Chapter 6
Chemistry in Biology
BIG Idea Atoms are the foundation of biological chemistry and the building blocks of all living organisms.

Chapter 7
Cellular Structure and Function
BIG Idea Cells are the structural and functional units of all living organisms.

Chapter 8
Cellular Energy
BIG Idea Photosynthesis converts the Sun’s energy into chemical energy, while cellular respiration uses chemical energy to carry out life functions.

Chapter 9
Cellular Reproduction
BIG Idea Cells go through a life cycle that includes interphase, mitosis, and cytokinesis.

CAREERS IN BIOLOGY
Forensic Pathologist
Forensic pathologists are medical specialists who investigate the cause and the manner of human death. Forensic pathologists work in the field and in a laboratory to analyze medical evidence such as skulls. Visit biologygmh.com to learn more about forensic pathology. Then write a summary of the classification of the manner of death that forensic pathologists use.
To read more about forensic pathologists in action, visit biologygmh.com.
Chemistry in Biology

Section 1
Atoms, Elements, and Compounds
MAIN Idea Matter is composed of tiny particles called atoms.

Section 2
Chemical Reactions
MAIN Idea Chemical reactions allow living things to grow, develop, reproduce, and adapt.

Section 3
Water and Solutions
MAIN Idea The properties of water make it well suited to help maintain homeostasis in an organism.

Section 4
The Building Blocks of Life
MAIN Idea Organisms are made up of carbon-based molecules.

BioFacts

- Collagen is the most abundant protein in mammals.
- Collagen can be found in muscle, bone, teeth, skin, and the cornea of the eye.
- Wrinkles that become visible as people age are the result of collagen breaking down.
How does the nutrient content of foods compare?

Your body’s structure and function depends on chemical elements including those found in proteins, carbohydrates, fats, vitamins, minerals, and water. In this lab, you will investigate nutrients that provide those elements.

Procedure
1. Read and complete the lab safety form.
2. Construct a data chart to record grams or percent of each nutrient listed above. Include columns for Serving Size, Calories, and Calories from Fat.
3. Study and record data from the Nutrition Facts label on a cereal box.
4. Choose three additional labeled food items. Predict how the nutrients in these items compare with the nutrients in the cereal. Use the Nutrition Facts labels to record data.

Analysis
1. Evaluate What factors influenced your predictions of the nutrient contents? Were your predictions correct?
2. Analyze Which food item has the greatest amount of proteins per serving? The least?

Enzymes Make this Foldable to help you organize information about enzyme structure and function.

STEP 1 Draw a line across the middle of a piece of paper.

STEP 2 Fold the top and bottom edges to meet at the middle of the paper.

STEP 3 Fold in half to make four sections as shown.

STEP 4 Cut along the fold lines of the top and bottom flaps to form four tabs of equal size. Label the tabs A, B, C, and D as shown.

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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 huge explosion 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 explosion. The study of those building blocks is the science of chemistry.

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

**Connection History** In the fifth century B.C., the 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 atoms** An atom is so small that billions of them 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 6.1. 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 that are located outside the nucleus (\( e^- \)). 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.
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 elements.

The periodic table of elements As shown in Figure 6.2, 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 6.3, elements found in living organisms also are found in Earth’s crust.

Interpret What is the most abundant element that exists in living things?

Relative Composition of Living v. Nonliving Matter

- Organisms
- Earth’s Crust

<table>
<thead>
<tr>
<th>Element</th>
<th>Organisms</th>
<th>Earth’s Crust</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>46%</td>
<td>8%</td>
</tr>
<tr>
<td>C</td>
<td>22%</td>
<td>11%</td>
</tr>
<tr>
<td>O</td>
<td>18%</td>
<td>39%</td>
</tr>
<tr>
<td>N</td>
<td>3%</td>
<td>5%</td>
</tr>
<tr>
<td>Ca and Mg</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>Na and K</td>
<td>0.5%</td>
<td>0.3%</td>
</tr>
<tr>
<td>Si</td>
<td>0.4%</td>
<td>0.2%</td>
</tr>
<tr>
<td>Others</td>
<td>1%</td>
<td>1%</td>
</tr>
</tbody>
</table>
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 6.4. 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 Previously, you read that neutrons have no charge. Changing the number of neutrons in an atom does not change the overall charge of the atom (it still has no charge). 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 and used for many applications. 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, such as in radiation therapy to treat cancers, as shown in Figure 6.5.

Figure 6.5 Radioactive isotopes are used to help doctors diagnose disease and locate and treat certain types of cancer.
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 6.6** shows you a few. Each compound has a chemical formula made up of the chemical symbols from the periodic table. You might know that water is the compound $\text{H}_2\text{O}$. Sodium chloride ($\text{NaCl}$) is the compound commonly called table salt. The fuel people use in cars is a mixture of hydrocarbon compounds. Hydrocarbons only have hydrogen and carbon atoms. Methane ($\text{CH}_4$) is the simplest hydrocarbon. Bacteria in areas such as the wetlands shown in **Figure 6.6** 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 than 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 6.7**, can break water down into hydrogen gas and oxygen gas.

**Brilliant fireworks displays depend on compounds containing the metal strontium.**

**Table salt is the compound NaCl.**

**Wetlands are sources of living things made of complex compounds and the simple compound methane ($\text{CH}_4$).**
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 6.8. 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 happens when atoms share electrons in their outer energy levels.

The chemical bond that forms when electrons are shared is called a covalent bond. Figure 6.9 illustrates the covalent bonds between oxygen and hydrogen to 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, but 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 6.10.
**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 in order 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 6.11** 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.
Some atoms tend to donate or accept electrons more easily than other atoms. 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 molecular compounds formed by covalent bonds.

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.

**Test for Simple Sugars**

**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. 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 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 the 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. Van der Waals forces are not as strong as covalent and ionic bonds, but they play a key role in biological processes.

Scientists have determined that geckos, such as the one shown in Figure 6.12, can climb smooth surfaces due to van der Waals forces between the atoms in the hairlike structures on their toes and the atoms on the surface they are climbing.

van der Waals forces in water Let’s consider how van der Waals forces work in a common substance—water. The areas of slight positive and negative charge 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 6.1 Assessment

Section Summary

➤ 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.

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 element.
3. **Explain** Are all compounds molecules? Why or why not?
4. **Compare** van der Waals forces, ionic bonds, and covalent bonds.

Think Scientifically

5. **Explain** how the number of electrons in an energy level affects bond formation.
6. **MATH in Biology** Beryllium has four protons in its nucleus. How many neutrons are in beryllium-9? Explain how you calculated your answer.
Chemical Reactions

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

Real-World Reading Link When you lie down for the night, you probably think that your body is completely at rest. In fact, you will still be digesting food you ate that day, the scrape on your elbow will be healing, and your muscles and bones will be growing and developing. All of the things that are happening inside your body are the result of chemical reactions. You are a 24-hour reaction factory!

Reactants and Products
A new car with its shining chrome and 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/or formed during chemical reactions. The rust on the chain in Figure 6.13 is a compound called iron oxide (Fe₂O₃), and it was formed when oxygen (O₂) 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 6.13. The water is undergoing a physical change. A physical change alters the substance’s appearance but not its composition. It 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 the surface of the chain in Figure 6.13 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 formation of a gas, liquid, or solid.
Chemical equations When scientists write chemical reactions, they express each component of the reaction in a chemical equation. When writing chemical equations, chemical formulas describe the substances in the reaction and arrows indicate the process of change.

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

Reactants → Products

The following chemical equation can be written to describe the reaction that provides energy in Figure 6.14.

\[ \text{C}_6\text{H}_{12}\text{O}_6 + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} \]
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 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. Use coefficients to make the number of atoms on each side of the arrow equal.

\[ \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} \]

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. You will study this important reaction further in Chapter 8.

Reading Check Explain why chemical equations must be balanced.

Energy of Reactions

A sugar cookie is made with flour, sugar, and other ingredients mixed together, but it is not a cookie until you bake it. Something must start the change from cookie dough to cookies. The key to starting a chemical reaction is energy. For the chemical reactions that transform the dough to cookies to happen, energy in the form of heat is needed. Similarly, most compounds in living things cannot undergo chemical reactions without energy.
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 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 6.15 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 go. Some reactions do not happen because they have a very high activation energy.

Energy change in chemical reactions  Compare the progress of the reaction in Figure 6.15 to the progress of the reaction in Figure 6.16. Both reactions require activation energy to get started. However, notice from the graph in Figure 6.15 that the energy of the product is lower than the energy of the reactants. This reaction is exothermic—it released energy in the form of heat. The reaction in Figure 6.16 is endothermic—it absorbed heat energy. The energy of the products is higher than the energy of the reactant. In every chemical reaction, there is a change in energy due to the making and breaking of chemical bonds as reactants for products. Your body temperature of about 37°C is evidence that chemical reactions are happening inside your body.
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 go thousands of times faster than the reaction would be able to go 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 6.17 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 your mouth when amylase speeds the breakdown of amylase, one of the two components of starch. Like amylase, most enzymes are specific to one reaction.

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Investigate Enzymatic Browning

**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 each of these apple wedges will show when exposed to air. Justify your prediction.
   - 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 on a paper towel, skin side down. Observe for 10 min, then record the relative amount of discoloration of each apple wedge.

**Analysis**

1. **Analyze** How did each treatment affect the chemical reaction that occurred on the fruit’s soft tissue? Why were some of the treatments successful?
2. **Think Critically** A restaurant owner wants to serve fresh-cut fruit. What factors might be considered in choosing a recipe and preparation method?
Follow Figure 6.18 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 6.18, 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 poisonous snake, enzymes in the venom break down the membranes of that person’s red blood cells. Hard green apples ripen due to the action of enzymes. Photosynthesis and cellular respiration, which you will learn more about in Chapter 8, 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 6.2 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: $A + B \rightarrow AB$.
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 Scientifically

5. **MATH in Biology** For the following chemical reaction, label the reactants and products, and then balance the chemical equation. $\text{H}_2\text{O}_2 \rightarrow \text{H}_2\text{O} + \text{O}_2$
6. **WRITING in Biology** Draw a diagram of a roller coaster and write a paragraph relating the ride to activation energy and a chemical reaction.
Section 6.3

Objectives

- Evaluate how the structure of water makes it a good solvent.
- Compare and contrast solutions and suspensions.
- Describe the difference 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

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 usually blue. That's because water covers about 70 percent of Earth's surface, giving it the blue color you see from a distance. Now zoom 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 oxygen's nucleus, the electrons in the covalent bond with hydrogen are not shared equally. In water, the electrons spend more time near the oxygen nucleus than they do near the hydrogen nuclei. Figure 6.19 shows that there is an unequal distribution of electrons in a water molecule. This, along with the bent shape of water, results in the oxygen end of the molecule having a slightly negative charge and the hydrogen ends of the molecule 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 interaction. Figure 6.20 describes polarity and the other unique properties of water that make it important to living things.
Figure 6.20
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 can survive only a few days without water.

- Water is made up of one oxygen atom and two hydrogen atoms.
- Water is polar. Its bent shape results in a slightly positive charge on the hydrogen atoms and a slightly negative charge on the oxygen. 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 due to changes in water density during spring and fall. Also, fish can survive winter because ice floats—they continue to live and function in the water beneath the ice.

Water is cohesive—the molecules are attracted to each other due to 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.

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.

Interactive Figure  To see an animation of water, visit biologygmh.com.
Mixtures with water

Most students are 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.

Homogenous 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 tea drink solution shown in Figure 6.21, tea is on top, tea is in the middle, and tea is 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.

Heterogenous 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 6.22. 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.
Acids and bases Many solutes readily dissolve in water due to 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 6.23. Substances that release hydrogen ions when 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 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 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 6.1

**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.

**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 $\text{H}^+$ in a solution is called **pH**. As shown in Figure 6.24, pure water is neutral and has a pH value of 7.0. Acidic solutions have an abundance of $\text{H}^+$ and have pH values lower than 7. Basic solutions have more $\text{OH}^-$ than $\text{H}^+$ and have pH values higher than 7.

**Connection to Health** 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 $\text{H}^+$ 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.

**Section 6.3 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, hydrochloric acid, and sodium hydroxide in their general areas on the scale.
4. **Compare and Contrast** solutions and suspensions. Give examples of each.

**Think Scientifically**

5. **Explain** how baking soda ($\text{NaHCO}_3$) is basic. Describe the effect of baking soda on the $\text{H}^+$ ion concentration of stomach contents with pH 4.
6. **Predict** If you add hydrochloric acid to water, what effect would this have on the $\text{H}^+$ ion concentration? On the pH?
The Building Blocks of Life

Organisms are made up of carbon-based molecules.

Real-World Reading Link: Many people spend hours at a time with a model train set, connecting the cars first in one configuration, then another. 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—those compounds containing carbon.

As shown in Figure 6.25, 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 6.25. Together, carbon compounds lead to the diversity of life on Earth.

Objectives

- Describe the role of carbon in living organisms.
- Summarize the four major families of biological macromolecules.
- Compare the functions of each group of biological macromolecules.

Review Vocabulary

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

New Vocabulary

macromolecule
polymer
carbohydrate
lipid
protein
amino acid
nucleic acid
nucleotide
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 6.1, biological macromolecules are organized into four major categories: carbohydrates, lipids, proteins, and nucleic acids.

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

<table>
<thead>
<tr>
<th>Group</th>
<th>Example</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbohydrates</td>
<td></td>
<td>• Store energy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Provide structural support</td>
</tr>
<tr>
<td>Lipids</td>
<td></td>
<td>• Store energy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Provide barriers</td>
</tr>
<tr>
<td>Proteins</td>
<td>Hemoglobin</td>
<td>• Transport substances</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Speed reactions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Provide structural support</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Make hormones</td>
</tr>
<tr>
<td>Nucleic acids</td>
<td>DNA</td>
<td>• Store and communicate genetic information</td>
</tr>
</tbody>
</table>

**Interactive Table** To explore more about biological macromolecules, visit biologygmh.com.

**Vocabulary**

**Word origin**

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

**Study Tip**

**Double-Entry Notes** Fold a piece of paper in half lengthwise and write the boldfaced headings that appear under the Biological Macromolecules label on the left side. As you read the text, make a bulleted list of notes about the important ideas and terms.
Chapter 6 • Chemistry in Biology

Figure 6.26 Glucose is a monosaccharide. Sucrose is a disaccharide composed of glucose and fructose monosaccharides. Glycogen is a branched polysaccharide made from glucose monomers.

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 \((\text{CH}_2\text{O})_n\). Here the subscript \(n\) indicates the number of \(\text{CH}_2\text{O}\) 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 rid). The monosaccharide glucose, shown in Figure 6.26, 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 6.26, 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 6.26. 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 6.27, 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 shell of shrimp, lobsters, and some insects, as well as the cell wall of some fungi.
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 your 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 in order to function properly. The basic structure of a lipid includes fatty acid tails as shown in Figure 6.28. 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 6.28, 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.

**Based on Real Data**

Interpret the 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).

![Effects of Soluble Fiber](image)

**Think Critically**

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


**Figure 6.28**  Stearic acid has no double bonds between carbon atoms; oleic acid has one double bond. Phospholipids have a polar head and two nonpolar tails.
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 6.29**. Recall that carbon can form four covalent bonds. 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 6.29**. A peptide 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 6.30** 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 6.1**, 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 all 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 the cell and between cells, speed up chemical reactions, and control cell growth.
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 called *nucleotides*. Nucleotides are composed of carbon, nitrogen, oxygen, phosphorus, and hydrogen atoms arranged as shown in **Figure 6.31**. There are six 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 sī rib oh noo klāy ihk) acid (DNA) and ribonucleic (rib oh noo klāy 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. You will learn more about the structure and function of DNA and RNA in Chapter 12.

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.
In the Field

Career: Field Chemist
pH and Alkalinity

Water is one of the most important abiotic factors in any ecosystem. Whether in the desert or the rainforest, the availability of water as rain, surface water, and ground water affects every living thing. It isn’t surprising that the task of monitoring and testing water is an important aspect of biological field work.

Effects of pH Several factors can affect the chemistry of available water in an ecosystem, including dissolved oxygen content, salinity, and pH. Factors such as agricultural runoff and acid rain can cause the pH of a body of water to change.

Acidity Acidic conditions, which indicate high levels of H\(^+\), can disrupt biological processes in many water-dwelling organisms, such as snails, clams, and fish. Disrupting these processes can hamper reproduction and can eventually kill the organisms. Although organisms exhibit various degrees of resistance to changes in pH, a resistant organism that is dependent on a susceptible one will feel the effects of pH through that relationship. In addition, pH also affects the solubility of certain substances. For example, the concentration dissolved aluminum in a stream or lake increases at lower pH. Aluminum in water is toxic to many living things.

Alkalinity Despite the fact that water quality is affected by pH, a body of water also has the ability to resist pH changes that are associated with increasing acidity. The ability of a body of water to neutralize acid is referred to as its alkalinity. Carbonate and bicarbonate compounds are important acid-neutralizing compounds found in lakes and streams. pH can be controlled as long as carbonates are present. If the carbonates are used up, additional acid in the water will lower the pH and possibly endanger the inhabitants.

Assessing pH Biologists who perform field testing can assess the pH and alkalinity of a stream or lake by testing the water. When monitoring water, the location of the body of water, the depth of the sample, and the speed of the current where the sample is taken are all important considerations. In general, most freshwater has a pH between 6.5 and 8.0, but there can be some variation. If the pH strays from the optimal range for the water source, local communities can take action to preserve the environment and restore the pH to normal levels.

In the wake of hurricanes Katrina and Rita, prepare a report that explains the water-quality problems caused by the hurricanes and what solutions were developed by the crisis management teams. For more information about water quality, visit biologygmh.com.
WHAT FACTORS AFFECT AN ENZYME REACTION?

Background: The compound hydrogen peroxide, H₂O₂, is produced when organisms metabolize food, but hydrogen peroxide damages cell parts. Organisms combat the buildup of H₂O₂ 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
- hot plate
- test tube rack
- ice
- beef liver
- dropper
- distilled water
- 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 (H₂O₂) 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, 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 are testing the same factor. Infer reasons why your group’s data might have differed from the data collected by other groups. To learn more about enzymes, visit Biolabs at biologygmh.com.
## Vocabulary Key Concepts

### Section 6.1 Atoms, Elements, and Compounds

- **atom** (p. 148)
- **compound** (p. 151)
- **covalent bond** (p. 152)
- **electron** (p. 148)
- **element** (p. 149)
- **ion** (p. 153)
- **ionic bond** (p. 153)
- **isotope** (p. 150)
- **molecule** (p. 152)
- **neutron** (p. 148)
- **nucleus** (p. 148)
- **proton** (p. 148)
- **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 6.2 Chemical Reactions

- **activation energy** (p. 158)
- **active site** (p. 160)
- **catalyst** (p. 159)
- **chemical reaction** (p. 156)
- **enzyme** (p. 159)
- **product** (p. 157)
- **reactant** (p. 157)
- **substrate** (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 6.3 Water and Solutions

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

**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 6.4 The Building Blocks of Life

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

**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.
Section 6.1

Vocabulary Review
Describe the difference between the terms in each set.
1. electron—proton
2. ionic bond—covalent bond
3. isotope—element
4. atom—ion

Understand Key Concepts
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. Which of the following 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. the number of protons
   B. the number of electrons
   C. the number of energy levels
   D. the number of neutrons

Constructed Response

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 surface. How is this method of adhesion more advantageous than covalent interactions?

Section 6.2

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

14. activation energy  A. a protein that speeds up a reaction
15. substrate  B. a substance formed by a chemical reaction
16. enzyme  C. the energy required to start a reaction
17. product  D. a substance that binds to an enzyme
Understand Key Concepts

18. Which of the following is a substance that lowers the activation energy?
   A. an ion    C. a catalyst
   B. a reactant D. a substrate

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

Section 6.3

Vocabulary Review
State the relationship between the terms in each set.

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

Understand Key Concepts

Use the figure below to answer question 30.

Think Critically

Use the graph to answer questions 23 and 24.

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

24. Infer Which enzyme is more active in a human cell? Why?

30. What does the image above show?
   A. a heterogeneous mixture    C. a solution
   B. a homogeneous mixture     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 dissolved in water?
   A. a base    C. a buffer
   B. an acid   D. salt

Constructed Response

33. Open Ended 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.
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 6.4**

**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 Key Concepts**

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. **Create** a table for the four main biological macromolecules that lists their components and functions.

---

**Additional Assessment**

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

**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 discs were incubated for three hours in sorbitol (the control), sucrose, and trehalose solutions. Then, levels of starch and sucrose in the leaves were measured. Use the data to answer the questions below.

![Production of Starch and Sucrose](chart)


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

50. What conclusion might the researchers have reached based on this data?

**Cumulative Review**

51. How do reproductive strategies differ? (Chapter 4)

52. Describe three broad categories of biodiversity value. (Chapter 5)
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.

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 store 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

7. Which term describes the part of the cycle labeled 1?
   A. condensation
   B. evaporation
   C. run off
   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
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.

<table>
<thead>
<tr>
<th>Factors Affecting Coral Survival</th>
<th>Optimal Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Temperature</td>
<td>23 to 25°C</td>
</tr>
<tr>
<td>Salinity</td>
<td>30 to 40 parts per million</td>
</tr>
<tr>
<td>Sedimentation</td>
<td>Little or no sedimentation</td>
</tr>
<tr>
<td>Depth</td>
<td>Up to 48 m</td>
</tr>
</tbody>
</table>

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?

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.