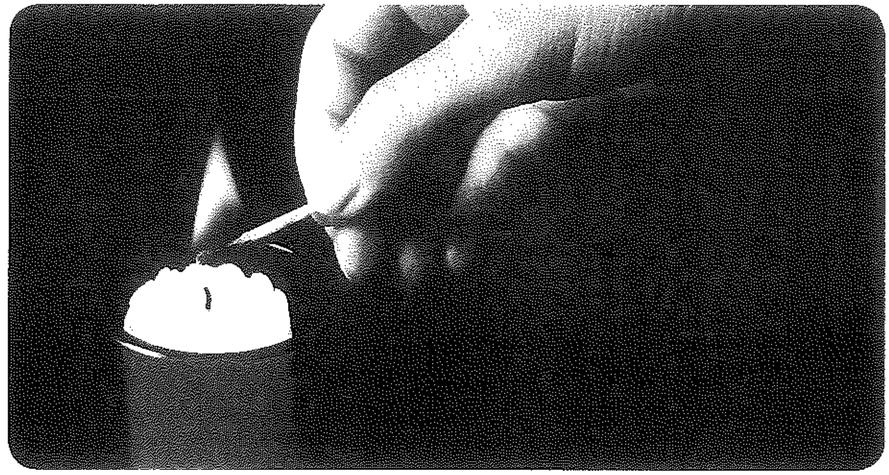


Figure 15 The flame of the match provides activation energy—the amount of energy needed to begin a reaction. The reaction gives off energy in the form of heat and light.

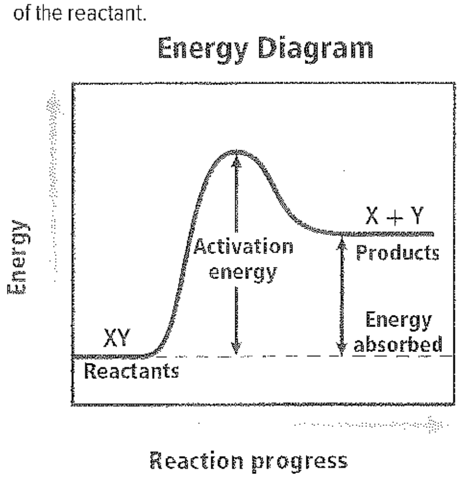
Virtual Lab

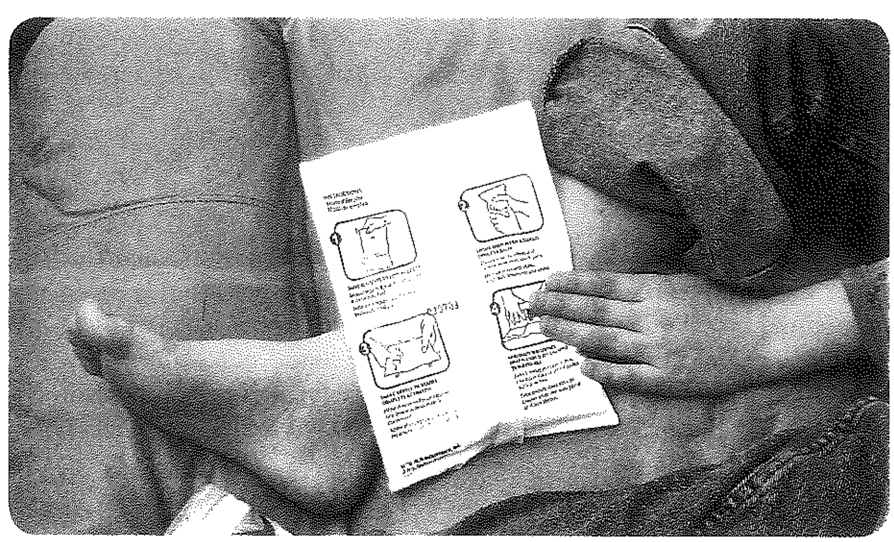
Video Lab

Activation energy The minimum amount of energy needed for reactants to form products in a chemical reaction is called the **activation energy.** For example, you know that a candle will not burn until you light its wick. The flame provides the activation energy for the reaction of the substances in the candle wick with oxygen. In this case, once the reaction begins, no further input of energy is needed and the candle continues to burn on its own. **Figure 15** shows that for the reactants X and Y to form product XY, energy is required to start the reaction. The peak in the graph represents the amount of energy that must be added to the system to make the reaction occur. Some reactions rarely happen because they have a very high activation energy.

Energy change in chemical reactions Compare how energy changes during the reaction in **Figure 15** to how energy changes during the reaction in **Figure 16.** Both reactions require activation energy to get started. However, the reaction in **Figure 15** has lower energy in the product than in the reactants. This reaction is exothermic–it released energy in the form of heat. The reaction in **Figure 16** is endothermic–it absorbed heat energy. The energy of the products is higher than the energy of the reactants. In every chemical reaction, there is a change in energy caused by the making and breaking of chemical bonds as reactants form products. Exothermic reactions keep your internal body temperature at about 37°C.

Figure 16 In an endothermic reaction, the energy of the products is higher than the energy of the reactant.





Enzymes

All living things are chemical factories driven by chemical reactions. However, these chemical reactions proceed very slowly when carried out in the laboratory because the activation energy is high. To be useful to living organisms, additional substances must be present where the chemical reactions occur to reduce the activation energy and allow the reaction to proceed quickly.

A **catalyst** is a substance that lowers the activation energy needed to start a chemical reaction. Although a catalyst is important in speeding up a chemical reaction, it does not increase how much product is made and it does not get used up in the reaction. Scientists use many types of catalysts to make reactions occur thousands of times faster than the reaction would be able to occur without the catalyst.

Special proteins called **enzymes** are the biological catalysts that speed up the rate of chemical reactions in biological processes. Enzymes are essential to life. Compare the progress of the reaction described in **Figure 17** to see the effect of an enzyme on a chemical reaction. Like all catalysts, the enzyme is not used up by the chemical reaction. Once it has participated in a chemical reaction, it can be used again.

An enzyme's name describes what it does. For example, amylase is an important enzyme found in saliva. Digestion of food begins in the mouth when amylase speeds the breakdown of amylose, one of the components of starch. Like amylase, most enzymes are specific to one reaction.

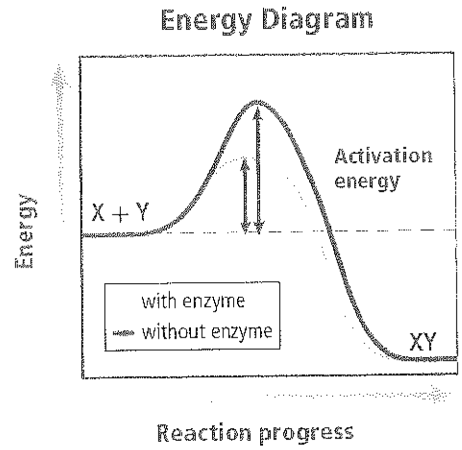


Figure 17 When an enzyme acts as a biological catalyst, the reaction occurs at a rate that is useful to cells.

***Compare** the activation energy of the reaction without an enzyme to the activation energy of the reaction with an enzyme.*

MiniLab 2

Investigate Enzymatic Browning

MiniLab

What factors affect enzymatic browning? When sliced, an apple's soft tissue is exposed to oxygen, causing a chemical reaction called oxidation. Enzymes in the apple speed this reaction, producing darkened, discolored fruit. In this lab, you will investigate methods used to slow enzymatic browning.

Procedure

1. Read and complete the lab safety form.
2. Predict the relative amount of discoloration that each of the following apple wedges will show when exposed to air. Justify your predictions.
   Sample 1: Untreated apple wedge
   Sample 2: Apple wedge submerged in boiling water
   Sample 3: Apple wedge submerged in lemon juice
   Sample 4: Apple wedge submerged in sugar solution
3. Prepare 75 mL of each of the following: **boiling water, lemon juice,** and **sugar solution** in three **250-mL beakers.**
4. Slice an **apple** into four wedges. Immediately use **tongs** to submerge each wedge in a different liquid. Put one wedge aside.
5. Submerge the wedges for three minutes, then place them on a **paper towel,** skin-side down. Observe for 10 min, and then record the relative amount of discoloration of each apple wedge.

Analysis

1. **Analyze** how each treatment affected the chemical reaction that occurred on the fruit's soft tissue. Why were some of the treatments successful?
2. **Think critically** about what factors a restaurant owner who wants to serve fresh-cut fruit might consider when choosing a recipe and preparation method.

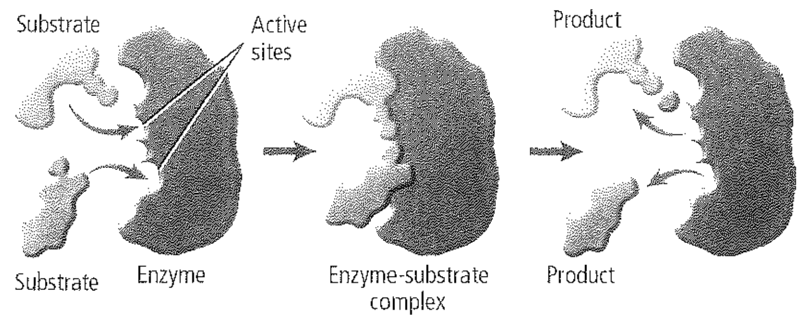


Figure 18 Substrates interact with enzymes at specific places called active sites. Only substrates with a specific shape can bind to the active site of an enzyme.

Animation

FOLDABLES Incorporate information from this section into your Foldable.

Follow **Figure 18** to learn how an enzyme works. The reactants that bind to the enzyme are called **substrates.** The specific location where a substrate binds on an enzyme is called the **active site.** The active site and the substrate have complementary shapes. This enables them to interact in a precise manner, similar to the way in which puzzle pieces fit together. As shown in **Figure 18,** only substrates with the same size and shape as the active site will bind to the enzyme.

Once the substrates bind to the active site, the active site changes shape and forms the enzyme-substrate complex. The enzyme-substrate complex helps chemical bonds in the reactants to be broken and new bonds to form—the substrates react to form products. The enzyme then releases the products.

Factors such as pH, temperature, and other substances affect enzyme activity. For example, most enzymes in human cells are most active at an optimal temperature close to 37°C. However, enzymes in other organisms, such as bacteria, can be active at other temperatures.

Enzymes affect many biological processes. When a person is bitten by a venomous snake, enzymes in the venom break down the membranes of that person's red blood cells. Hard green apples ripen because of the action of enzymes. Photosynthesis and cellular respiration provide energy for the cell with the help of enzymes. Just as worker bees are important for the survival of a beehive, enzymes are the chemical workers in cells.

Section 2 Assessment

Section Summary

- Balanced chemical equations must show an equal number of atoms for each element on both sides.
- Activation energy is the energy required to begin a reaction.
- Catalysts are substances that alter chemical reactions.
- Enzymes are biological catalysts.

Understand Main Ideas

1. MAIN Idea **Identify** the parts of this chemical reaction: A+B → AB.
2. **Diagram** the energy changes that can take place in a chemical reaction.
3. **Explain** why the number of atoms of reactants must equal the number of atoms of products formed.
4. **Describe** the importance of enzymes to living organisms.

Think Critically

MATH in Biology

5. For the following chemical reaction, label the reactants and products, and then balance the chemical equation. ____H_2O_2 → ____H_2O + ____O_2

WRITING in Biology

6. Draw a diagram of a roller coaster and write a paragraph relating the ride to activation energy and a chemical reaction.

Online Quiz

Section 3

Reading Preview

Essential Questions

- How does the structure of water make it a good solvent?
- What are the similarities and differences between solutions and suspensions?
- What are the differences between acids and bases?

Review Vocabulary

physical property: characteristic of matter, such as color or melting point, that can be observed or measured without changing the composition of the substance

New Vocabulary

polar molecule
hydrogen bond
mixture
solution
solvent
solute
acid
base
pH
buffer

Multilingual eGlossary

Water and Solutions

MAIN Idea The properties of water make it well suited to help maintain homeostasis in an organism.

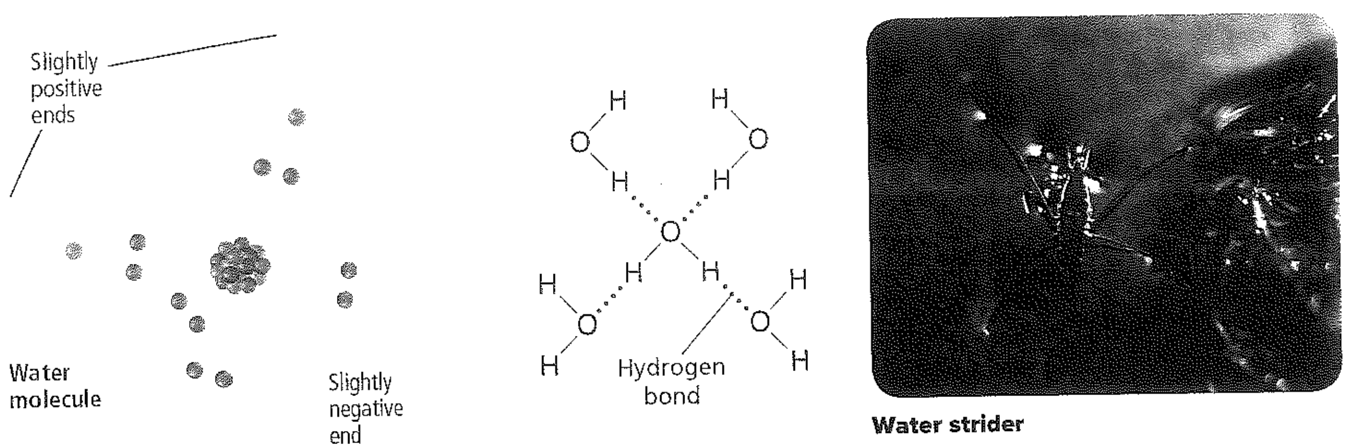
Real-World Reading Link You probably know that the main color on a globe is blue. That's because water covers about 70 percent of Earth's surface, giving it the blue color you see from a distance. Now imagine zooming in to a single cell of an organism on Earth. Water accounts for approximately 70 percent of that cell's mass. It is one of the most important molecules for life.

Water's Polarity

Earlier in this chapter, you discovered that water molecules are formed by covalent bonds that link two hydrogen (H) atoms to one oxygen (O) atom. Because electrons are more strongly attracted to the oxygen atom's nucleus, the electrons in the covalent bond with hydrogen are not shared equally. In water, the electrons spend more time near the oxygen atom's nucleus than they do near the hydrogen atoms' nuclei. **Figure 19** shows that there is an unequal distribution of electrons in a water molecule. This, along with the bent shape of water molecules, results in the oxygen end of the molecule having a slightly negative charge and the hydrogen ends of the molecule having a slightly positive charge. Molecules that have an unequal distribution of charges are called **polar molecules,** meaning that they have oppositely charged regions.

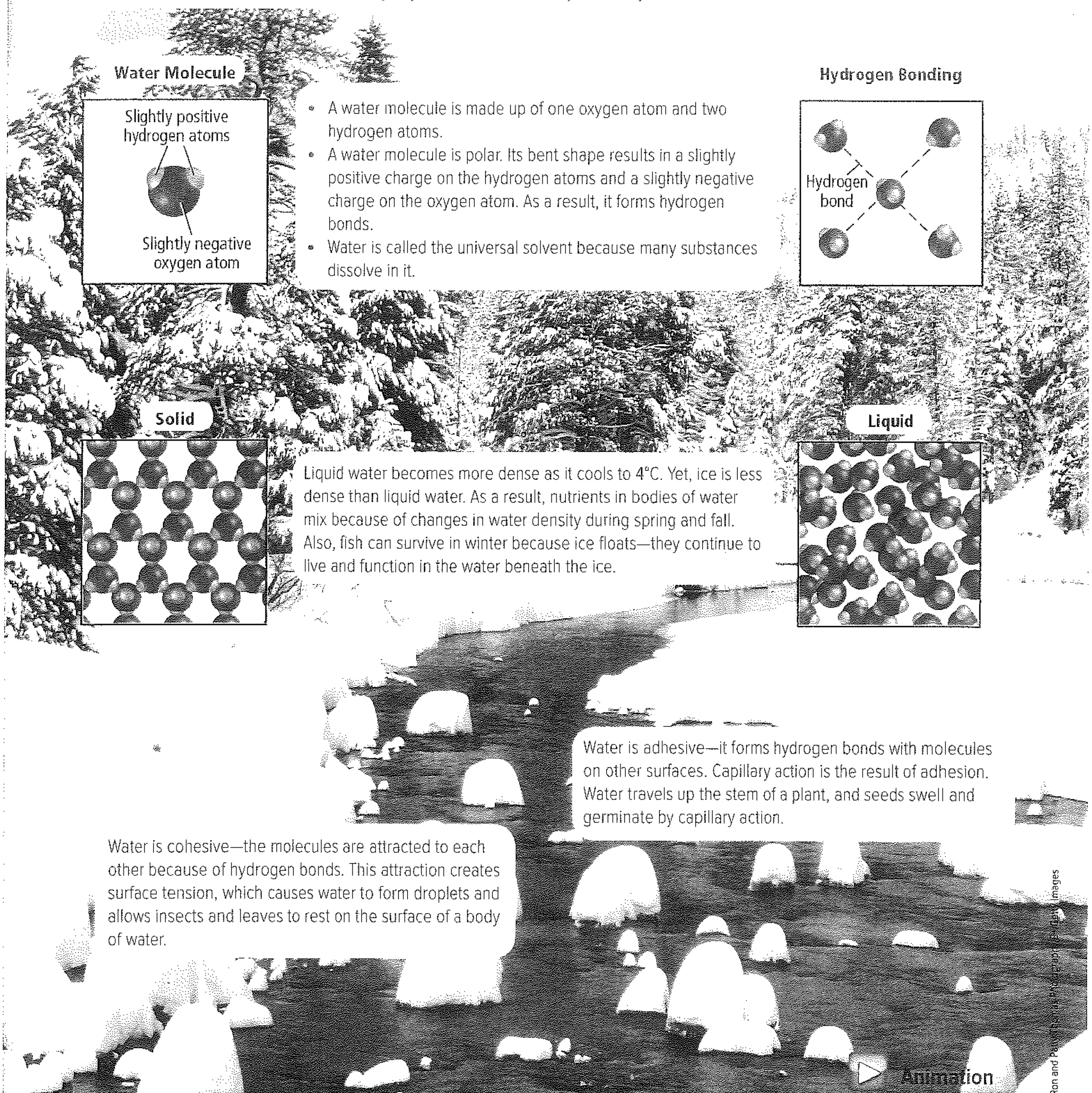
Polarity is the property of having two opposite poles, or ends. A magnet has polarity–there is a north pole and a south pole. When the two ends are brought close to each other, they attract each other. Similarly, when a charged region of a polar molecule comes close to the oppositely charged region of another polar molecule, a weak electrostatic attraction results. In water, the electrostatic attraction is called a hydrogen bond. A **hydrogen bond** is a weak interaction involving a hydrogen atom and a fluorine, oxygen, or nitrogen atom. Hydrogen bonding is a strong type of van der Waals force. **Figure 20** describes polarity and the other unique properties of water that make it important to living things.

Figure 19 Because water molecules have a bent shape and electrons are not shared equally between hydrogen and oxygen, hydrogen bonds form among the molecules. Due to the attraction among the atoms that make up water, the surface of water supports a water strider.



Visualizing Properties of Water

Figure 20
Water is vital to life on Earth. Its properties allow it to provide environments suitable for life and to help organisms maintain homeostasis. Humans can survive many days without food but only a few days without water.



- A water molecule is made up of one oxygen atom and two hydrogen atoms.
- A water molecule is polar. Its bent shape results in a slightly positive charge on the hydrogen atoms and a slightly negative charge on the oxygen atom. As a result, it forms hydrogen bonds.
- Water is called the universal solvent because many substances dissolve in it.

Liquid water becomes more dense as it cools to 4°C. Yet, ice is less dense than liquid water. As a result, nutrients in bodies of water mix because of changes in water density during spring and fall. Also, fish can survive in winter because ice floats—they continue to live and function in the water beneath the ice.

Water is adhesive—it forms hydrogen bonds with molecules on other surfaces. Capillary action is the result of adhesion. Water travels up the stem of a plant, and seeds swell and germinate by capillary action.

Water is cohesive—the molecules are attracted to each other because of hydrogen bonds. This attraction creates surface tension, which causes water to form droplets and allows insects and leaves to rest on the surface of a body of water.

Mixtures with Water

You are probably familiar with powdered drink products that dissolve in water to form a flavored beverage. When you add a powdered substance to water, it does not react with water to form a new product. You create a mixture. A **mixture** is a combination of two or more substances in which each substance retains its individual characteristics and properties.

Homogeneous mixtures When a mixture has a uniform composition throughout, it is called a homogeneous (hoh muh JEE nee us) mixture. A **solution** is another name for a homogeneous mixture. For example, in the powdered drink mix solution shown in **Figure 21**, the drink mix is on top, in the middle, and at the bottom of the container. The water retains its properties and the drink mix retains its properties.

In a solution, there are two components: a solvent and a solute. A **solvent** is a substance in which another substance is dissolved. A **solute** is the substance that is dissolved in the solvent. In the case of the drink mix, water is the solvent and the powdered substance is the solute. A mixture of salt and water is another example of a solution because the solute (salt) dissolves completely in the solvent (water). Saliva moistens your mouth and begins the digestion of some of your food. Saliva is a solution that contains water, proteins, and salts. In addition, the air you breathe is a solution of gases.

Heterogeneous mixtures Think about the last time you ate a salad. Perhaps it contained lettuce and other vegetables, croutons, and salad dressing. Your salad was a heterogeneous mixture. In a heterogeneous mixture, the components remain distinct, that is, you can tell what they are individually. Compare the mixture of sand and water to the solution of salt and water next to it in **Figure 22.** Sand and water form a type of heterogeneous mixture called a suspension. Over time, the particles in a suspension settle to the bottom.

A colloid is a heterogeneous mixture in which the particles do not settle out like the sand settled from the water. You are probably familiar with many colloids, including fog, smoke, butter, mayonnaise, milk, paint, and ink. Blood is a colloid made up of plasma, cells, and other substances.

Reading Check **Distinguish** between solutions and suspensions.

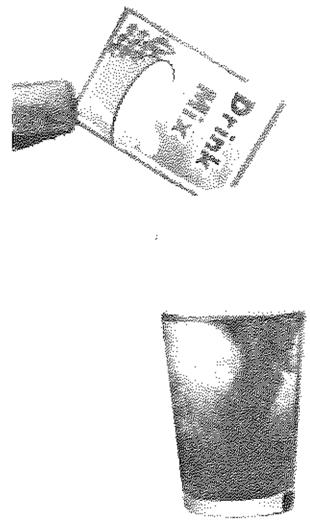


Figure 21 The drink mix forms a homogeneous mixture in water. The particles of the solute (drink mix) are dissolved and spread throughout the solvent (water).

VOCABULARY

ACADEMIC VOCABULARY

Suspend
to keep from falling or sinking
A slender thread suspended the spider from the web.

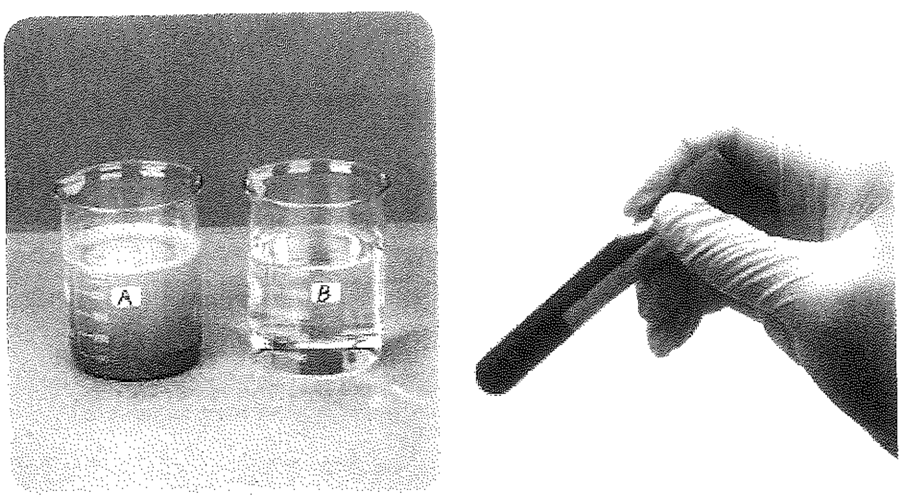
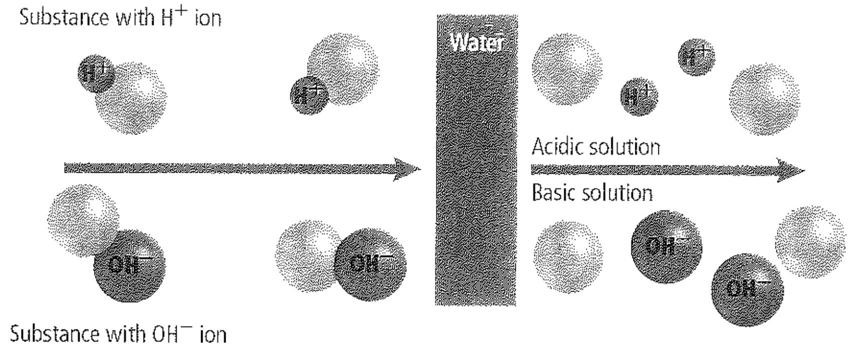


Figure 22
Left: Sand and water form a heterogeneous mixture; you can see both the liquid and the solid. The homogeneous mixture of salt and water is a liquid; you cannot see the salt.
Right: Blood is a heterogeneous mixture called a colloid.

Figure 23 Substances that release H^+ in water are acids. Substances that release OH^- in water are bases.



Acids and bases Many solutes readily dissolve in water because of water's polarity. This means that an organism, which might be as much as 70 percent water, can be a container for a variety of solutions. When a substance that contains hydrogen is dissolved in water, the substance might release a hydrogen ion (H^+) because it is attracted to the negatively charged oxygen atoms in water, as shown in **Figure 23.** Substances that release hydrogen ions when they are dissolved in water are called **acids.** The more hydrogen ions a substance releases, the more acidic the solution becomes.

Similarly, substances that release hydroxide ions (OH^-) when they are dissolved in water are called **bases.** Sodium hydroxide ($NaOH$) is a common base that breaks apart in water to release sodium ions (Na^+) and hydroxide ions (OH^-). The more hydroxide ions a substance releases, the more basic the solution becomes.

Acids and bases are key substances in biology. Many of the foods and beverages that we eat and drink are acidic, and the substances in the stomach that break down the food, called gastric juices, are highly acidic.

DATA ANALYSIS LAB 1

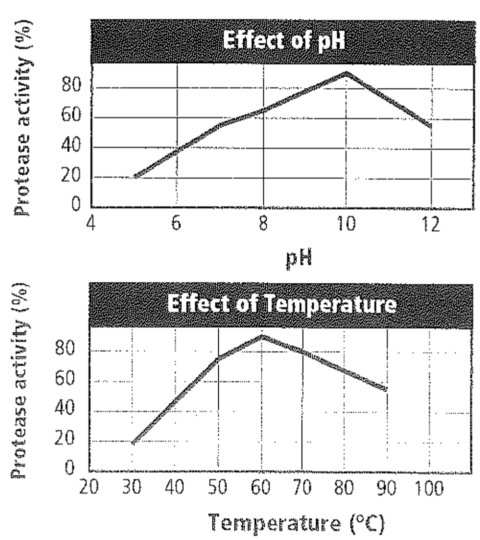
Based on Real Data*

Recognize Cause and Effect

How do pH and temperature affect protease activity? Proteases are enzymes that break down protein. Bacterial proteases often are used in detergents to help remove stains such as egg, grass, blood, and sweat from clothes.

Data and Observations

A protease from a newly isolated strain of bacteria was studied over a range of pH values and temperatures.



Think Critically

1. **Identify** the range of pH values and temperatures used in the experiment.
2. **Summarize** the results of the two graphs.
3. **Infer** If a laundry detergent is basic and requires hot water to be most effective, would this protease be useful? Explain.

*Data obtained from: Adinarayana, et al. 2003. Purification and partial characterization of thermostable serine alkaline protease from a newly isolated *Bacillus subtilis* PE-11. *AAPS PharmSciTech 4: article 56.*

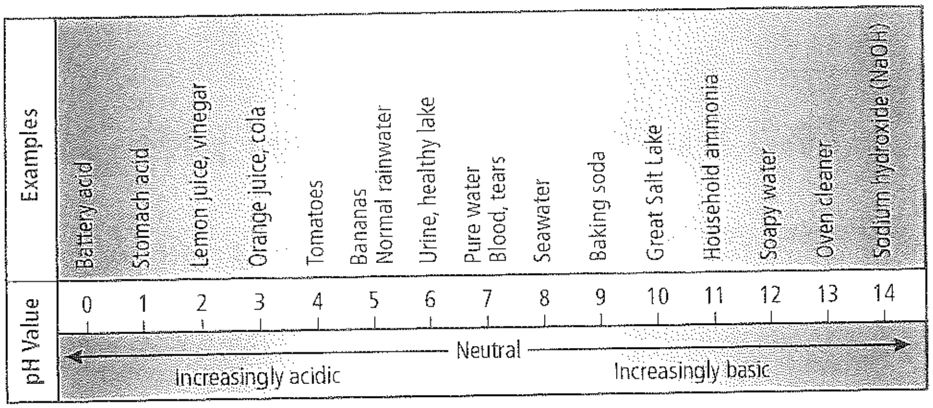


Figure 24 The pH scale is used to indicate the relative strength of acids and bases—in other words, the amount of hydrogen ions (H^+) in a solution.

pH and buffers The amount of hydrogen ions or hydroxide ions in a solution determines the strength of an acid or base. Scientists have devised a convenient way to measure how acidic or basic a solution is. The measure of concentration of H^+ in a solution is called **pH.** As shown in **Figure 24,** pure water is neutral and has a pH value of 7.0. Acidic solutions have an abundance of H^+ and have pH values lower than 7. Basic solutions have more OH^- than H^+ and have pH values higher than 7.

Connection to The majority of biological processes carried out by cells occur between pH 6.5 and 7.5. In order to maintain homeostasis, it is important to control H^+ levels. If you've ever had an upset stomach, you might have taken an antacid to feel better. The antacid tablet is a buffer to help neutralize the stomach acid. **Buffers** are mixtures that can react with acids or bases to keep the pH within a particular range. In cells, buffers keep the pH in a cell within the 6.5 to 7.5 pH range. Your blood, for example, contains buffers that keep the pH about 7.4.

CAREERS IN BIOLOGY

Pool Technician Every recreational body of water, such as a recreational swimming pool, training spa, or medical therapy pool, must meet strict requirements for water quality. Pool technicians make sure these requirements are met by monitoring water pH, bacteria and algae levels, and water clarity.

Section 3 Assessment

Section Summary

- Water is a polar molecule.
- Solutions are homogeneous mixtures formed when a solute is dissolved in a solvent.
- Acids are substances that release hydrogen ions into solutions. Bases are substances that release hydroxide ions into solutions.
- pH is a measure of the concentration of hydrogen ions in a solution.

Understand Main Ideas

1. MAIN Idea **Describe** one way in which water helps maintain homeostasis in an organism.
2. **Relate** the structure of water to its ability to act as a solvent.
3. **Draw** a pH scale and label water (H2O), hydrochloric acid (HCl), and sodium hydroxide (NaOH) in their general areas on the scale.
4. **Compare and contrast** solutions and suspensions. Give examples of each.

Think Critically

5. **Explain** how baking soda ($NaHCO_3$) is basic. Describe the effect of baking soda on the H^+ ion concentration of stomach contents with pH 4.
6. **Predict** If you add hydrochloric acid (HCl) to water, what effect would this have on the H+ ion concentration? On the pH?

Online Quiz

Section 4

Reading Preview

Essential Questions

- What is the role of carbon in living organisms?
- What are the four major families of biological macromolecules?
- What are the functions of each group of biological macromolecules?

Review Vocabulary

organic compound: a carbon-based substance that is the basis of living matter

New Vocabulary

macromolecule
polymer
carbohydrate
lipid
protein
amino acid
nucleic acid
nucleotide

Multilingual eGlossary

The Building Blocks of Life

MAIN Idea **Organisms are made up of carbon-based molecules.**

Real-World Reading Link Children enjoy toy trains because they can link long lines of cars together and make patterns by joining cars of similar color or function. Similarly, in biology, there are large molecules made of many smaller units joined together.

Organic Chemistry

The element carbon is a component of almost all biological molecules. For this reason, life on Earth often is considered carbon-based. Because carbon is an essential element, scientists have devoted an entire branch of chemistry, called organic chemistry, to the study of organic compounds, which are those compounds containing carbon.

As shown in **Figure 25,** carbon has four electrons in its outermost energy level. Recall that the second energy level can hold eight electrons, so one carbon atom can form four covalent bonds with other atoms. These covalent bonds enable the carbon atoms to bond to each other, which results in a variety of important organic compounds. These compounds can be in the shape of straight chains, branched chains, and rings, such as those illustrated in **Figure 25.** Together, carbon compounds lead to the diversity of life on Earth.

Straight chain molecules

Branched molecules

Ring molecules

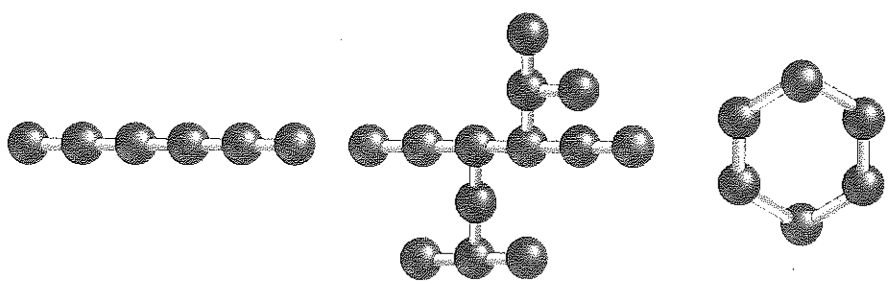
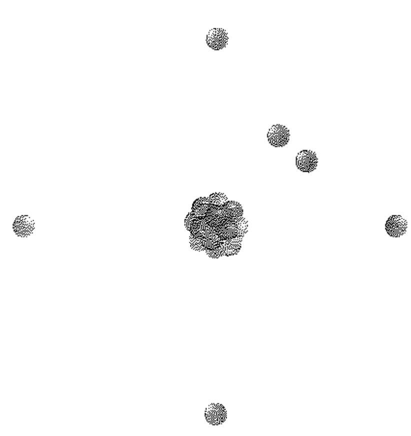
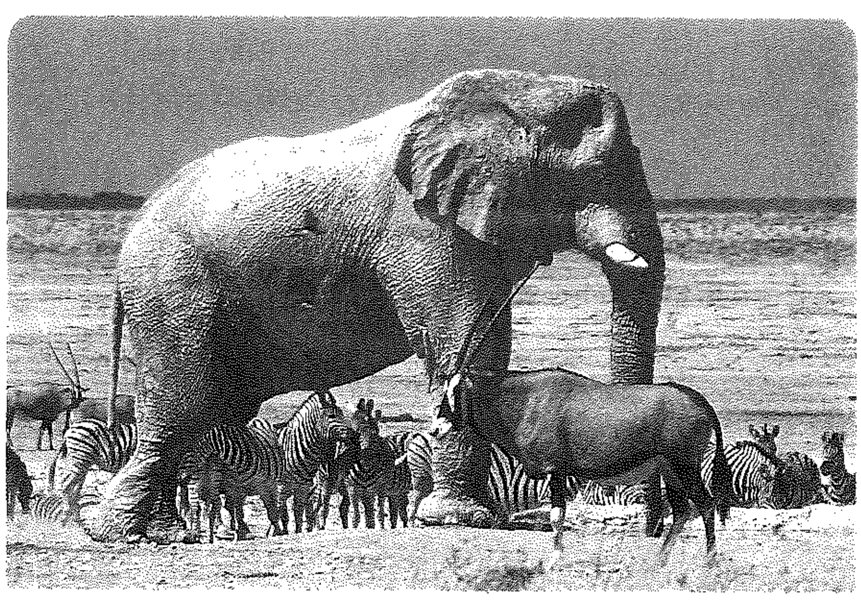


Figure 25 The amazing diversity of life is based on the variety of carbon compounds. The half-filled outer energy level of carbon allows for the formation of straight chain, branched, and ring molecules.



Carbon



Seth Lazar/Alamy

Macromolecules

Carbon atoms can be joined to form carbon molecules. Similarly, most cells store small carbon compounds that serve as building blocks for large molecules. **Macromolecules** are large molecules that are formed by joining smaller organic molecules together. These large molecules are also called polymers. **Polymers** are molecules made from repeating units of identical or nearly identical compounds called monomers that are linked together by a series of covalent bonds. As shown in **Table 1**, biological macromolecules are organized into four major categories: carbohydrates, lipids, proteins, and nucleic acids.

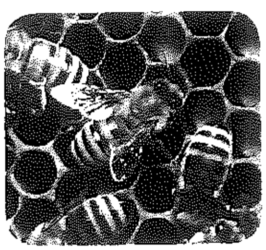
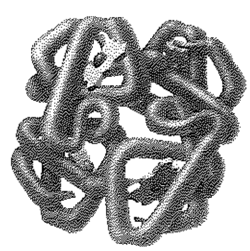
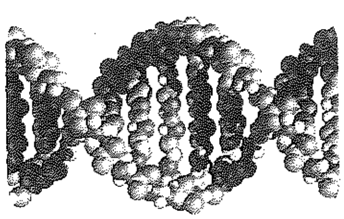
Reading Check **Use an analogy** to describe macromolecules.

VOCABULARY

WORD ORIGIN

Polymer
poly- prefix; from Greek, meaning *many*
-meros from Greek, meaning *part*

Table 1 Biological Macromolecules — Interactive Table

Group	Example	Function
Carbohydrates	 **Bread and grains**	• Store energy • Provide structural support
Lipids	 **Bees' wax**	• Store energy • Provide barriers
Proteins	 **Hemoglobin**	• Transport substances • Speed reactions • Provide structural support • Make hormones
Nucleic acids	 **DNA**	• Store and communicate genetic information

APPLYING PRACTICES

Construct and Revise an Explanation Go to the resources tab in ConnectED to find the Applying Practices worksheet *Exploring Macromolecules.*

Study Tip

Double-Entry Notes Fold a piece of paper in half lengthwise and write the boldfaced subheadings that appear under the *Biological Macromolecules* heading on the left side. As you read the text, make a bulleted list of notes about the important ideas and terms.

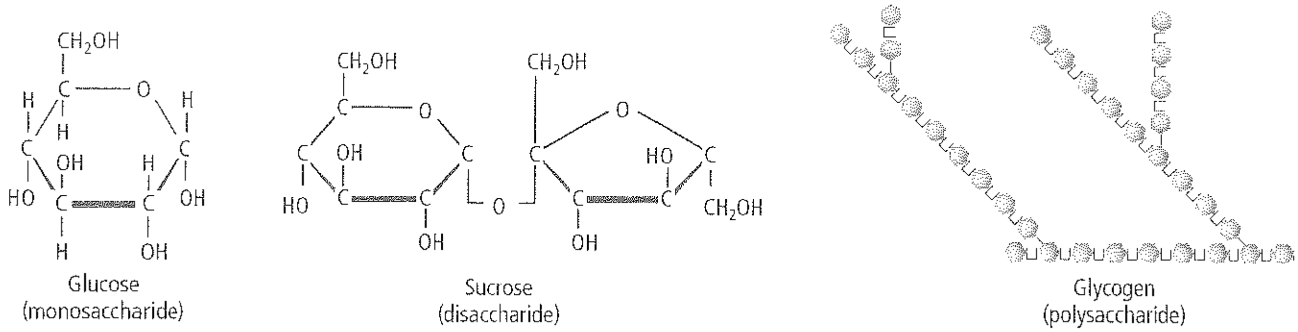


Figure 26 Glucose is a monosaccharide. Sucrose is a disaccharide composed of glucose and fructose monosaccharides. Glycogen is a branched polysaccharide made from glucose monomers.

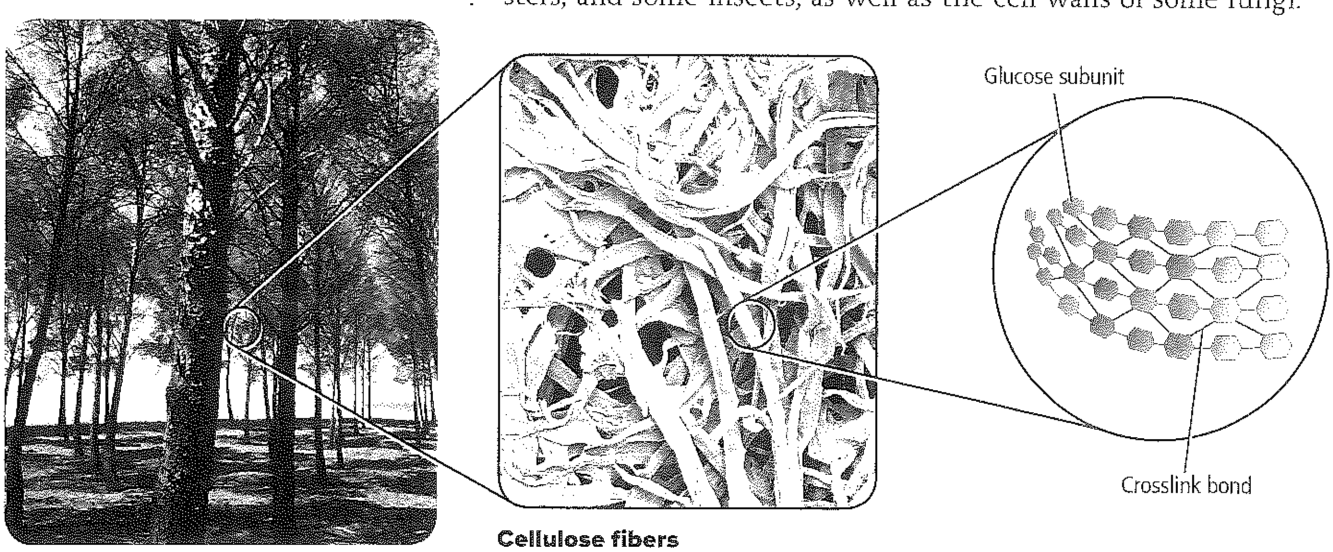
Personal Tutor

Carbohydrates Compounds composed of carbon, hydrogen, and oxygen in a ratio of one oxygen and two hydrogen atoms for each carbon atom are called **carbohydrates.** A general formula for carbohydrates is written as $(CH_2O)_n$. Here the subscript n indicates the number of CH_2O units in a chain. Biologically important carbohydrates that have values of n ranging from three to seven are called simple sugars, or monosaccharides (mah nuh SA kuh ridz). The monosaccharide glucose, shown in **Figure 26,** plays a central role as an energy source for organisms.

Monosaccharides can be linked to form larger molecules. Two monosaccharides joined together form a disaccharide (di SA kuh rid). Like glucose, disaccharides serve as energy sources. Sucrose, also shown in **Figure 26,** which is table sugar, and lactose, which is a component of milk, are both disaccharides. Longer carbohydrate molecules are called polysaccharides. One important polysaccharide is glycogen, which is shown in **Figure 26.** Glycogen is an energy storage form of glucose that is found in the liver and skeletal muscle. When the body needs energy between meals or during physical activity, glycogen is broken down into glucose.

In addition to their roles as energy sources, carbohydrates have other important functions in biology. In plants, a carbohydrate called cellulose provides structural support in cell walls. As shown in **Figure 27,** cellulose is made of chains of glucose linked together into tough fibers that are well suited for their structural role. Chitin (KI tun) is a nitrogen-containing polysaccharide that is the main component in the hard outer shells of shrimp, lobsters, and some insects, as well as the cell walls of some fungi.

Figure 27 The cellulose in plant cells provides the structural support for trees to stand in a forest.



Lipids Another important group of biological macromolecules is the lipid group. **Lipids** are molecules made mostly of carbon and hydrogen that make up the fats, oils, and waxes. Lipids are composed of fatty acids, glycerol, and other components. The primary function of lipids is to store energy. A lipid called a triglyceride (tri GLIH suh rid) is a fat if it is solid at room temperature and an oil if it is liquid at room temperature. In addition, triglycerides are stored in the fat cells of the body. Plant leaves are coated with lipids called waxes to prevent water loss, and the honeycomb in a beehive is made of beeswax.

Saturated and unsaturated fats Organisms need lipids to function properly. The basic structure of a lipid includes fatty acid tails, as shown in **Figure 28.** Each tail is a chain of carbon atoms bonded to hydrogen and other carbon atoms by single or double bonds. Lipids that have tail chains with only single bonds between the carbon atoms are called saturated fats because no more hydrogens can bond to the tail. Lipids that have at least one double bond between carbon atoms in the tail chain can accommodate at least one more hydrogen and are called unsaturated fats. Fats with more than one double bond in the tail are called polyunsaturated fats.

Phospholipids A special lipid shown in **Figure 28,** called a phospholipid, is responsible for the structure and function of the cell membrane. Lipids are hydrophobic, which means they do not dissolve in water. This characteristic is important because it allows lipids to serve as barriers in biological membranes.

Steroids Another important category of lipids is the steroid group. Steroids include substances such as cholesterol and hormones. Despite its reputation as a "bad" lipid, cholesterol provides the starting point for other necessary lipids such as vitamin D and the hormones estrogen and testosterone.

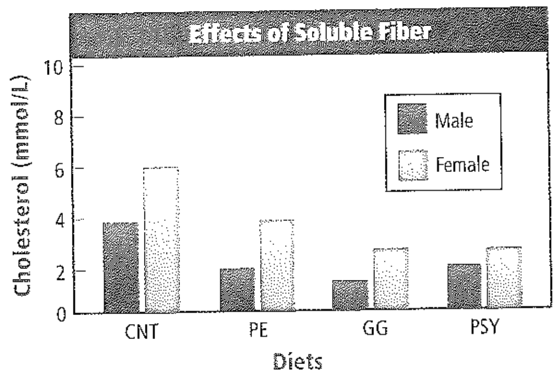
DATA ANALYSIS LAB 2

Based on Real Data*

Does soluble fiber affect cholesterol levels? High amounts of a steroid called cholesterol in the blood are associated with the development of heart disease. Researchers study the effects of soluble fiber in the diet on cholesterol.

Data and Observations

This experiment evaluated the effects of three soluble fibers on cholesterol levels in the blood: pectin (PE), guar gum (GG), and psyllium (PSY). Cellulose was the control (CNT).



Think Critically

1. **Calculate** the percentage of change in cholesterol levels as compared to the control.
2. **Describe** the effects that soluble fiber appears to have on cholesterol levels in the blood.

*Data obtained from: Shen, et al. 1998. Dietary soluble fiber lowers plasma LDL cholesterol concentrations by altering lipoprotein metabaolism in female Guinea pigs. *Journal of Nutrition* 128: 1434-1441.

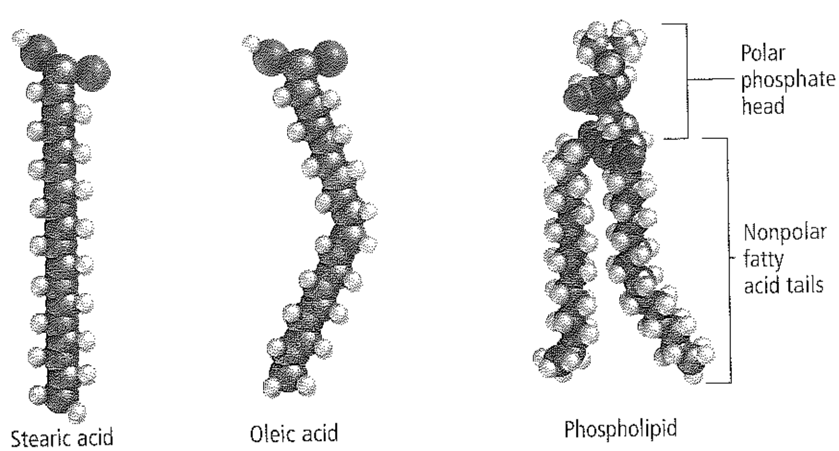
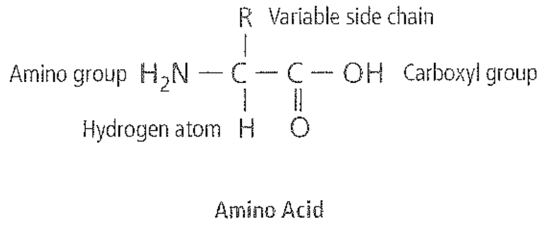


Figure 28 Stearic acid has no double bonds between carbon atoms; oleic acid has one double bond. Phospholipids have a polar head and two nonpolar tails.



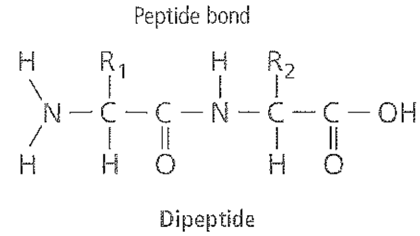


Figure 29
Left: The general structure of an amino acid has four groups around a central carbon.
Right: The peptide bond in a protein happens as a result of a chemical reaction.
Interpret ***which other molecule is a product when a peptide bond forms.***

Animation

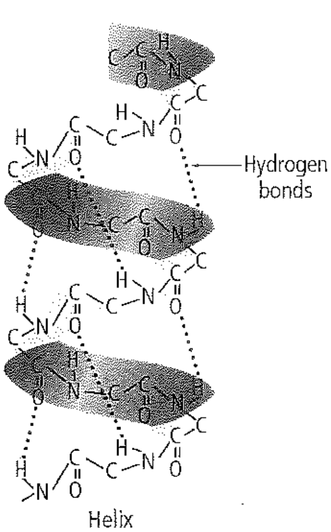
Proteins Another primary building block of living things is protein. A **protein** is a compound made of small carbon compounds called amino acids. **Amino acids** are small compounds that are made of carbon, nitrogen, oxygen, hydrogen, and sometimes sulfur. All amino acids share the same general structure.

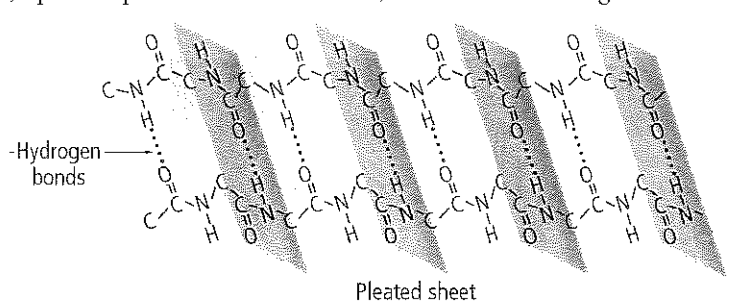
Amino acid structure Amino acids have a central carbon atom like the one shown in **Figure 29.** Recall that carbon can form four covalent bonds. One of those bonds is with hydrogen. The other three bonds are with an amino group (-NH_2), a carboxyl group (-COOH), and a variable group (-R). The variable group makes each amino acid different. There are 20 different variable groups, and proteins are made of different combinations of all 20 different amino acids. Several covalent bonds called peptide bonds join amino acids together to form proteins, which is also shown in **Figure 29.** A peptide bond forms between the amino group of one amino acid and the carboxyl group of another.

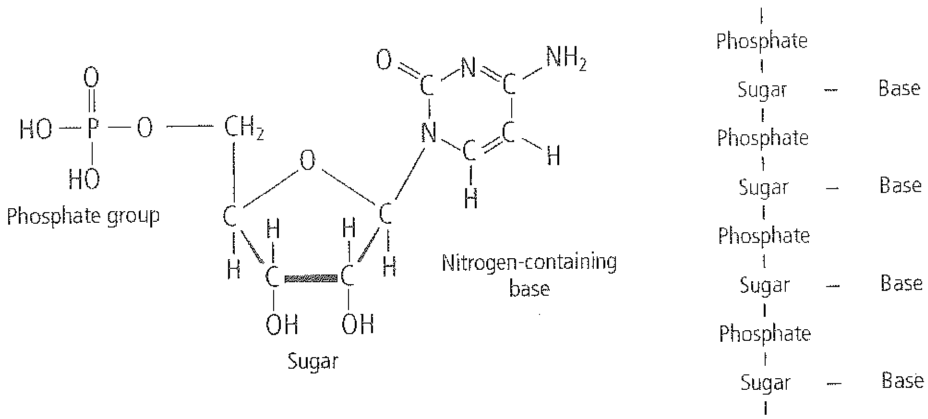
Three-dimensional protein structure Based on the variable groups contained in the different amino acids, proteins can have up to four levels of structure. The number of amino acids in a chain and the order in which the amino acids are joined define the protein's primary structure. After an amino acid chain is formed, it folds into a unique three-dimensional shape, which is the protein's secondary structure. **Figure 30** shows two basic secondary structures: the helix and the pleat. A protein might contain many helices, pleats, and folds. The tertiary structure of many proteins is globular, such as the hemoglobin protein shown in **Table 1,** but some proteins form long fibers. Some proteins form a fourth level of structure by combining with other proteins.

Protein function Proteins make up about 15 percent of your total body mass and are involved in nearly every function of your body. For example, your muscles, skin, and hair are made of proteins. Your cells contain about 10,000 different proteins that provide structural support, transport substances inside the cell and between cells, communicate signals within a cell and between cells, speed up chemical reactions, and control cell growth.

Figure 30 The shape of a protein depends on the interactions among the amino acids. Hydrogen bonds help the protein hold its shape.







Nucleotide **Nucleic acid**

Figure 31
Left: DNA nucleotides contain the sugar deoxyribose. RNA nucleotides contain the sugar ribose.
Right: Nucleotides are joined together by bonds between their sugar group and phosphate group.

Nucleic acids The fourth group of biological macromolecules are nucleic acids. **Nucleic acids** are complex macromolecules that store and transmit genetic information. Nucleic acids are made of smaller repeating subunits composed of carbon, nitrogen, oxygen, phosphorus, and hydrogen atoms, called **nucleotides.** **Figure 31** shows the basic structure of a nucleotide and nucleic acid. There are five major nucleotides, all of which have three units–a phosphate, a nitrogenous base, and a ribose sugar.

There are two types of nucleic acids found in living organisms: deoxyribonucleic (dee AHK sih rib oh noo klay ihk) acid (DNA) and ribonucleic (rib oh noo KLAY ihk) acid (RNA). In nucleic acids such as DNA and RNA, the sugar of one nucleotide bonds to the phosphate of another nucleotide. The nitrogenous base that sticks out from the chain is available for hydrogen bonding with other bases in other nucleic acids.

A nucleotide with three phosphate groups is adenosine triphosphate (ATP). ATP is a storehouse of chemical energy that can be used by cells in a variety of reactions. It releases energy when the bond between the second and third phosphate group is broken. Less energy is released when the bond between the first and second phosphate group is broken.

Section 4 Assessment

Section Summary

- Carbon compounds are the basic building blocks of living organisms.
- Biological macromolecules are formed by joining small carbon compounds into polymers.
- There are four types of biological macromolecules.
- Peptide bonds join amino acids in proteins.
- Chains of nucleotides form nucleic acids.

Understand Main Ideas

1. MAIN Idea **Explain** If an unknown substance found on a meteorite is determined to contain no trace of carbon, can scientists conclude that there is life at the metorite's origin?
2. **Compare** the types of biological macromolecules and their functions.
3. **Determine** the components of carbohydrates and proteins.
4. **Discuss** the importance of amino acid order to a protein's function.

Think Critically

5. **Summarize** Given the large number of proteins in the body, explain why the shape of an enzyme is important to its function.
6. **Draw** two structures (one straight chain and one ring) of a carbohydrate with the chemical formula $(CH_2O)_6$.

Online Quiz

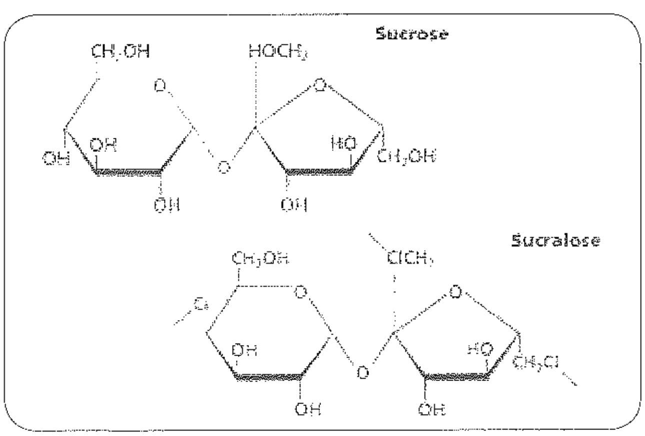
CUTTING-EDGE BIOLOGY

SWEETER THAN SUGAR

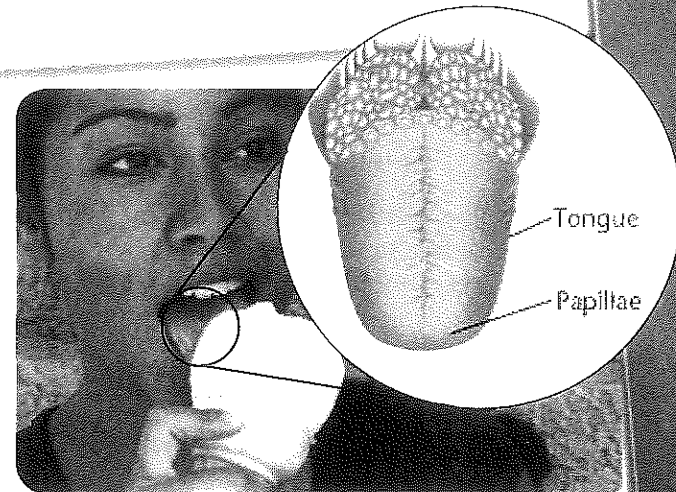
The reason why people love desserts is right on the tips of their tongues—literally. The taste buds in that location are the receptors that register sweetness most strongly. Many of the small bumps, called papillae, that you see on your tongue contain taste buds.

Registering Sweetness When you eat, the molecules from food temporarily bind themselves to protein molecules in the receptor cells of your tongue. As a result, the receptors send electrical impulses through your nerves to your brain. Your brain interprets the impulses as taste. Sometimes the taste is what you think of as sweet.

Natural vs. Artificial Sweeteners are substances added to foods to make them taste sweet. There are many natural sweeteners, such as table sugar and honey. An artificial sweetener is a man-made substance that has the same effect on taste buds as sugar does. Artificial sweeteners, such as saccharin, cyclamate, and aspartame, are hundreds of times sweeter than any naturally occurring sugar.



The difference between sucrose and sucralose is the substitution of three chlorine (Cl) atoms for three hydroxyl (OH) groups.



Taste buds on your tongue send impulses to your brain so that your brain can interpret how the food or drink tastes.

The molecules of these artificial sweeteners mimic the geometry and composition of natural sweeteners and are able to bind to the receptor cells in human taste buds.

One recently developed artificial sweetener, sucralose, has a chemical structure that is nearly identical to sucrose, or table sugar. The only difference is three hydroxyl (OH) groups in sucrose are replaced by chlorine atoms (Cl) in sucralose. This keeps the human body from metabolizing sucralose and makes it calorie-free.

Artificial sweeteners are used in many products, from diet sodas to children's medications. They provide the sweetness that people crave without the calories that natural sweeteners contain. Scientists continue to search for new sweeteners that are economical and healthful to customers.

WRITING in Biology

Marketing Campaign Research an artificial sweetener that has been approved by the FDA. Devise a marketing campaign to inform consumers about your chosen artificial sweetener. Your marketing campaign might include a press release, television or radio commercials, Web ads, social networking sites, or other methods of spreading information.

Tony Freeman/Photo Edit

WebQuest

Design Your Own

BIOLAB

WHAT FACTORS AFFECT AN ENZYME REACTION?

Background: The compound hydrogen peroxide, H_2O_2, is produced when organisms metabolize food, but hydrogen peroxide damages cell parts. Organisms combat the buildup of H_2O_2 by producing the enzyme peroxidase. Peroxidase speeds up the breakdown of hydrogen peroxide into water and oxygen.

Question: *What factors affect peroxidase activity?*

Possible Materials

400-mL beaker	50-mL graduated cylinder
kitchen knife	10-mL graduated cylinder
hot plate	tongs or large forceps
test-tube rack	square or rectangular pan
ice	stopwatch or timer
beef liver	nonmercury thermometer
dropper	3% hydrogen peroxide
distilled water	potato slices

18-mm × 150-mm test tubes
buffer solutions (pH 5, pH 6, pH 7, pH 8)

Safety Precautions

CAUTION: ***Use only GFCI-protected circuits for electrical devices.***

Plan and Perform the Experiment

1. Read and complete the lab safety form.
2. Choose a factor to test. Possible factors include temperature, pH, and substrate (H_2O_2) concentration.
3. Form a hypothesis about how the factor will affect the reaction rate of peroxidase.
4. Design an experiment to test your hypothesis. Create a procedure and identify the controls and variables.
5. Create a data table for recording your observations and measurements.
6. Make sure your teacher approves your plan before you proceed.
7. Conduct your approved experiment.
8. **Cleanup and Disposal** Clean up all equipment as instructed by your teacher and return everything to its proper place. Wash your hands thoroughly with soap and water.

Analyze and Conclude

1. **Describe** how the factor you tested affected the enzyme activity of peroxidase.
2. **Graph** your data, and then analyze and interpret your graph.
3. **Discuss** whether or not your data supported your hypothesis.
4. **Infer** why hydrogen peroxide is not the best choice for cleaning an open wound.
5. **Error Analysis** Identify any experimental errors or other errors in your data that might have affected the accuracy of your results.

SHARE YOUR DATA

Compare your data with the data collected by other groups in the class that tested the same factor. Infer reasons why your group's data might differ from the data collected by other groups.

Chapter 6 Study Guide

THEME FOCUS Energy and Matter In every chemical reaction, there is a change in energy caused by the making and breaking of chemical bonds as reactants form products.

BIG Idea Atoms are the foundation of biological chemistry and the building blocks of all living things.

Section 1 Atoms, Elements, and Compounds

atom (p. 148)
nucleus (p. 148)
proton (p. 148)
neutron (p. 148)
electron (p. 148)
element (p. 149)
isotope (p. 150)
compound (p. 151)
covalent bond (p. 152)
molecule (p. 152)
ion (p. 153)
ionic bond (p. 153)
van der Waals force (p. 155)

MAIN Idea Matter is composed of tiny particles called atoms.

- Atoms consist of protons, neutrons, and electrons.
- Elements are pure substances made up of only one kind of atom.
- Isotopes are forms of the same element that have a different number of neutrons.
- Compounds are substances with unique properties that are formed when elements combine.
- Elements can form covalent and ionic bonds.

Section 2 Chemical Reactions

chemical reaction (p. 156)
reactant (p. 157)
product (p. 157)
activation energy (p. 158)
catalyst (p. 159)
enzyme (p. 159)
substrate (p. 160)
active site (p. 160)

MAIN Idea Chemical reactions allow living things to grow, develop, reproduce, and adapt.

- Balanced chemical equations must show an equal number of atoms for each element on both sides.
- Activation energy is the energy required to begin a reaction.
- Catalysts are substances that alter chemical reactions.
- Enzymes are biological catalysts.

Section 3 Water and Solutions

polar molecule (p. 161)
hydrogen bond (p. 161)
mixture (p. 163)
solution (p. 163)
solvent (p. 163)
solute (p. 163)
acid (p. 164)
base (p. 164)
pH (p. 165)
buffer (p. 165)

MAIN Idea The properties of water make it well suited to help maintain homeostasis in an organism.

- Water is a polar molecule.
- Solutions are homogeneous mixtures formed when a solute is dissolved in a solvent.
- Acids are substances that release hydrogen ions into solutions. Bases are substances that release hydroxide ions into solutions.
- pH is a measure of the concentration of hydrogen ions in a solution.

Section 4 The Building Blocks of Life

macromolecule (p. 167)
polymer (p. 167)
carbohydrate (p. 168)
lipid (p. 169)
protein (p. 170)
amino acid (p. 170)
nucleic acid (p. 171)
nucleotide (p. 171)

MAIN Idea Organisms are made up of carbon-based molecules.

- Carbon compounds are the basic building blocks of living organisms.
- Biological macromolecules are formed by joining small carbon compounds into polymers.
- There are four types of biological macromolecules.
- Peptide bonds join amino acids in proteins.
- Chains of nucleotides form nucleic acids.

Vocabulary eGames

Section 1

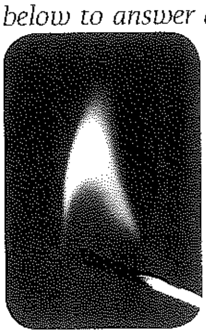
Vocabulary Review

Describe the difference between the terms in each pair.

1. electron, proton
2. ionic bond, covalent bond
3. isotope, element
4. atom, ion

Understand Main Ideas

Use the photo below to answer question 5.



5. What does the image above show?
   A. a covalent bond
   B. a physical property
   C. a chemical reaction
   D. van der Waals forces

6. Which process changes a chlorine atom into a chloride ion?
   A. electron gain
   B. electron loss
   C. proton gain
   D. proton loss

7. MAIN Idea Which of these is a pure substance that cannot be broken down by a chemical reaction?
   A. a compound
   B. a mixture
   C. an element
   D. a neutron

8. How do the isotopes of hydrogen differ?
   A. in the number of protons
   B. in the number of electrons
   C. in the number of energy levels
   D. in the number of neutrons

Constructed Response

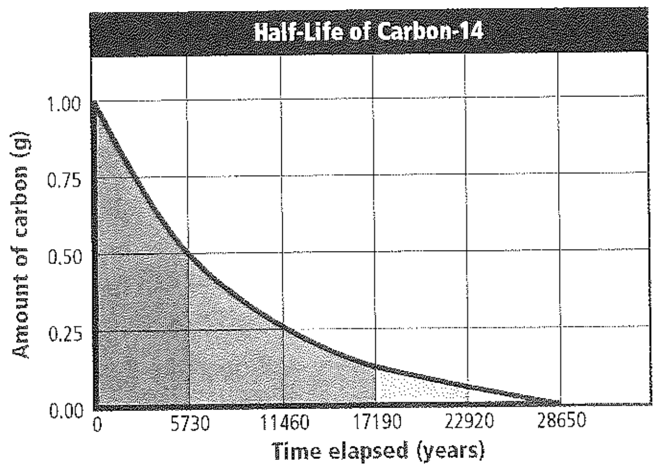
9. **Short Answer** What is a radioactive isotope? List uses of radioactive isotopes.

10. **Short Answer** What factor determines that an oxygen atom can form two covalent bonds while a carbon atom can form four?

11. **Open Ended** Why is it important for living organisms to have both strong bonds (covalent and ionic) and weak bonds (hydrogen and van der Waals forces)?

Think Critically

Use the graph below to answer question 12.



12. **Analyze** According to the data, what is the half-life of carbon-14? How can this information be used by scientists?

13. **Explain** The gecko is a reptile that climbs on smooth surfaces such as glass using van der Waals forces to adhere to the surfaces. How is this method of adhesion more advantageous than covalent interactions?

Section 2

Vocabulary Review

Match the term on the left with the correct definition on the right.

14. activation energy
15. substrate
16. enzyme
17. product

A. a protein that speeds up a reaction
B. a substance formed by a chemical reaction
C. the energy required to start a reaction
D. a substance that binds to an enzyme

Understand Main Ideas

18. **THEME FOCUS Energy and Matter** Which of the following is a substance that lowers the activation energy?
    A. an ion
    B. a reactant
    C. a catalyst
    D. a substrate

19. In which of the following are bonds broken and new bonds formed?
    A. chemical reactions
    B. elements
    C. isotopes
    D. polar molecules

20. Which statement is true of chemical equations?
    A. Reactants are on the right.
    B. Products are on the right.
    C. Products have fewer atoms than reactants.
    D. Reactants have fewer atoms than products.

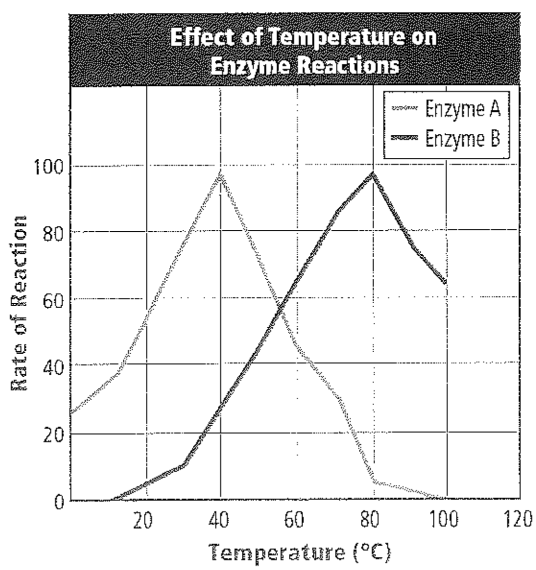
Constructed Response

21. **Short Answer** What features do all reactions involving enzymes have in common?

22. **Open Ended** Identify and describe factors that can influence enzyme activity.

Think Critically

Use the graph to answer questions 23 and 24.



23. **Describe** the effect that temperature has on the rate of the reactions using the graph above.

24. **MAIN Idea** Which enzyme is more active in a human cell? Why?

Section 3

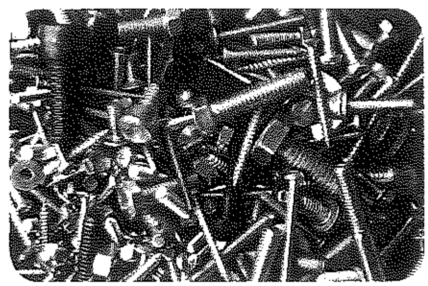
Vocabulary Review

State the relationship between the terms in each pair.

25. solution, mixture
26. pH, buffer
27. acid, base
28. solvent, solute
29. polar molecule, hydrogen bond

Understand Main Ideas

Use the figure below to answer question 30.



30. What does the image above show?
    A. a heterogeneous mixture
    B. a homogeneous mixture
    C. a solution
    D. a suspension

31. Which statement is not true about pure water?
    A. It has a pH of 7.0.
    B. It is composed of polar molecules.
    C. It is composed of ionic bonds.
    D. It is a good solvent.

32. Which is a substance that produces OH^- ions when it is dissolved in water?
    A. a base
    B. an acid
    C. a buffer
    D. salt

Constructed Response

33. **MAIN Idea** Why are hydrogen bonds so important for living organisms?

34. **Short Answer** Hydrochloric acid (HCl) is a strong acid. What ions are formed when HCl dissolves in water? What is the effect of HCl on the pH of water?

35. **Open Ended** Explain the importance of buffers to living organisms.

Online Test Practice

Think Critically

36. **Predict** two places in the body where buffers are used to limit sharp changes in pH.

37. **Draw** a diagram of table salt (NaCl) dissolved in water.

Section 4

Vocabulary Review

Complete the following sentences with vocabulary terms from the Study Guide page.

38. Carbohydrates, lipids, proteins, and nucleic acids are __________.

39. Proteins are made from __________ that are joined by __________.

40. __________ make up fats, oils, and waxes.

41. DNA and RNA are examples of __________.

Understand Main Ideas

42. Which two elements are always found in amino acids?
    A. nitrogen and sulfur
    B. carbon and oxygen
    C. hydrogen and phosphorus
    D. sulfur and oxygen

43. Which joins amino acids together?
    A. peptide bonds
    B. hydrogen bonds
    C. van der Waals forces
    D. ionic bonds

44. Which substance is not part of a nucleotide?
    A. a phosphate
    B. a base
    C. a sugar
    D. water

Constructed Response

45. **Open Ended** Why do cells contain both macromolecules and small carbon compounds?

46. **Open Ended** Why can't humans digest all carbohydrates?

Think Critically

47. BIG Idea **Create** a table for the four main biological macromolecules that lists their component and functions.

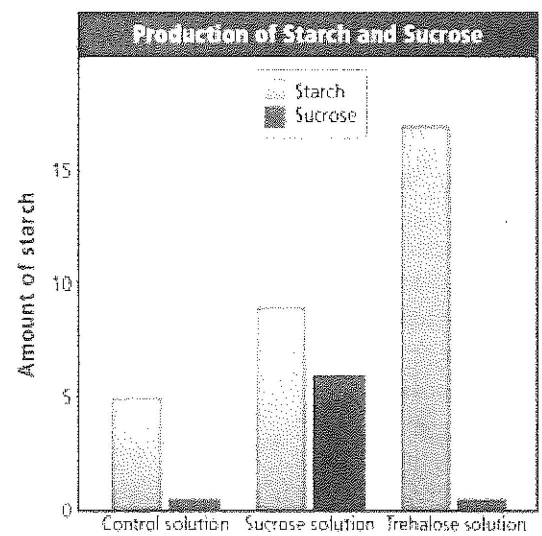
Summative Assessment

48. BIG Idea Diagram the basic unit of matter, describe the parts, and relate them to each other.

49. WRITING in Biology Research and write a job description for a biochemist. Include the types of tasks that biochemists perform and materials that are used in their research.

DBQ Document-Based Questions

Starch is the major carbon storehouse in plants. Experiments were performed to determine if trehalose might regulate starch production in plants. Leaf disks were incubated for three hours in sorbitol (the control), sucrose, and trelahose solutions. Then, levels of starch and sucrose in the leaves were measured. Use the data to answer the questions below.



Data obtained from: Kolbe, et al. Trehalose 6-phosphate regulates starch synthesis via post translational redox activation of ADP-glucose pyrophophorylase. *Proceedings of the National Academy of Sciences of the USA* 102(31): 11118–11123.

50. Summarize the production of starch and sucrose in the three solutions.

51. What conclusion might the researchers have reached based on these data?

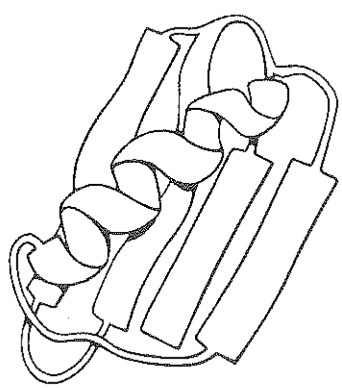
Standardized Test Practice

Cumulative

Multiple Choice

1. If a population of parrots has greater genetic diversity than a hummingbird population in the same region, which outcome could result?
   A. The parrot population could have a greater resistance to disease than the hummingbird population.
   B. Other parrot populations in different regions could become genetically similar to this one.
   C. The parrot population could have a greater variety of abiotic factors with which to interact.
   D. The parrot population could interact with a greater variety of other populations.

Use the diagram below to answer questions 2 and 3.



2. Which type of macromolecule can have a structure like the one shown?
   A. a carbohydrate
   B. a lipid
   C. a nucleotide
   D. a protein

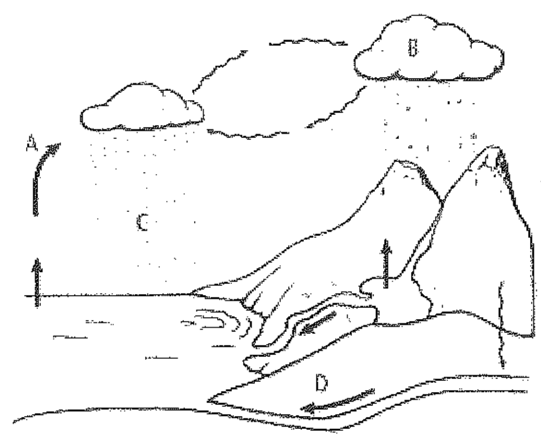
3. Which molecular activity requires a folded structure?
   A. behavior as a nonpolar compound
   B. function of an active site
   C. movement through cell membranes
   D. role as energy storage for the cell

4. Which describes the effects of population increase and resource depletion?
   A. increased competition
   B. increased emigration
   C. exponential population growth
   D. straight-line population growth

5. Which property of populations might be described as random, clumped, or uniform?
   A. density
   B. dispersion
   C. growth
   D. size

6. Which is an example of biodiversity with direct economic value?
   A. sparrow populations that have great genetic diversity
   B. species of a water plant that makes a useful antibiotic
   C. trees that create a barrier against hurricane winds
   D. villagers who all use the same rice species for crops

Use the illustration below to answer question 7.



7. Which term describes the part of the cycle labeled *A*?
   A. condensation
   B. evaporation
   C. runoff
   D. precipitation

8. Which is a characteristic of exponential growth?
   A. the graphical representation goes up and down
   B. the graphical representation has a flat line
   C. a growth rate that increases with time
   D. a growth rate that stays constant in time

Short Answer

9. Assess what might happen if there were no buffers in human cells.

10. Choose an example of an element and a compound and then contrast them.

Use the chart below to answer question 11.

Factors Affecting Coral Survival	
Factor	**Optimal Range**
Water temperature	23°C to 25°C
Salinity	30 to 40 parts per million
Sedimentation	little or no sedimentation
Depth	up to 48 m

11. Using the data in the chart, describe which region of the world would be optimal for coral growth.

12. Provide a hypothesis to explain the increase in species diversity as you move from the polar regions to the tropics.

13. In a country with a very slow growth rate, predict which age groups are the largest in the population.

14. Why is it important that enzymes can bind only to specific substrates?

Extended Response

15. Suddenly, after very heavy rains, many fish in a local lake begin to die, yet algae in the water seem to be doing very well. You know that the lake receives runoff from local fields and roads. Form a hypothesis about why the fish are dying, and suggest how to stop the deaths.

16. When scientists first discovered atoms, they thought they were the smallest parts into which matter could be divided. Relate how later discoveries led scientists to revise this definition.

17. Identify and describe three types of symbiotic relationships and provide an example of each.

Essay Question

Many kinds of molecules found in living organisms are made of smaller monomers that are put together in different sequences, or in different patterns. For example, organisms use a small number of nucleotides to make nucleic acids. Thousands of different sequences of nucleotides in nucleic acids provide the basic coding for all the genetic information in living things.

Using the information in the paragraph above, answer the following question in essay format.

18. Describe how it is beneficial for organisms to use monomers to create complex macromolecules.

NEED EXTRA HELP?

If You Missed Question . . .	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Review Section . . .	5.1	6.4	6.4	4.1	5.1	2.3	4.1	4.1	6.3	5.3	3.1, 3.3	5.1	4.2	6.2	5.2	6.1	2.1	6.4