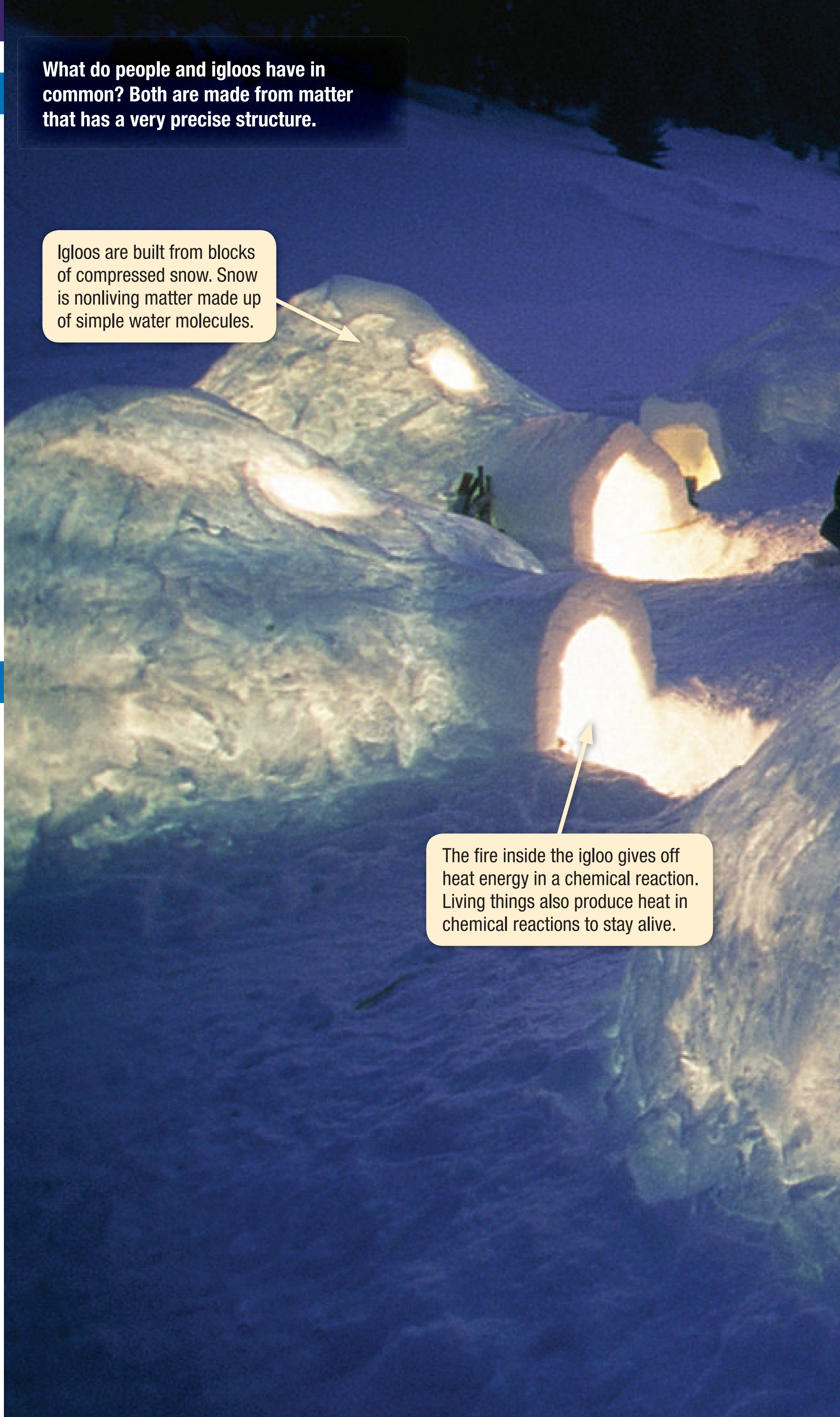
Chapter 3

Chemistry of Life

What do people and igloos have in common? Both are made from matter that has a very precise structure.



Preview

1 Matter and Substances
- Atoms
- Chemical Bonds
- Polarity

2 Water and Solutions
- Properties of Water
- Solutions

3 Carbon Compounds
- Building Blocks of Cells
- Carbohydrates
- Lipids
- Proteins
- Nucleic Acids

4 Energy and Metabolism
- Changing Matter
- Chemical Reactions
- Biological Reactions

Why It Matters

The chemicals that make up living things are more complex than those in nonliving things. Learning the chemical basis of biology can help you understand how processes occur and how living things respond to their environment.

Section 1

Matter and Substances

Key Ideas	Key Terms	Why It Matters
What makes up matter? Why do atoms form bonds? What are some important interactions between substances in living things?	atom element valence electron compound molecule ion	All living things are made of matter, so understanding the structure and behavior of matter can help you understand how your body works.

Every living and nonliving thing is made of matter. Matter is anything that has mass and takes up space. To understand how living things work and interact, you must first understand the structure of matter.

Atoms

What does all matter have in common? It is made of very small particles called atoms. An **atom** is the smallest unit of matter that cannot be broken down by chemical means. **All matter is made up of atoms. An atom has a positively charged core surrounded by a negatively charged region.**

Atomic Structure Atoms are made of three types of particles. *Protons* have a positive charge, *electrons* have a negative charge, and *neutrons* have no charge. Atoms have no overall charge because each atom has as many electrons as protons. Protons and neutrons have about the same mass and make up the core, or nucleus, of an atom. Electrons have very little mass and move around the nucleus in a region called the *electron cloud*, which is much larger than the nucleus.

Elements An **element** is a substance made up of atoms that have the same number of protons. For example, each atom of the element carbon has six protons, as **Figure 1** shows. Atoms of an element may have different numbers of neutrons. These atoms are called *isotopes* of elements.

Reading Check *What is a proton? (See the Appendix for answers to Reading Checks.)*

atom the smallest unit of an element that maintains the chemical properties of that element

element a substance that cannot be separated or broken down into simpler substances by chemical means

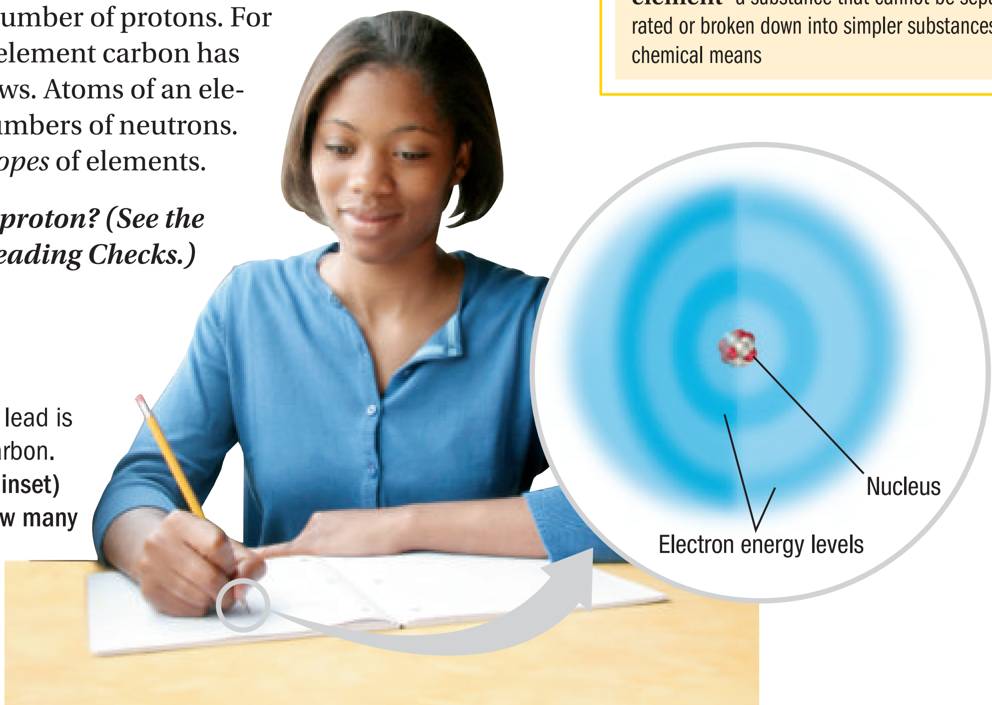
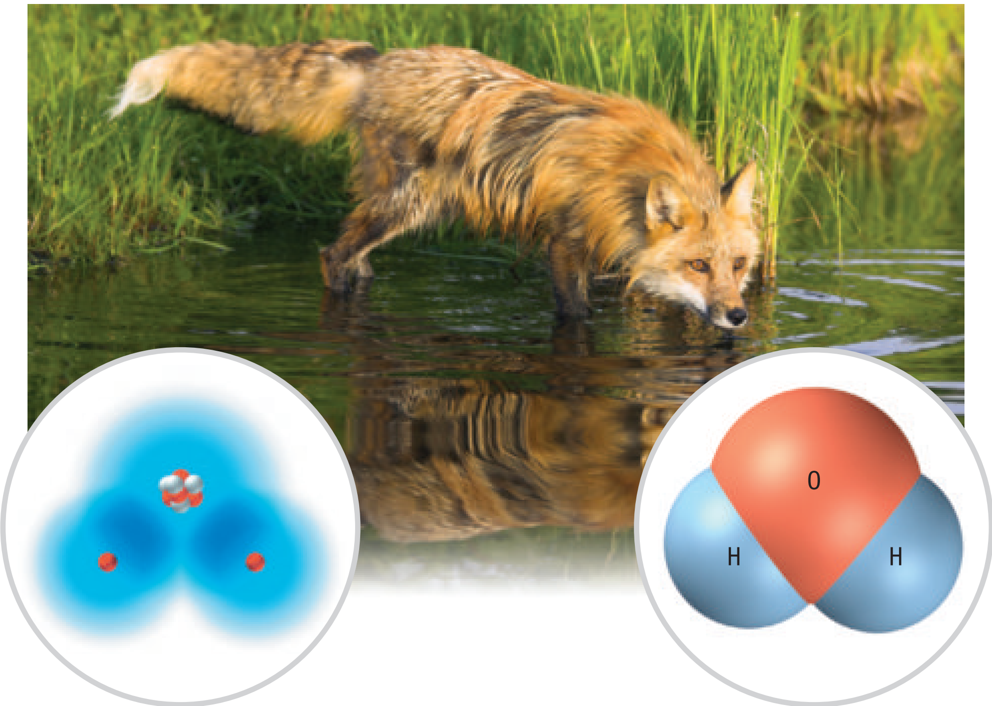


Figure 1 The graphite in pencil lead is made of atoms of the element carbon. **If an uncharged carbon atom (inset) has six protons in its nucleus, how many electrons does it have?**

Figure 2 A water molecule consists of an oxygen atom covalently bonded to two hydrogen atoms. The electron cloud model (left) shows the interaction between the atoms of the molecule. The space-filling model (right) shows the three-dimensional structure of a molecule.



Electron cloud model

Space-filling model

READING TOOLBOX

Comparison Table Make a comparison table that compares covalent bonding and ionic bonding.

valence electron an electron that is found in the outermost shell of an atom and that determines the atom's chemical properties

compound a substance made up of atoms of two or more different elements joined by chemical bonds

molecule a group of atoms that are held together by chemical forces

ion an atom, radical, or molecule that has gained or lost one or more electrons and has a negative or positive charge

Chemical Bonds

The electron cloud of an atom may have levels. The innermost level can hold only two electrons. Levels farther from the nucleus can usually hold eight electrons. Electrons in the outermost level, or shell, are called **valence electrons.** Atoms tend to combine with each other such that eight electrons will be in the valence shell.

When atoms combine, a force called a *chemical bond* holds them together. **Chemical bonds form between groups of atoms because most atoms become stable when they have eight electrons in the valence shell.** However, the smallest atoms, such as hydrogen, are stable when they have only two valence electrons. When atoms of different elements bond, a compound forms. A **compound** is a substance made of the bonded atoms of two or more different elements.

Covalent Bonding One way that atoms bond is by sharing valence electrons to form a *covalent bond.* A **molecule** is a group of atoms held together by covalent bonds. Not all substances that have covalent bonds are compounds. The oxygen in the air you breathe consists of molecules made of two oxygen atoms sharing electrons in a covalent bond. To represent an oxygen molecule, write "O_2," not "O." A carbon dioxide molecule has two oxygen atoms bonded to a single carbon atom, so its formula is CO_2.

Water: A Covalent Compound As **Figure 2** shows, a water molecule, H_2O, forms when an oxygen atom combines with two hydrogen atoms. The atoms form chemical bonds by sharing electrons in a way that gives oxygen eight valence electrons, making it stable. The hydrogen atoms become stable because sharing gives each two valence electrons.

Reading Check ***What is a chemical bond?***

Hands-On
QuickLab

15 min

Atom Models

Scientists use models to represent their understanding of things that they cannot directly observe.

Procedure

1. Using **assorted materials** provided by your teacher, work in groups to make model atoms for hydrogen, carbon, oxygen, sodium, and chlorine.
2. Model the covalent bonds in a water molecule.
3. Model an ionic bond in sodium chloride.

Analysis

1. **Model** the covalent bonds in a carbon dioxide molecule, CO_2. How many electrons are shared?
2. CRITICAL THINKING **Critiquing Models** Exchange models with another group. What is accurate and useful about those models? What could be improved? Write down your comments for the other group.

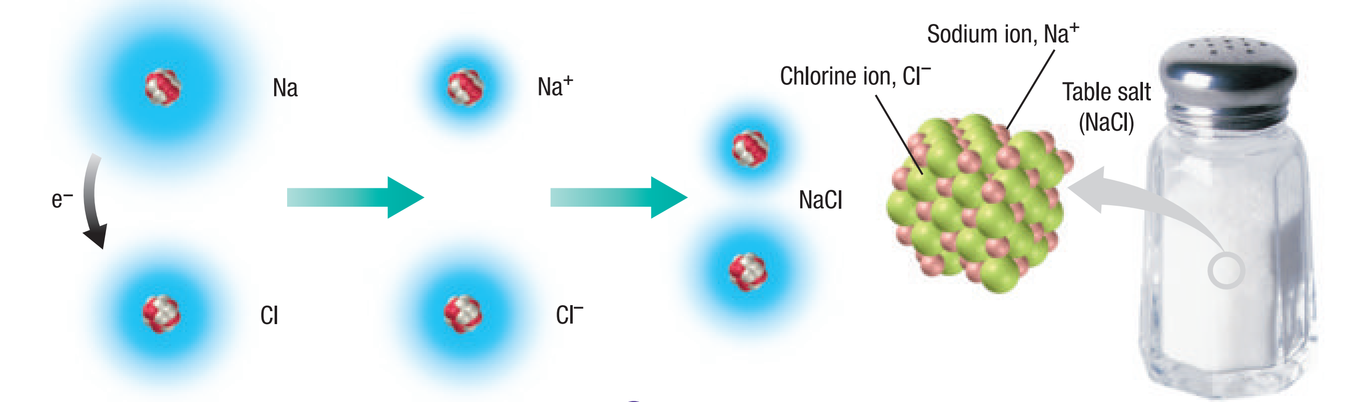
Ionic Bonding Atoms can achieve a stable valence level in another way—by losing or gaining electrons. This results in a positive or negative charge. An **ion** is an atom or group of atoms that has an electric charge because it has gained or lost electrons. The attractive force between oppositely charged ions is an *ionic bond.*

Table Salt: An Ionic Compound One familiar example of an ionic compound is table salt, NaCl, shown in **Figure 3.** A sodium atom has one valence electron, while a chlorine atom has seven. (1) Sodium readily gives up its electron, while chlorine readily accepts an electron. (2) The sodium atom is now a sodium ion, Na^+. The chlorine atom is now a chloride ion, Cl^-. (3) The positively charged sodium ion and negatively charged chloride ion attract each other and form sodium chloride, NaCl. (4) The attractive forces between several sodium ions and chloride ions form a crystal of table salt.

Figure 3 Salt crystals in sodium chloride, NaCl, are formed by the interaction between sodium ions, Na^+, and chloride ions, Cl^-. **How many electrons are in the valence shell of a chloride ion?**

go.hrw.com
interact online
Keyword: HX8BCMF3

Ionic Bonding in Salt



1. A Na atom loses an electron to a Cl atom.
2. Each atom becomes a stable, charged ion.
3. The attraction of the oppositely charged ions forms an ionic bond.
4. Several ions interact to form a salt crystal.

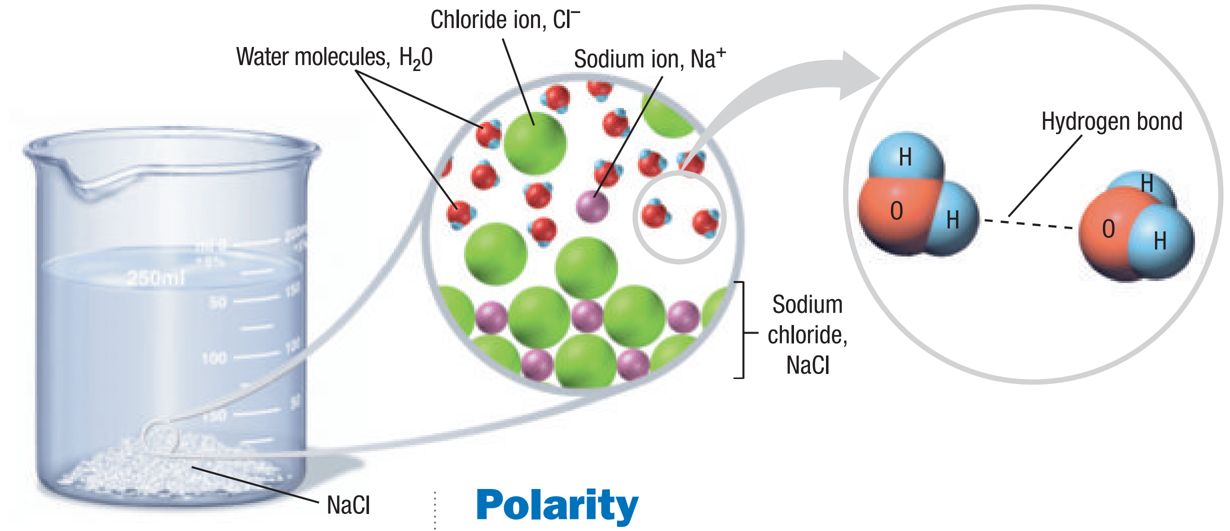


Figure 4 Water dissolves ionic compounds. When sodium chloride, NaCl, is dissolved in water, sodium ions, Na^+, and chloride ions, Cl^-, become surrounded by water molecules, H_2O.

SCILINKS.
www.scilinks.org
Topic: Hydrogen Bonding
Code: HX80777

Polarity

In some covalent bonds, the shared electrons are attracted more strongly to one atom than to the other. As a result, one end, or pole, of the molecule has a partial negative charge, while the opposite end has a partial positive charge. Molecules with partial charges on opposite ends are said to be *polar*. The water molecule is polar.

Solubility The partially charged ends of polar molecules attract opposite charges. Because of this behavior, water can dissolve polar molecules, such as sugar, and ionic compounds, such as the salt in **Figure 4.** Nonpolar substances, such as oil, grease, and wax, do not dissolve well in water. Instead, they remain together in clumps or a separate layer. The reason is that water molecules are more attracted to each other than to the nonpolar molecules.

Hydrogen Bonds When bonded to an oxygen, nitrogen, or fluorine atom, a hydrogen atom has a partial charge nearly as great as a proton's charge. It attracts the negative pole of other nearby molecules. This attraction, called a *hydrogen bond*, is stronger than attractions between other molecules, but not as strong as a covalent bond. › **Hydrogen bonding plays an important role in many of the molecules that make up living things.** For example, the two strands of a DNA molecule are held together by hydrogen bonds between the bases.

› **Reading Check** ***Why does salt dissolve in water?***

Section 1 Review

› KEY IDEAS

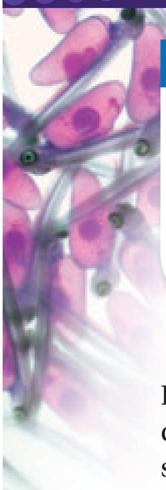
1. **Identify** the parts of atoms and their locations.
2. **Name** two ways that atoms can combine to become more stable in compounds.
3. **Explain** how charges cause salt and sugar to dissolve in water.

CRITICAL THINKING

4. **Analyzing Information** Scientists use the isotope carbon-14 in radiocarbon dating. How many protons, neutrons, and electrons are in a carbon-14 atom?
5. **Recognizing Differences** Explain the difference between polar and nonpolar molecules. Give an example of a polar molecule, and describe its structure.

USING SCIENCE GRAPHICS

6. **Periodic Table** Elements on the periodic table are arranged in groups based on how many electrons their atoms have in the valence shell. Using the periodic table in the Appendix, propose why the noble gases in Group 18 rarely form chemical bonds.



Section 2

Water and Solutions

Key Ideas	Key Terms	Why It Matters
❯ What makes water a unique substance? ❯ How does the presence of substances dissolved in water affect the properties of water?	cohesion, adhesion, solution, acid, base, pH, buffer	The processes of life take place in water. Without water's unique properties, life as we know it could not exist.

Humans can survive for a few weeks without food but only a few days without water. In fact, all life on Earth depends on this simple substance.

Properties of Water

Water has many unique properties that make it an important substance for life. ❯ **Most of the unique properties of water result because water molecules form hydrogen bonds with each other.**

- **Ice floats.** When water freezes, hydrogen bonds lock water molecules into a crystal structure that has empty spaces. This structure makes water less dense as a solid than as a liquid, so ice floats. Floating ice prevents rivers, lakes, and oceans from freezing solid, so life can exist in the water under the ice.
- **Water absorbs and retains heat.** Hydrogen bonds are constantly breaking and forming between water molecules. Because of this, water can absorb a large amount of heat without changing temperature. It is also why water takes a long time to cool. Large bodies of water can help keep temperatures on Earth from changing too fast. This property of water can also help organisms maintain a constant internal temperature.
- **Water molecules stick to each other.** Hydrogen bonds hold water molecules together in much the same way holding hands keeps a crowd of people together. Thus small drops, such as the dewdrops on the flower in **Figure 5**, are pulled into a ball shape. **Cohesion** is the attraction of particles of the same substance. Water is a liquid at ordinary temperatures because such forces keep it from evaporating easily.
- **Water molecules stick to other polar substances.** Attraction between particles of different substances is called **adhesion.** As **Figure 5** shows, a combination of adhesion and cohesion causes water to move upward through the stem of a plant from the roots to the leaves.

cohesion the force that holds molecules of a single material together

adhesion the attractive force between two bodies of different substances that are in contact with each other

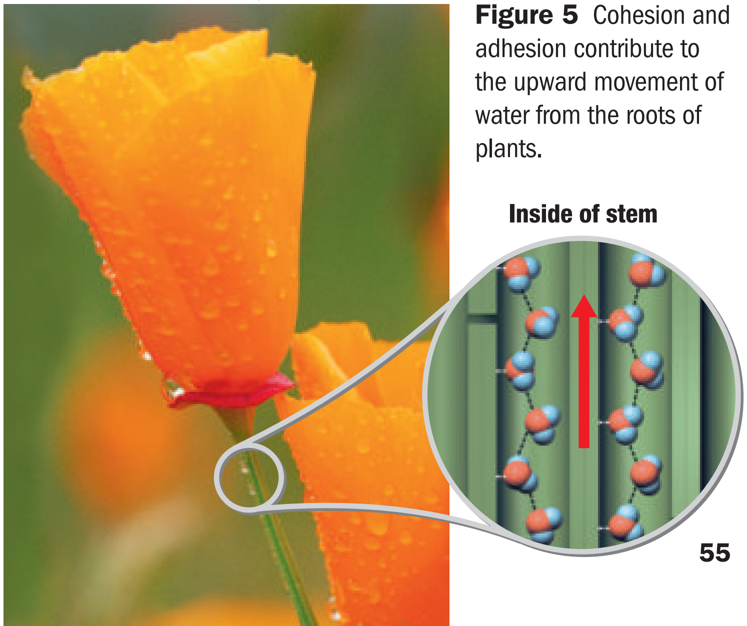


Figure 5 Cohesion and adhesion contribute to the upward movement of water from the roots of plants.

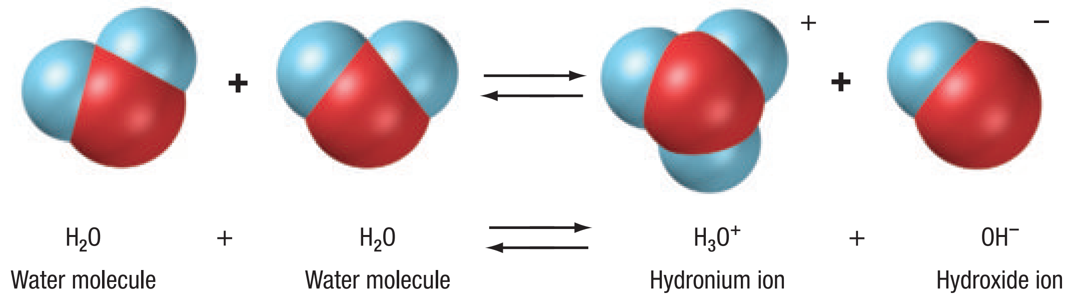


Figure 6 A hydronium ion, H_3O^+, and a hydroxide ion, OH^-, form when a hydrogen ion, H^+, separates from a water molecule and bonds to another. This reaction can also re-form two water molecules from a hydronium ion and a hydroxide ion.

solution a homogeneous mixture throughout which two or more substances are uniformly dispersed

acid any compound that increases the number of hydronium ions when dissolved in water

base any compound that increases the number of hydroxide ions when dissolved in water

pH a value that is used to express the acidity or alkalinity (basicity) of a system

buffer a solution made from a weak acid and its conjugate base that neutralizes small amounts of acids or bases added to it

Solutions

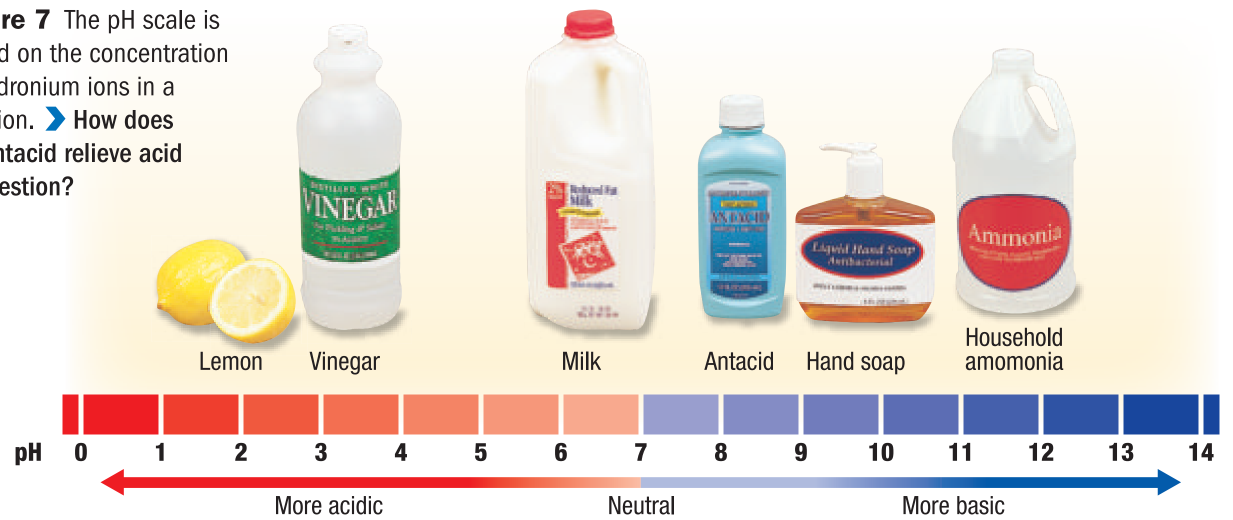
A **solution** is a mixture in which ions or molecules of one or more substances are evenly distributed in another substance. Many substances are transported throughout living things as solutions of water. Dissolved substances can move more easily within and between cells. Water dissolves many ionic and polar substances but does not dissolve nonpolar substances.

Acids and Bases Some water molecules break apart to form ions, as **Figure 6** shows. In pure water, hydronium ions and hydroxide ions are present in equal numbers. **› In solutions, some substances change the balance of these ions. Acids** are compounds that form extra hydronium ions when dissolved in water. Your stomach uses a solution of hydrochloric acid, HCl, to digest food.

In contrast, **bases** are compounds that form extra hydroxide ions when dissolved in water. Many bases contain hydroxide ions. An example is sodium hydroxide, NaOH, which is used to remove clogs from drains. Other bases react with water molecules. For example, ammonia, NH_3, reacts with a water molecule, H_2O, to form an ammonium ion, NH_4^+, and a hydroxide ion, OH^-.

When acids and bases are mixed, the extra hydronium and hydroxide ions react to form water. Depending on the amounts of extra ions, the solution will be either less acidic, less basic, or neutral.

Figure 7 The pH scale is based on the concentration of hydronium ions in a solution. **› How does an antacid relieve acid indigestion?**



Hands-On

QuickLab

15 min

Telltale Cabbage

Red cabbage contains a natural indicator that can be used to identify how acidic or basic a solution is.

Procedure

1. Cut up a **cabbage leaf** into very tiny clippings by using **scissors.**
2. Put on **safety goggles.** Place the clippings in a **beaker** of **warm water.** Swirl the mixture. Wait several minutes until the water changes color.
3. Add several drops of **lemon juice.** Note any changes in appearance.
4. Add about **1/4 tsp of baking soda.** Note any changes in appearance. Continue adding small amounts of baking soda, and observe additional color changes.

Analysis

1. **Describe** what happened when the leaf clippings were placed in warm water.
2. **Describe** what happened when lemon juice (an acid) was added to the indicator solution.
3. **Describe** what happened when the baking soda was added to the acidic solution.
4. CRITICAL THINKING **Inferring Relationships** From your observations, what probably happened when the baking soda was added to the acidic solution?

pH and Buffers **pH** is a measure of how acidic or basic a solution is. The pH scale is shown in **Figure 7.** Each one-point increase in pH represents a 10-fold decrease in hydronium ion concentration. So, the H_3O^+ concentration in a solution of pH 2 is 10 times as great as it is in a solution of pH 3. Pure water has a pH of 7. Acidic solutions have a pH below 7, and basic solutions have a pH above 7.

The pH of the solutions in living things must be stable. The pH of human blood is about 7.4. If the pH goes down to 7.0 or up to 7.8, an individual will die within minutes. For a stable pH to be maintained, the solutions in living things contain buffers. A **buffer** is a substance that reacts to prevent pH changes in a solution. An important buffer in living things is the bicarbonate ion, HCO_3^-.

READING TOOLBOX

Everyday Words in Science Write a sentence that uses the everyday meaning of the word *basic.* Then, write a sentence that uses the scientific meaning of the word *basic.*

Section 2 Review

KEY IDEAS

1. **Identify** four unique properties of water that make life on Earth possible.
2. **Differentiate** between acids and bases.
3. **Explain** the role of buffers in maintaining homeostasis.

CRITICAL THINKING

4. **Recognizing Relationships** Cells contain mostly water. If cells contained mostly oil, how would an organism's ability to maintain homeostasis be affected?
5. **Applying Information** The active ingredient in aspirin is acetylsalicylic acid. Why would doctors recommend buffered aspirin, especially for people with a sensitive stomach?

MATH SKILLS

6. **Exponents** The pH of solution A is 2. The pH of solution B is 4. Which solution has the greater concentration of hydronium ions? The concentration of that solution is how many times the concentration of the other solution?

Section 3

Carbon Compounds

Key Ideas	Key Terms	Why It Matters
› What are chemicals of life made from? › What is the role of carbohydrates in cells? › What do lipids do? › What determines the functions of proteins? › What do nucleic acids do?	carbohydrate lipid protein amino acid nucleic acid nucleotide DNA RNA ATP	Your body works by using the same four types of molecules that bacteria and plants do.

Suppose that you are building a house. You need wood for framing and metal for nails, screws, and electrical wiring. You also need concrete for the foundation, glass for windows, and drywall siding. This complex structure is made of a few basic materials that must be assembled in a highly organized way. The same is true of the molecules that make up living things.

Building Blocks of Cells

The parts of a cell are made up of large, complex molecules, often called *biomolecules.* › **Large, complex biomolecules are built from a few smaller, simpler, repeating units arranged in an extremely precise way.** These simple units are like the toy blocks in **Figure 8,** which connect to build the large sculpture. Not all of the blocks are exactly the same, but they all connect with other blocks in a few different ways.

Carbon Compounds The basic units of most biomolecules contain atoms of carbon. Carbon atoms have four valence electrons, so they can form covalent bonds with as many as four other atoms. Carbon atoms can bond with each other to form chains or rings. The carbon atoms in these chains and rings can also connect with atoms of other elements to form the basic units of most biomolecules.

› **Reading Check** *What element is the basis of biomolecules?*

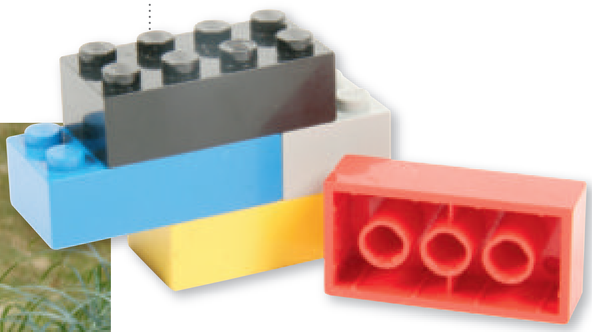


Figure 8 Large, complex structures can be built from a few basic units arranged in a precise way. › **Describe two shapes that you could make from these five blocks.**

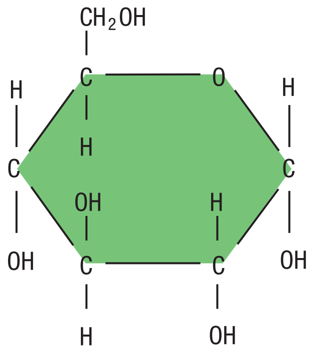


Figure 9 The sugar glucose, $C_6H_{12}O_6$, is made from carbon, hydrogen, and oxygen atoms. Sugars are the building blocks of carbohydrates.

Carbohydrates

You may have heard about carbohydrates in foods such as grains, fruits, and vegetables. **Carbohydrates** are molecules made of sugars. A sugar contains carbon, hydrogen, and oxygen in a ratio of 1:2:1. **Figure 9** shows the ring structure of glucose, a common sugar found in grape juice. Glucose is a *monosaccharide,* or "single sugar."

Two sugars can be linked to make a *disaccharide.* Examples of disaccharides are sucrose (table sugar) and lactose (found in milk). Many sugars can be linked together to make a *polysaccharide*. Starch consists of hundreds of glucose units bonded together. Glycogen (found in animals) consists of many branched chains of glucose.

Monosaccharides and disaccharides are considered simple carbohydrates. Polysaccharides are considered complex carbohydrates. **Figure 10** shows an example of each carbohydrate. **Cells use carbohydrates for sources of energy, structural materials, and cellular identification.**

carbohydrate a class of molecules that includes sugars, starches, and fiber; contains carbon, hydrogen, and oxygen

lipid a fat molecule or a molecule that has similar properties, including waxes and steroids

Energy Supply

Carbohydrates are a major source of energy for many organisms, including humans. Plants store the sun's energy for future use by making glucose and converting it to starch. Organisms release chemical energy for cell activities by breaking down glucose.

Structural Support

Chitin and *cellulose* are two complex carbohydrates that provide support. The shells of crabs, lobsters, and insects are made of chitin. Chitin is also found in the cell walls of mushrooms and molds. The cell walls of plants are made of cellulose. Bundles of cellulose are stiff enough to hold plants upright.

Cell Recognition

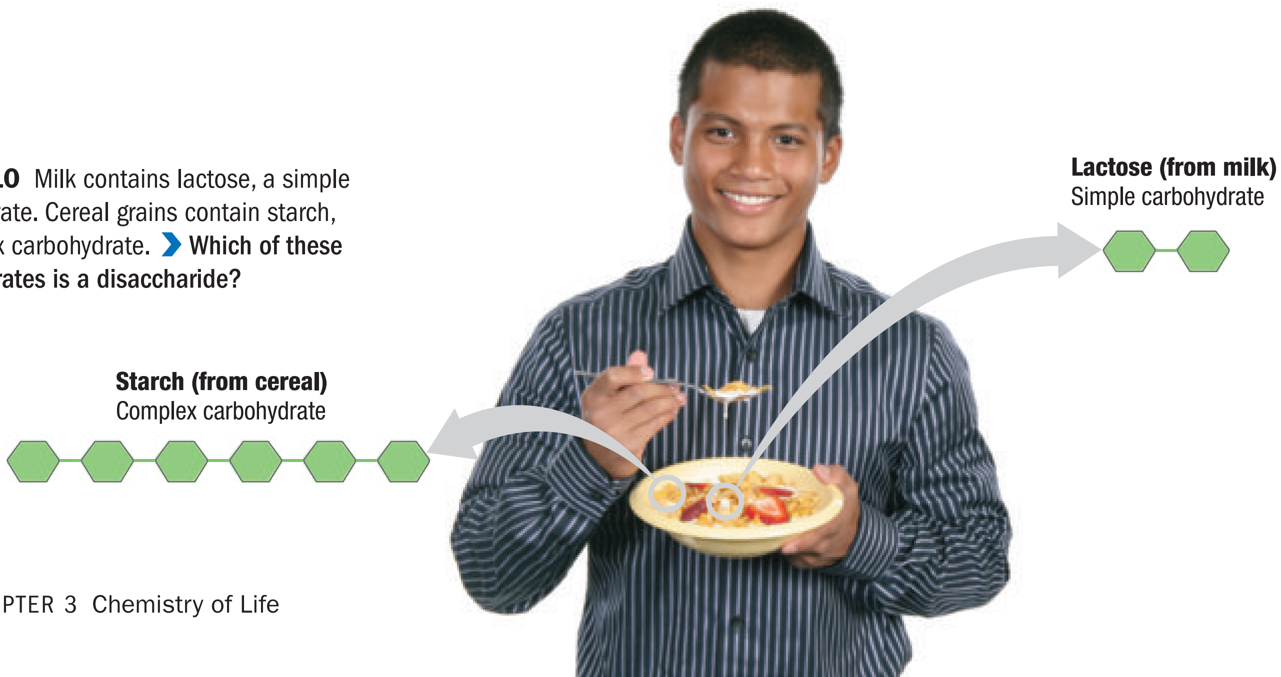
Cells may have short, branched chains of varying sugar units on their outer surface. In a complex organism, cells recognize neighboring cells by these carbohydrates. Carbohydrates on the outside of invading cells allow the body to recognize them as not being part of the body so that they can be destroyed.

Academic Vocabulary

vary to make a minor or partial change in

Reading Check *What is the basic unit of a carbohydrate?*

Figure 10 Milk contains lactose, a simple carbohydrate. Cereal grains contain starch, a complex carbohydrate. **Which of these carbohydrates is a disaccharide?**



Lipids

Lipids are another class of biomolecules, which includes fats, phospholipids, steroids, and waxes. Lipids consist of chains of carbon atoms bonded to each other and to hydrogen atoms. This structure makes lipids repel water. **The main functions of lipids include storing energy and controlling water movement.** Lipids also include steroid hormones, used as signaling molecules, and some pigments, which absorb light.

Energy Stores The main purpose of fats is to store energy. Fats can store energy even more efficiently than carbohydrates. Many animals, such as the dormouse in **Figure 11,** can survive without a steady diet because of fat storage. When food is plentiful, the animal converts the excess food into fats for long-term energy storage. When food is scarce, the animal can break down the fat molecules to release energy for life processes. Plant oils are stored in seeds to provide energy to start the growth of a new plant.

Hands-On

QuickLab

15 min

Brown Paper Test

You can test substances for fats by using ordinary brown paper. Oils are fats that are liquid at room temperature. This test also works for oils.

Procedure

1. Place a drop of **water** in one area of your **brown paper.** Place a drop of **oil** in another area. Rub a spot of **butter** into a third area.
2. Fan the paper to evaporate any of these substances. Hold the stained paper to the light. What do you see?
3. Now, test **other substances** provided by your teacher.

Analysis

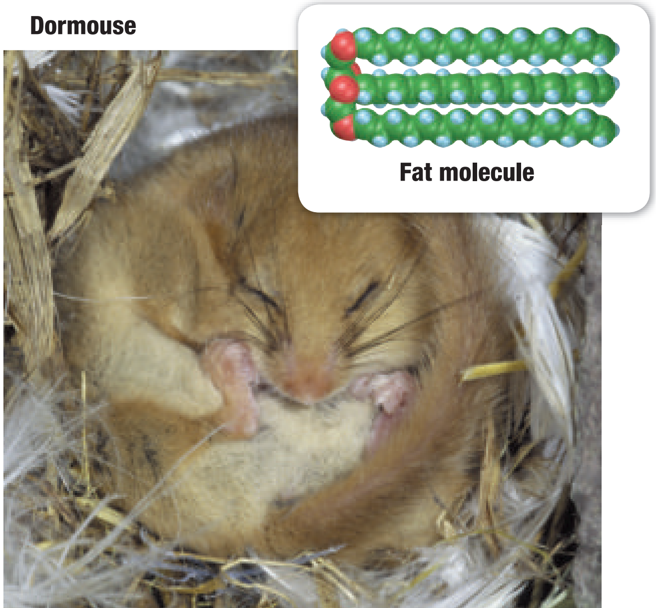
1. **Compare** how the butter, oil, and water affected the paper.
2. **Describe** how each of the other substances that you tested affected the paper. Which ones contained lipids?

Water Barriers The cell's boundary is made of phospholipids. One end of this molecule is attracted by water molecules. The other end, which is made of long carbon chains, is not. You will learn more about the behavior of these molecules when you study the structure of cell membranes.

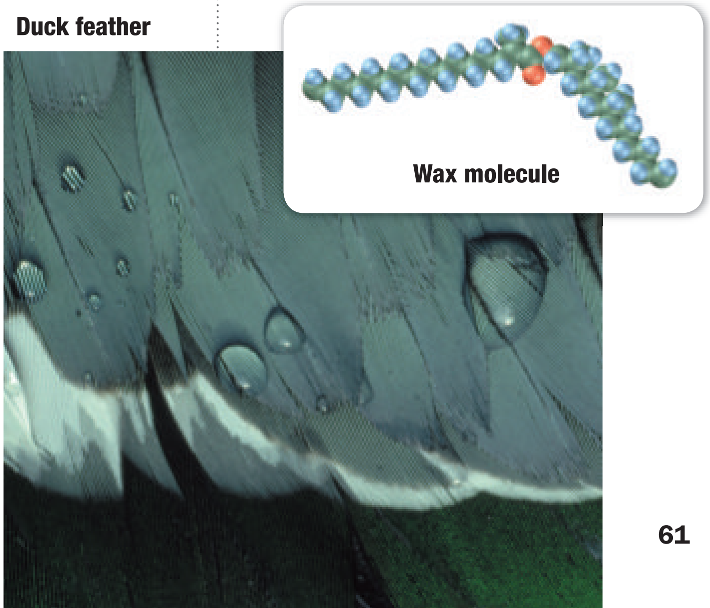
The stems and leaves of many plants are covered with a thin layer of wax, another type of lipid. This wax helps prevent the evaporation of water from the cells at the surface of a plant. Waxy feathers can also help keep ducks and other aquatic birds dry. One type of wax molecule found on bird feathers is shown in **Figure 11.**

Figure 11 Many fat molecules have three long chains of carbons. Waxes may be composed of chains of about 24 to 34 carbon atoms.

Dormouse



Duck feather



Quantifiers Describe the levels of protein structure, and identify the quantifier used to describe each level.

protein an organic compound that is made of one or more chains of amino acids and that is a principal component of all cells

amino acid a compound of a class of simple organic compounds that contain a carboxyl and an amino group and that combine to form proteins

SCILINKS.
www.scilinks.org
Topic: Proteins
Code: HX81241

Proteins

Proteins are the workhorse molecules of all living things. There are many types of proteins that perform many types of functions. **Proteins are chains of amino acids that twist and fold into certain shapes that determine what the proteins do.** Some proteins provide structure and support. Others enable movement. Some proteins aid in communication or transportation. Others help carry out important chemical reactions.

Amino Acids A **protein** is a molecule (usually a large one) made up of **amino acids,** the building blocks link to form proteins. **Figure 12** shows the basic structure of an amino acid. Every amino acid has an amino group (-NH_2), a carboxyl group (-COOH), and a variable side group. The carboxyl group of one unit can link to the amino group of another. This link is a *peptide bond.*

The side group gives an amino acid its unique properties. Twenty different amino acids are found in proteins. In order to build proteins, the body requires a supply of the correct amino acids. The body can make many amino acids from other substances, but a few amino acids must be included in the diet. To get these amino acids, your body breaks apart the proteins in the foods you eat.

Levels of Structure For each type of protein, amino acids are arranged in a specific order. This order is the protein's primary structure. The various side groups interact to bend and twist the chain. Portions of the chain may form coils and folds. These patterns are known as the protein's secondary structure.

Some small proteins consist of only one chain, but most proteins consist of two or more chains. The tertiary structure of proteins is the overall shape of a single chain of amino acids. The quaternary structure is the overall shape that results from combining the chains to form the protein. This shape suits the function of each protein.

Reading Check ***What is a protein's primary structure?***

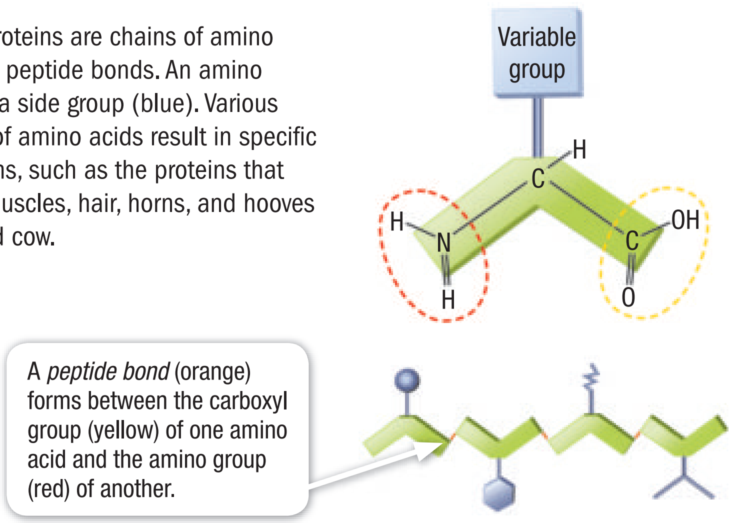


Figure 12 Proteins are chains of amino acids linked by peptide bonds. An amino acid (top) has a side group (blue). Various combinations of amino acids result in specific types of proteins, such as the proteins that make up the muscles, hair, horns, and hooves of this highland cow.

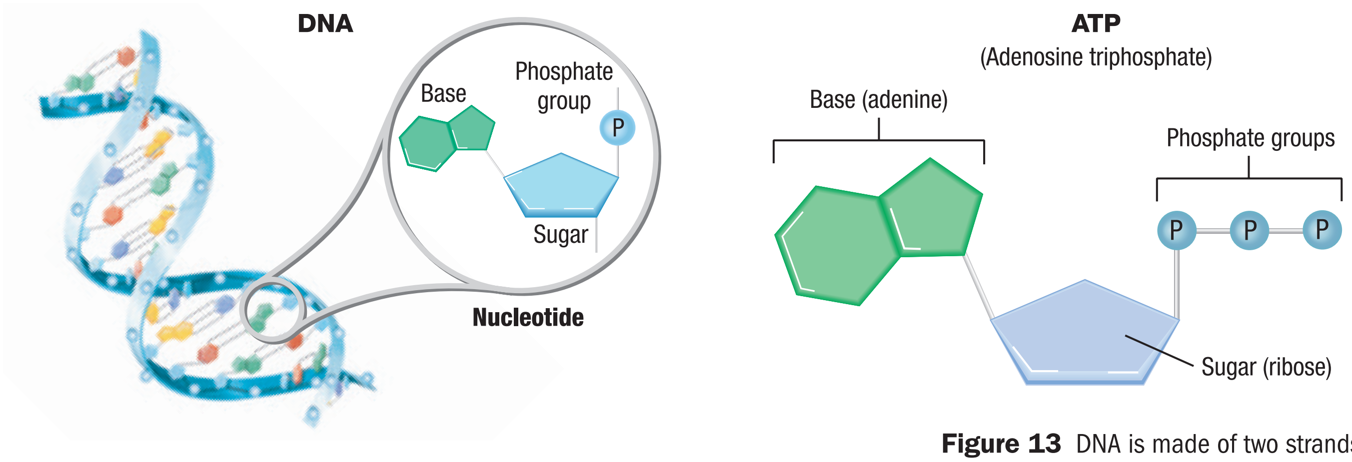


Figure 13 DNA is made of two strands of multiple nucleotides (inset) linked by hydrogen bonds. ATP is also a nucleotide and is made up of a sugar, a base, and three phosphate groups. **❯ What is the function of ATP?**

Nucleic Acids

All of your cells contain nucleic acids. A **nucleic acid** is a long chain of nucleotide units. A **nucleotide** is a molecule made up of three parts: a sugar, a base, and a phosphate group. Nucleotides of deoxyribonucleic acid, or **DNA,** contain the sugar deoxyribose. Nucleotides of ribonucleic acid, or **RNA,** contain the sugar ribose.

Hereditary Information DNA molecules act as "instructions" for the processes of an organism's life. These instructions, called the *genetic code,* depend on the order of bases in the nucleotides of the DNA molecule. DNA consists of two strands of nucleotides that spiral around each other, as **Figure 13** shows. The bases in one strand of nucleotides form hydrogen bonds with the bases on the other to hold the DNA molecule together and protect the code. RNA also interacts with DNA to help decode the information. **❯ Nucleic acids store and transmit hereditary information.**

Energy Carriers Some single nucleotides have other important roles. Cells need a steady supply of adenosine triphosphate, or **ATP,** to function. ATP, shown in **Figure 13,** is a nucleotide that has three phosphate groups. Energy is released in the reaction that breaks off the third phosphate group. Other single nucleotides transfer electrons or hydrogen atoms for other life processes.

nucleic acid an organic compound, either RNA or DNA, whose molecules are made up of one or two chains of nucleotides and carry genetic information

nucleotide an organic compound that consists of a sugar, a phosphate, and a nitrogenous base

DNA deoxyribonucleic acid, the material that contains the information that determines inherited characteristics

RNA ribonucleic acid, a natural polymer that is present in all living cells and that plays a role in protein synthesis

ATP adenosine triphosphate, an organic molecule that acts as the main energy source for cell processes

Section 3 Review

❯ KEY IDEAS

1. **Discuss** how one type of atom (carbon) can be the basis of so many types of biomolecules.
2. **List** three major functions of carbohydrates.
3. **Describe** two functions of lipids.
4. **Explain** how two different proteins will have two different shapes.
5. **Summarize** the role of nucleic acids in a cell.

CRITICAL THINKING

6. **Applying Information** Before a long race, runners often "carbo load." In other words, they eat substantial quantities of carbohydrates. How might this practice help their performance?

METHODS OF SCIENCE

7. **Identifying Unknown** Analysis of an unknown substance shows that the substance contains carbon, hydrogen, and oxygen and is soluble in oil, but not in water. Which of the four types of biomolecules could this substance be?

Section 4

Energy and Metabolism

Key Ideas	Key Terms	Why It Matters
Where do living things get energy? How do chemical reactions occur? Why are enzymes important to living things?	energy reactant product activation energy enzyme substrate active site	All living things need energy to survive. You get that energy by breaking complex molecules from food you eat into simpler, stabler molecules.

Changes constantly occur in living things. In fact, you could say that a key feature of life is change. The ability to move or change matter is called **energy.** Energy exists in many forms—including light, heat, chemical energy, mechanical energy, and electrical energy—and can be converted from one form to another. The athlete in **Figure 14** is using mechanical energy to move the basketball.

Changing Matter

Living things are made of matter, which consists of a substance with a form. A physical change occurs when only the form or shape of the matter changes. The substances that make up the matter do not change into different substances. When you pour sugar into iced tea and stir, the sugar crystals disappear. The sweet taste shows that the sugar is still there but has changed form.

A chemical change occurs when a substance changes into a different substance. In a chemical change, the identity of the matter changes. When wood burns, the carbohydrates in the wood fibers combine with oxygen, O_2, in the air. The wood fibers change to different substances: carbon dioxide, CO_2, and water vapor, H_2O.

Conservation of Mass Matter is neither created nor destroyed in any change. The same mass is present before and after the wood burns and the sugar dissolves. This observation is called the *law of conservation of mass*.

Conservation of Energy Every change in matter requires a change in energy. Energy may change from one form to another, but the total amount of energy does not change. This observation is called the *law of conservation of energy*. In some changes, energy is taken in from the surroundings. In others, energy is released into the surroundings. The total amount of *usable* energy decreases because some energy is given off to the surroundings as heat. **Living things use different chemical reactions to get the energy needed for life processes.**

Figure 14 This athlete uses energy to move the basketball. **What form of energy is used to move the basketball?**

Reading Check *What is a chemical change?*

Chemical Reactions

Changing a substance requires a chemical reaction. During this process, bonds between atoms are broken, and new ones are formed. A **reactant** is a substance that is changed in a chemical reaction. A **product** is a new substance that is formed. Scientists summarize reactions by writing equations in the following form:

$$\text{Reactants} \longrightarrow \text{Products}$$

The arrow means "changes to" or "forms." For example, carbon dioxide and water can react to form carbonic acid, H_2CO_3, in your blood. The following equation represents this reaction:

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

The double arrow indicates that the products can reform reactants. In this example, carbonic acid changes back to carbon dioxide and water in your lungs.

Activation Energy Chemical reactions can occur only under the right conditions. To form new bonds, particles must get close enough to share electron clouds. However, even though the particles move constantly, as they get close, their negatively charged electron clouds tend to push them apart. To react, the particles must collide fast enough to have kinetic energy to overcome the repulsion between them. The **activation energy** of the reaction is the minimum kinetic energy that colliding particles need to start a chemical reaction.

Alignment Even if enough energy is available, the product still may not form. When the reactant particles collide, the correct atoms must be brought close together in the proper orientation, as **Figure 15** shows. Otherwise, the product will not form. **Chemical reactions can occur only when the activation energy is available and the correct atoms are aligned.** In living things, chemical reactions occur between large, complex biomolecules. Life can only exist if these molecules collide in the correct orientation.

Reading Check *What causes particles to repel other particles?*

energy the capacity to do work

reactant a substance or molecule that participates in a chemical reaction

product a substance that forms in a chemical reaction

activation energy the minimum amount of energy required to start a chemical reaction

ACADEMIC VOCABULARY

orientation the relative position or direction of something

Reaction Conditions

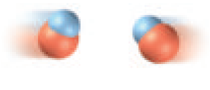
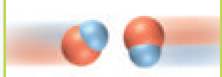
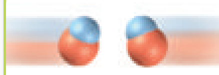
Reactants	Conditions	Result	Products
	not enough energy	no reaction	none
	enough energy; wrong orientation	no reaction	none
	enough energy; proper orientation	reaction	

Figure 15 Chemical reactions can occur only under the right conditions. The correct atoms of reactants must be aligned, and they must collide with enough energy. **What term describes the minimum amount of energy needed for a reaction to occur?**

Biological Reactions

Living things carry out many chemical reactions that help maintain a stable internal environment. Many of these reactions require large activation energies. Often, the reactants are large biomolecules that must collide in a very specific orientation. Many of these reactions would not occur without the help of enzymes.

enzyme a molecule, either protein or RNA, that acts as a catalyst in biochemical reactions

active site on an enzyme, the site that attaches to a substrate

substrate the reactant in reactions catalyzed by enzymes

Enzymes An **enzyme** is a molecule that increases the speed of biochemical reactions. Enzymes hold molecules close together and in the correct orientation. This way, the molecules do not have to depend on random collisions to react. An enzyme lowers the activation energy of a reaction, as **Figure 16** shows. **By assisting in necessary biochemical reactions, enzymes help organisms maintain homeostasis.** Without enzymes, chemical reactions would not occur quickly and easily enough for life to go on.

Enzyme Activity Enzymes fit with reactants like a lock fits a key. As **Figure 17** shows, each enzyme has an **active site,** the region where the reaction takes place. The shape of the active site determines which reactants, or **substrates,** will bind to it. Each different enzyme acts only on specific substrates.

Step 1 Two substrates bind to an enzyme's active site. The substrates fit in a specific position and location, like a key in a lock.

Step 2 Binding of the substrates causes the enzyme's shape to change slightly. The substrates fit more tightly in the enzyme's active site. The change in shape causes some bonds in the substrates to break and new bonds to form.

Step 3 The chemical reaction is complete when the product, a new substance, is formed. The unchanged enzyme releases the product, and can then be reused for another reaction.

Conditions Many enzymes are proteins. Changes in temperature and pH can change a protein's shape. If an enzyme changes shape, it won't work well. Most enzymes need a certain range of temperatures and pH.

SCILINKS.
www.scilinks.org
Topic: Enzymes
Code: HX80531

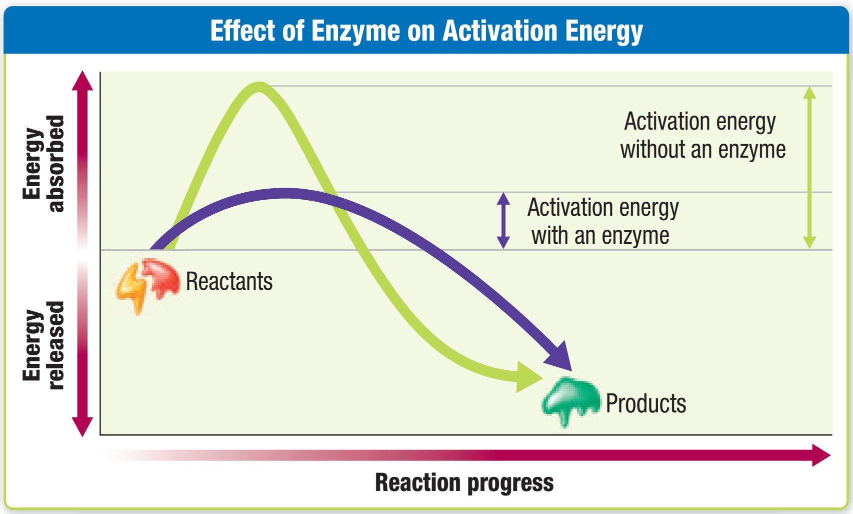


Figure 16 Enzymes decrease the amount of energy needed to start a chemical reaction without changing the amount of energy contained in either the reactants or the products.

go.hrw.com
interact online
Keyword: HX8BCMF17

Enzyme Action

1. The substrates bind to the enzyme's active site.
2. The enzyme changes shape, which catalyzes the chemical reaction between the substrates.
3. The product is released when the reaction is complete.

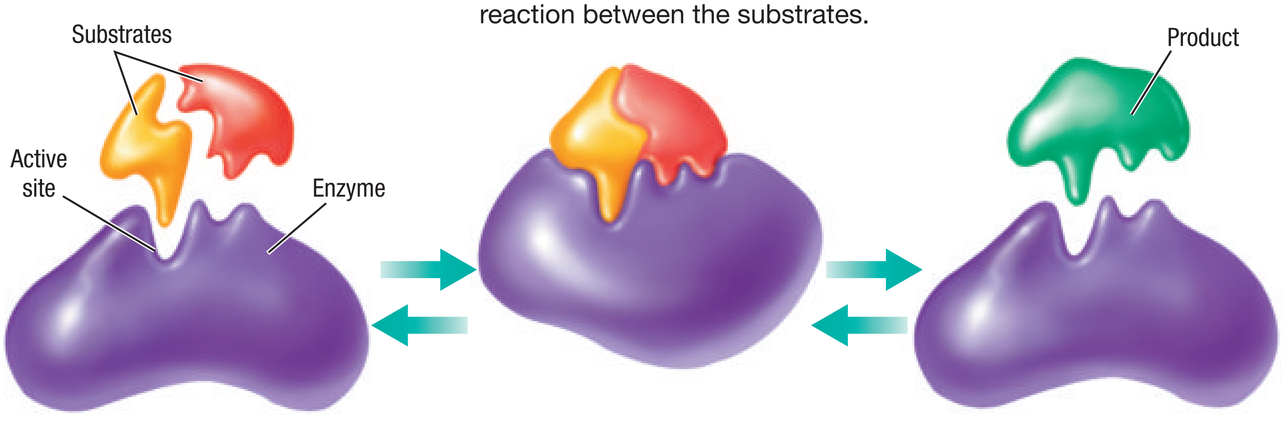


Figure 17 Enzymes catalyze specific reactions between specific reactants.
› **How would a change in the shape of the active site affect the enzyme's activity?**

Metabolism Your cells get most of the energy needed for metabolism from the food you eat. When food is digested, it is broken into small molecules that can enter the blood, which delivers them to cells. Here, chemical reactions release energy by breaking down these food molecules so that cells can use it. The release of energy from food molecules involves many steps and many enzymes.

Consider the breakdown of sugar to release energy. You can use a match to supply enough activation energy to set fire to cellulose, a polysaccharide, when you burn wood. However, the match flame is hot, and the reaction of glucose with oxygen gets even hotter because it is so fast. Living things also "burn" sugars, but they use enzymes to do so. The enzymes reduce the activation energy so much that only a little energy is needed to start the reaction. Then, a series of enzymes carries out the reaction in a slower, step-by-step manner so that the energy can be captured in the form of ATP molecules. In this process, very little heat is produced.

› Reading Check *Why is the shape of an enzyme important?*

Section 4 Review

› KEY IDEAS

1. **Explain** the importance of chemical reactions in living things.
2. **Describe** two conditions necessary for a chemical reaction to occur.
3. **Relate** enzymes and homeostasis.

CRITICAL THINKING

4. **Applying Information** Explain the difference between usable energy and the total amount of energy. How is this difference accounted for in living organisms?
5. **Recognizing Relationships** Your body breaks down starch into glucose molecules. In this reaction, which substance is the reactant, and which is the product?

WRITING FOR SCIENCE

6. **Predicting Outcomes** Research the enzyme carbonic anhydrase. Explain its role in maintaining homeostasis in the human body. How might a molecule that interferes with the action of carbonic anhydrase affect your body?

Chapter 3

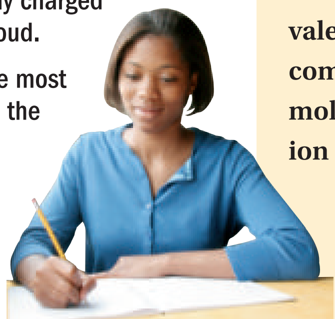
Summary

go.hrw.com
SUPER SUMMARY
Keyword: HX8BCMS

Key Ideas | **Key Terms**

1 Matter and Substances

- All matter is made up of atoms. An atom has a positively charged nucleus surrounded by a negatively charged electron cloud.
- Chemical bonds form between groups of atoms because most atoms become stable when they have eight electrons in the valence shell.
- Polar attractions and hydrogen bonds are forces that play an important role in many of the molecules that make up living things.



Key Terms: **atom** (51), **element** (51), **valence electron** (52), **compound** (52), **molecule** (52), **ion** (53)

2 Water and Solutions

- The hydrogen bonding between water molecules explains many of the unique properties that make water an important substance for life.
- Acids and bases change the concentration of hydronium ions in aqueous solutions. The pH of solutions in living things must be stable.

Key Terms: **cohesion** (55), **adhesion** (55), **solution** (56), **acid** (56), **base** (56), **pH** (57), **buffer** (57)

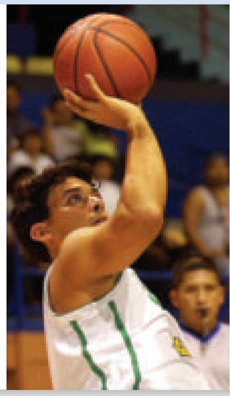
3 Carbon Compounds

- Large, complex biomolecules are built from a few smaller, simpler, repeating units arranged in an extremely precise way.
- Cells use carbohydrates for sources of energy, structural materials, and cellular identification.
- The main functions of lipids include storing energy and controlling water movement.
- Proteins are chains of amino acids that twist and fold into shapes that determine what the protein does.
- Nucleic acids store and transmit hereditary information.

Key Terms: **carbohydrate** (60), **lipid** (61), **protein** (62), **amino acid** (62), **nucleic acid** (63), **nucleotide** (63), **DNA** (63), **RNA** (63), **ATP** (63)

4 Energy and Metabolism

- Living things use different chemical reactions to get the energy needed for life processes.
- An activation energy is needed to start a chemical reaction. The reactants must also be aligned to form the product.
- By assisting in necessary biochemical reactions, enzymes help organisms maintain homeostasis.



Key Terms: **energy** (64), **reactant** (65), **product** (65), **activation energy** (65), **enzyme** (66), **active site** (66), **substrate** (66)