2.1 Atoms, Ions, and Molecules

KEY CONCEPT All living things are based on atoms and their interactions.

MAIN IDEAS

- Living things consist of atoms of different elements.
- Ions form when atoms gain or lose electrons.
- Atoms share pairs of electrons in covalent bonds.

VOCABULARY

atom, p. 36
element, p. 36
compound, p. 37
ion, p. 38
ionic bond, p. 38
covalent bond, p. 39
molecule, p. 39

Review
cell, organism

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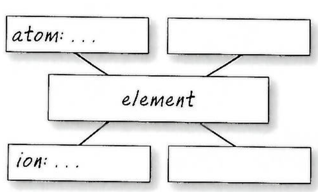
Connect The Venus flytrap produces chemicals that allow it to consume and digest insects and other small animals, including an unlucky frog. Frogs also produce specialized chemicals that allow them to consume and digest their prey. In fact, all organisms depend on many chemicals and chemical reactions. For this reason, the study of living things also involves the study of chemistry.

MAIN IDEA

Living things consist of atoms of different elements.

TAKING NOTES

Use a main idea web to help you make connections among elements, atoms, ions, compounds, and molecules.



What do a frog, a skyscraper, a car, and your body all have in common? Every physical thing you can think of, living or not, is made of incredibly small particles called atoms. An **atom** is the smallest basic unit of matter. Millions of atoms could fit in a space the size of the period at the end of this sentence. And it would take you more than 1 trillion (1,000,000,000,000, or 10^{11}) years to count the number of atoms in a single grain of sand.

Atoms and Elements

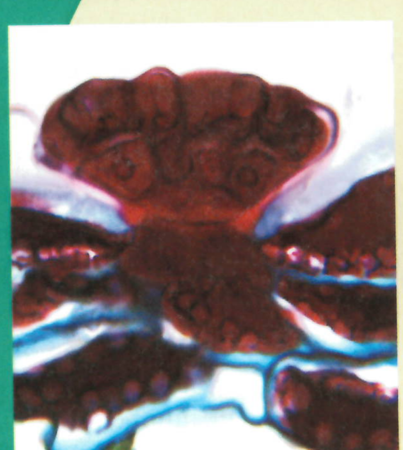
Although there is a huge variety of matter on Earth, all atoms share the same basic structure. Atoms consist of three types of smaller particles: protons, neutrons, and electrons. Protons and neutrons form the dense center of an atom—the atomic nucleus. Electrons are much smaller particles outside of the nucleus. Protons have a positive electrical charge, and electrons have a negative electrical charge. Neutrons, as their name implies, are neutral—they have no charge. Because an atom has equal numbers of positively charged protons and negatively charged electrons, it is electrically neutral.

An **element** is one particular type of atom, and it cannot be broken down into a simpler substance by ordinary chemical means. An element can also refer to a group of atoms of the same type. A few familiar elements include the gases hydrogen and oxygen and the metals aluminum and gold. Because all atoms are made of the same types of particles, what difference among atoms makes one element different from other elements? Atoms of different elements differ in the number of protons they have. All atoms of a given element have a specific number of protons that never varies. For example, all hydrogen atoms have one proton, and all oxygen atoms have eight protons.

How can this plant digest a frog?

Like other carnivores, the Venus flytrap eats animals to get nutrients that it needs to make molecules such as proteins and nucleic acids. Other chemical compounds made by the plant's cells enable the Venus flytrap to digest the animals that it eats. These chemicals are similar to the chemicals that allow you to digest the food that you eat.

Connecting CONCEPTS



Cell Function The Venus flytrap has specialized cells on the surfaces of its leaves. Some of these cells allow the plant to snap shut on its prey within 0.5 seconds. Other cells, such as those that appear purple in this light micrograph, secrete digestive chemicals that allow the plant to consume its prey. (LM; magnification 500×)

The electrons in the atoms of each element determine the properties of that element. As **FIGURE 2.1** shows, electrons are considered to be in a cloud around the nucleus. The simplified models of a hydrogen atom and an oxygen atom on the left side of **FIGURE 2.2** illustrate how electrons move around the nucleus in regions called energy levels. Different energy levels can hold different numbers of electrons. For example, the first energy level can hold two electrons, and the second energy level can hold eight electrons. Atoms are most stable when they have a full outermost energy level.

Of the 91 elements that naturally occur on Earth, only about 25 are found in organisms. Just 4 elements—carbon (C), oxygen (O), nitrogen (N), and hydrogen (H)—make up 96 percent of the human body's mass. The other 4 percent consists of calcium (Ca), phosphorus (P), potassium (K), sulfur (S), sodium (Na), and several other trace elements. Trace elements are found in very small amounts in your body, but you need them to survive. For example, iron (Fe) is needed to transport oxygen in your blood. Chromium (Cr) is needed for your cells to break down sugars for usable energy.

FIGURE 2.1 The exact position of electrons cannot be known. They are somewhere in a three-dimensional electron cloud around the nucleus.

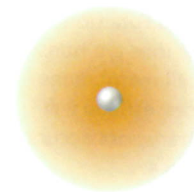
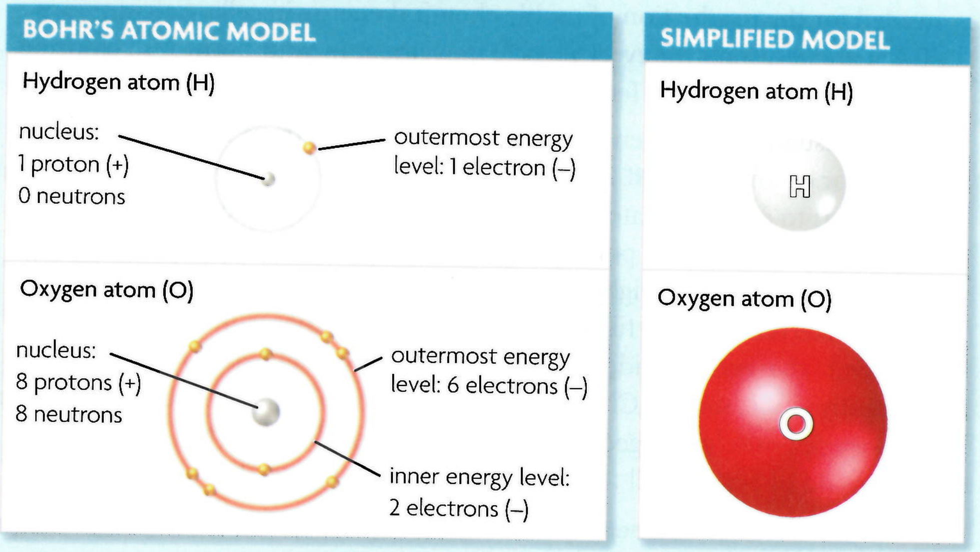


FIGURE 2.2 Representing Atoms



The model of the atom developed by Niels Bohr (left) shows that an atom's electrons are located outside the nucleus in regions called energy levels. Different types of atoms have different numbers of electrons and energy levels.

Often, atoms are shown as simplified spheres (right). Different types of atoms are shown in different sizes and colors.

Apply **How many electrons would need to be added to fill the outermost energy level of hydrogen? of oxygen?**

Compounds

The atoms of elements found in organisms are often linked, or bonded, to other atoms. A **compound** is a substance made of atoms of different elements bonded together in a certain ratio. Common compounds in living things include water (H_2O) and carbon dioxide (CO_2). A compound's properties are often different from the properties of the elements that make up the compound. At temperatures on Earth, for example, hydrogen and oxygen are both gases. Together, though, they can form water. Similarly, a diamond is pure carbon, but carbon atoms are also the basis of sugars, proteins, and millions of other compounds.

Contrast **How are elements different from compounds?**

MAIN IDEA

Ions form when atoms gain or lose electrons.

Connecting CONCEPTS

Cell Structure and Function Several different ions are transported across cell membranes during cell processes. You will learn how this transport occurs in **Chapters 3** and **4**.

An **ion** is an atom that has gained or lost one or more electrons. An ion forms because an atom is more stable when its outermost energy level is full; the gain or loss of electrons results in a full outermost energy level. An atom becomes an ion when its number of electrons changes and it gains an electrical charge. This charge gives ions certain properties. For example, compounds consisting only of ions—ionic compounds—easily dissolve in water.

Some ions are positively charged, and other ions are negatively charged. The type of ion that forms depends on the number of electrons in an atom's outer energy level. An atom with few electrons in its outer energy level tends to lose those electrons. An atom that loses one or more electrons becomes a positively charged ion because it has more protons than electrons. In contrast, an atom with a nearly full outer energy level tends to gain electrons. An atom that gains one or more electrons becomes a negatively charged ion because it has more electrons than protons.

Ions play large roles in organisms. For example, hydrogen ions (H^+) are needed for the production of usable chemical energy in cells. Calcium ions (Ca^{2+}) are necessary for every muscle movement in your body. And chloride ions (Cl^-) are important for a certain type of chemical signal in the brain.

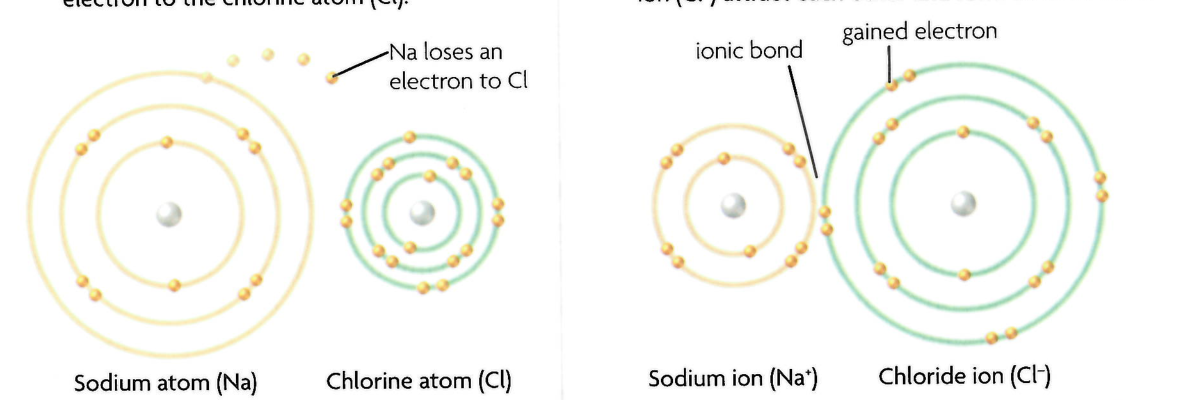
Ions usually form when electrons are transferred from one atom to another. For example, **FIGURE 2.3** shows the transfer of an electron from a sodium atom (Na) to a chlorine atom (Cl). When it loses its one outer electron, the sodium atom becomes a positively charged sodium ion (Na^+). Its second energy level, which has eight electrons, is now a full outermost energy level. The transferred electron fills chlorine's outermost energy level, forming a negatively charged chloride ion (Cl^-). Positive ions, such as Na^+, are attracted to negative ions, such as Cl^-. An **ionic bond** forms through the electrical force between oppositely charged ions. Salt, or sodium chloride (NaCl), is an ionic compound of Na^+ and Cl^-. Sodium chloride is held together by ionic bonds.

Apply **What determines whether an atom becomes a positive ion or a negative ion?**

FIGURE 2.3 IONS AND IONIC BONDS

1 The sodium atom (Na) loses its one outer electron to the chlorine atom (Cl).

2 The positive sodium ion (Na^+) and negative chloride ion (Cl^-) attract each other and form an ionic bond.



MAIN IDEA

Atoms share pairs of electrons in covalent bonds.

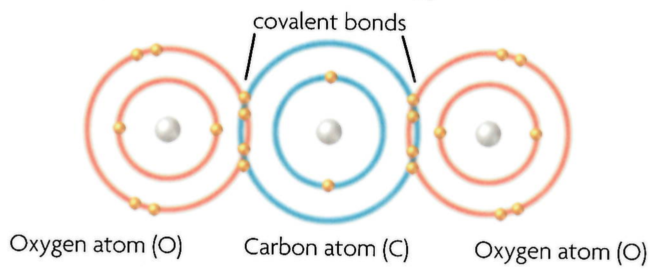
Not all atoms easily gain or lose electrons. Rather, the atoms of many elements share pairs of electrons. The shared pairs of electrons fill the outermost energy levels of the bonded atoms. A **covalent bond** forms when atoms share a pair of electrons. Covalent bonds are generally very strong, and depending on how many electrons an atom has, two atoms may form several covalent bonds to share several pairs of electrons. **FIGURE 2.4** illustrates how atoms of carbon and oxygen share pairs of electrons in covalent bonds. All three atoms in a molecule of carbon dioxide (CO_2) have full outer energy levels.

VOCABULARY

The prefix *co-* means "together," and *valent* comes from a Latin word that means "power" or "strength."

FIGURE 2.4 COVALENT BONDS

A carbon atom needs four electrons to fill its outer energy level. An oxygen atom needs two electrons to fill its outer energy level. In carbon dioxide, carbon makes a double bond, or shares two pairs of electrons, with each oxygen atom.



Carbon dioxide (CO_2)

A **molecule** is two or more atoms held together by covalent bonds. In the compound carbon dioxide, each oxygen atom shares two pairs of electrons (four electrons) with the carbon atom. Some elements occur naturally in the form of diatomic, or "two-atom," molecules. For example, a molecule of oxygen (O_2) consists of two oxygen atoms that share two pairs of electrons. Almost all of the substances that make up organisms, from lipids to nucleic acids to water, are molecules held together by covalent bonds.

Summarize **What happens to electrons in outer energy levels when two atoms form a covalent bond?**

2.1 ASSESSMENT

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REVIEWING MAIN IDEAS

1. What distinguishes one **element** from another?
2. Describe the formation of an **ionic compound.**
3. What is the difference between an **ionic bond** and a **covalent bond**?

CRITICAL THINKING

4. **Compare and Contrast** How does a **molecule** differ from an **atom**?
5. **Apply** Explain why a hydrogen atom can become either an **ion** or a part of a molecule.

Connecting CONCEPTS

6. **Chemistry** A sodium atom has one outer electron, and a carbon atom has four outer electrons. How might this difference be related to the types of compounds formed by atoms of these two elements?

2.2 Properties of Water

KEY CONCEPT Water's unique properties allow life to exist on Earth.

MAIN IDEAS

- Life depends on hydrogen bonds in water.
- Many compounds dissolve in water.
- Some compounds form acids or bases.

VOCABULARY

hydrogen bond, p. 41
cohesion, p. 41
adhesion, p. 41
solution, p. 42
solvent, p. 42
solute, p. 42
acid, p. 42
base, p. 42
pH, p. 42

Review
ion, molecule

REVIEW AT CLASSZONE.COM

Connect When you are thirsty, you need to drink something that is mostly water. Why is the water you drink absolutely necessary? Your cells, and the cells of every other living thing on Earth, are mostly water. Water gives cells structure and transports materials within organisms. All of the processes necessary for life take place in that watery environment. Water's unique properties, which are related to the structure of the water molecule, are important for living things.

MAIN IDEA

Life depends on hydrogen bonds in water.

How do fish survive a cold winter if their pond freezes? Unlike most substances, water expands when it freezes. Water is less dense as a solid (ice) than as a liquid. In a pond, ice floats and covers the water's surface. The ice acts as an insulator that allows the water underneath to remain a liquid. Ice's low density is related to the structure of the water molecule.

Water and Hydrogen Bonds

Water is a polar molecule. You can think about polar molecules in the same way that you can think about a magnet's poles. That is, polar molecules have a region with a slight positive charge and a region with a slight negative charge. Polar molecules, such as the water molecule shown in **FIGURE 2.5**, form when atoms in a molecule have unequal pulls on the electrons they share. In a molecule of water, the oxygen nucleus, with its eight protons, attracts the shared electrons more strongly than do the hydrogen nuclei, with only one proton each. The oxygen atom gains a small negative charge, and the hydrogen atoms gain small positive charges. Other molecules, called nonpolar molecules, do not have these charged regions. The atoms in nonpolar molecules share electrons more equally.

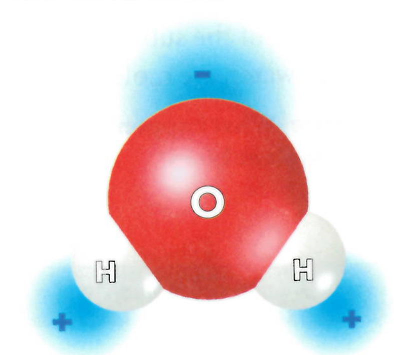


FIGURE 2.5 In water molecules, the oxygen atom has a slightly negative charge, and the hydrogen atoms have slightly positive charges.

Opposite charges of polar molecules can interact to form hydrogen bonds. A **hydrogen bond** is an attraction between a slightly positive hydrogen atom and a slightly negative atom, often oxygen or nitrogen. Hydrogen bonding is shown among water molecules in **FIGURE 2.6**, but these bonds are also found in many other molecules. For example, hydrogen bonds are part of the structures of proteins and of DNA, which is the genetic material for all organisms.

Animated BIOLOGY
See hydrogen bonding in action at ClassZone.com.

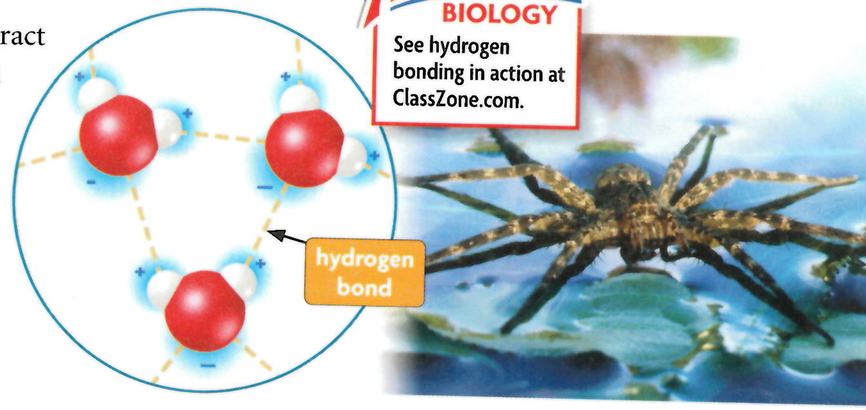


FIGURE 2.6 Water's surface tension comes from hydrogen bonds (left) that cause water molecules to stick together.

Properties Related to Hydrogen Bonds

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

- **High specific heat** Hydrogen bonds give water an abnormally high specific heat. This means that water resists changes in temperature. Compared to many other compounds, water must absorb more heat energy to increase in temperature. This property is very important in cells. The processes that produce usable chemical energy in cells release a great deal of heat. Water absorbs the heat, which helps to regulate cell temperatures.
- **Cohesion** The attraction among molecules of a substance is **cohesion.** Cohesion from hydrogen bonds makes water molecules stick to each other. You can see this when water forms beads, such as on a recently washed car. Cohesion also produces surface tension, which makes a kind of skin on water. Surface tension keeps the spider in **FIGURE 2.6** from sinking.
- **Adhesion** The attraction among molecules of different substances is called **adhesion.** In other words, water molecules stick to other things. Adhesion is responsible for the upward curve on the surface of the water in **FIGURE 2.7** because water molecules are attracted to the glass of the test tube. Adhesion helps plants transport water from their roots to their leaves because water molecules stick to the sides of the vessels that carry water.

FIGURE 2.7 The water's surface (left, dyed red) is curved down because water has greater adhesion than cohesion. The surface of the mercury (right) is curved up because mercury has greater cohesion than adhesion.

Compare How are hydrogen bonds similar to ionic bonds?

MAIN IDEA

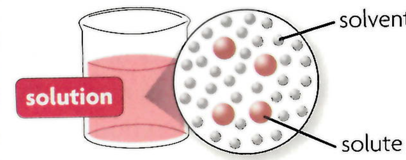
Many compounds dissolve in water.

Molecules and ions cannot take part in chemical processes inside cells unless they dissolve in water. Important materials such as sugars and oxygen cannot be transported from one part of an organism to another unless they are dissolved in blood, plant sap, or other water-based fluids.

Many substances dissolve in the water in your body. When one substance dissolves in another, a solution forms. A **solution** is a mixture of substances that is the same throughout—it is a homogeneous mixture. A solution has two parts. The **solvent** is the substance that is present in the greater amount and that dissolves another substance. A **solute** is a substance that dissolves in a solvent. The amount of solute dissolved in a certain amount of solvent is a solution's concentration. One spoonful of a drink mix in water has little flavor because it has a low concentration. But a solution with four spoonfuls in the same amount of water tastes stronger because it has a higher concentration.

VISUAL VOCAB

The **solvent** is the substance that is present in the greatest amount, and is the substance that dissolves solutes.



A **solute** is the substance that dissolves.

The liquid part of your blood, called plasma, is about 95 percent water. Therefore, the solvent in plasma is water and all of the substances dissolved in it are solutes. Most of these solutes, such as sugars and proteins, dissolve in the water of blood plasma because they are polar. Polar molecules dissolve in water because the attraction between the water molecules and the solute molecules is greater than the attraction among the molecules of the solute. Similarly, ionic compounds, such as sodium chloride, dissolve in water because the charges of the water molecules attract the charges of the ions. The water molecules surround each ion and pull the compound apart.

Nonpolar substances, such as fats and oils, rarely dissolve in water. Nonpolar molecules do not have charged regions, so they are not attracted to polar molecules. Polar molecules and nonpolar molecules tend to remain separate, which is why we say, "Oil and water don't mix." But nonpolar molecules will dissolve in nonpolar solvents. For example, some vitamins, such as vitamin E, are nonpolar and dissolve in fat in your body.

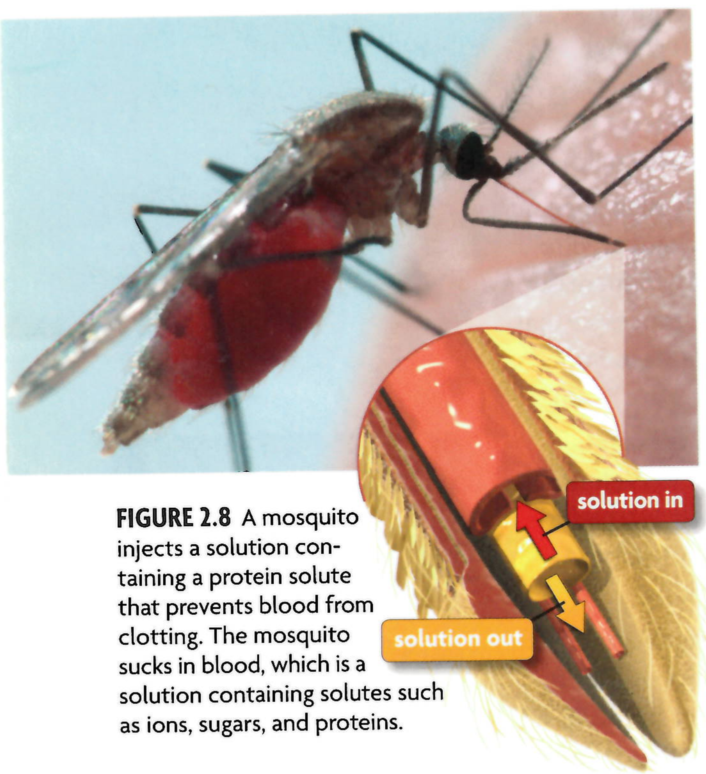


FIGURE 2.8 A mosquito injects a solution containing a protein solute that prevents blood from clotting. The mosquito sucks in blood, which is a solution containing solutes such as ions, sugars, and proteins.

Connect **What are the solvent and solutes in a beverage you drink?**

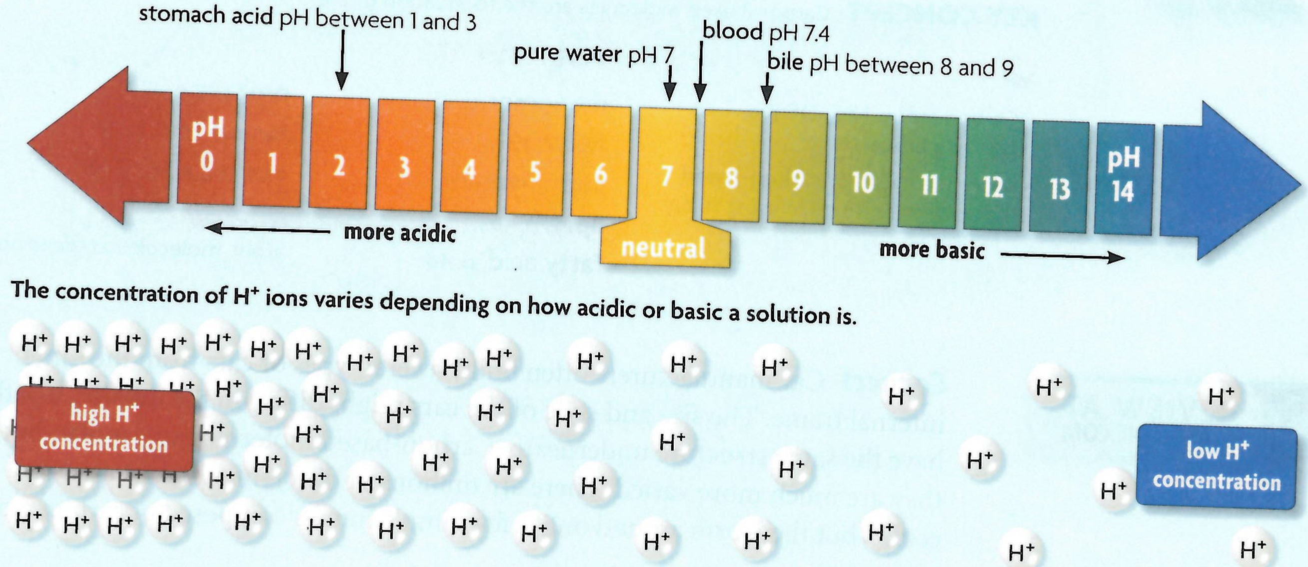
MAIN IDEA

Some compounds form acids or bases.

Some compounds break up into ions when they dissolve in water. An **acid** is a compound that releases a proton—a hydrogen ion (H^+)—when it dissolves in water. An acid increases the concentration of H^+ ions in a solution. **Bases** are compounds that remove H^+ ions from a solution. When a base dissolves in water, the solution has a low H^+ concentration. A solution's acidity, or H^+ ion concentration, is measured by the **pH** scale. In **FIGURE 2.9** you can see that pH is usually between 0 and 14. A solution with a pH of 0 is very acidic, with a high H^+ concentration. A solution with a pH of 14 is very basic, with a low H^+ concentration. Solutions with a pH of 7 are neutral—neither acidic nor basic.

FIGURE 2.9 Understanding pH

The pH of a solution depends on the concentration of H^+ ions.



Summarize **Describe the relationship between the H^+ concentration and the pH value.**

Most organisms, including humans, need to keep their pH within a very narrow range around neutral (pH 7.0). However, some organisms need a very different pH range. The azalea plant thrives in acidic (pH 4.5) soil, and a microorganism called *Picrophilus* survives best at an extremely acidic pH of 0.7. For all of these different organisms, pH must be tightly controlled.

One way pH is regulated in organisms is by substances called buffers. A buffer is a compound that can bind to an H^+ ion when the H^+ concentration increases, and can release an H^+ ion when the H^+ concentration decreases. In other words, a buffer "locks up" H^+ ions and helps to maintain homeostasis. For example, the normal pH of human blood is between 7.35 and 7.45, so it is slightly basic. Just a small change in pH can disrupt processes in your cells, and a blood pH greater than 7.8 or less than 6.8, for even a short time, is deadly. Buffers in your blood help prevent any large changes in blood pH.

Apply **Cells have higher H^+ concentrations than blood. Which has a higher pH? Why?**

Connecting CONCEPTS

Human Biology In the human body, both the respiratory system and the excretory system help regulate pH. You will learn about human systems and homeostasis in **Chapter 28**.

2.2 ASSESSMENT

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REVIEWING ▶ MAIN IDEAS

1. How do polar molecules form **hydrogen bonds**?
2. What determines whether a compound will dissolve in water?
3. Make a chart that compares **acids** and **bases.**

CRITICAL THINKING

4. **Compare and Contrast** How do polar molecules differ from nonpolar molecules? How does this difference affect their interactions?
5. **Connect** Describe an example of **cohesion** or **adhesion** that you might observe during your daily life.

Connecting CONCEPTS

6. **Cellular Respiration** When sugars are broken down to produce usable energy for cells, a large amount of heat is released. Explain how the water inside a cell helps to keep the cell's temperature constant.

2.3 Carbon-Based Molecules

KEY CONCEPT Carbon-based molecules are the foundation of life.

MAIN IDEAS

- Carbon atoms have unique bonding properties.
- Four main types of carbon-based molecules are found in living things.

VOCABULARY

monomer, p. 45
polymer, p. 45
carbohydrate, p. 45
lipid, p. 46
fatty acid, p. 46
protein, p. 47
amino acid, p. 47
nucleic acid, p. 48

Review
atom, molecule, covalent bond

REVIEW AT CLASSZONE.COM

Connect Car manufacturers often build several types of cars from the same internal frame. The size and style of the cars might differ on the outside, but they have the same structure underneath. Carbon-based molecules are similar, but they are much more varied. There are millions of different carbon-based molecules, but they form around only a few simple frames composed of carbon atoms.

MAIN IDEA

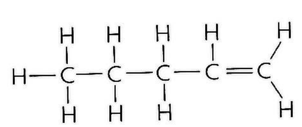
Carbon atoms have unique bonding properties.

Carbon is often called the building block of life because carbon atoms are the basis of most molecules that make up living things. These molecules form the structure of living things and carry out most of the processes that keep organisms alive. Carbon is so important because its atomic structure gives it bonding properties that are unique among elements. Each carbon atom has four unpaired electrons in its outer energy level. Therefore, carbon atoms can form covalent bonds with up to four other atoms, including other carbon atoms.

As **FIGURE 2.10** shows, carbon-based molecules have three fundamental structures—straight chains, branched chains, and rings. All three types of molecules are the result of carbon's ability to form four covalent bonds. Carbon chains can bond with carbon rings to form very large, very complex molecules. These large molecules can be made of many small molecules that are bonded together. In a sense, the way these molecules form is similar to the way in which individual links of metal come together to make a bicycle chain.

FIGURE 2.10 CARBON CHAINS AND RINGS

Straight chain

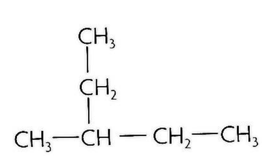


A simplified structure can also be shown as:

$CH_3—CH_2—CH_2—CH=CH_2$

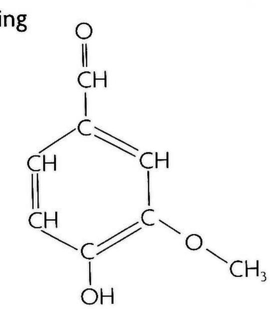
Pentene

Branched chain



Hexane

Ring



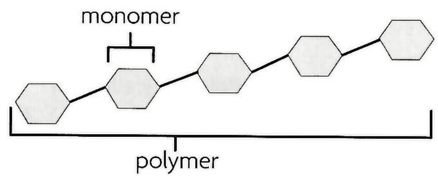
Vanillin

In many carbon-based molecules, small molecules are subunits of an entire molecule, like links in a chain. Each subunit in the complete molecule is called a **monomer.** When monomers are linked, they form molecules called polymers. A **polymer** is a large molecule, or macromolecule, made of many monomers bonded together. All of the monomers in a polymer may be the same, as they are in starches, or they may be different, as they are in proteins.

VISUAL VOCAB

Each smaller molecule is a subunit called a **monomer.**

mono- = one
poly- = many



A **polymer** is a molecule that contains many monomers bonded together.

Synthesize **Write your own analogy for the formation of a polymer from monomers.**

MAIN IDEA

Four main types of carbon-based molecules are found in living things.

All organisms are made of four types of carbon-based molecules: carbohydrates, lipids, proteins, and nucleic acids. These molecules have different structures and functions, but all are formed around carbon chains and rings.

TAKING NOTES

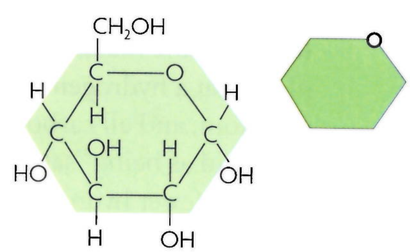
Use a content frame to help you understand monomers and polymers in carbon-based molecules.

Monomer	Polymer	Example	Function

Carbohydrates

Fruits and grains are in different food groups, but they both contain large amounts of carbohydrates. **Carbohydrates** are molecules composed of carbon, hydrogen, and oxygen, and they include sugars and starches. Carbohydrates can be broken down to provide a source of usable chemical energy for cells. Carbohydrates are also a major part of plant cell structure.

The most basic carbohydrates are simple sugars, or monosaccharides (MAHN-uh-SAK-uh-RYDZ). Many simple sugars have either five or six carbon atoms. Fruits contain a six-carbon sugar called fructose. Glucose, one of the sugars made by plant cells during photosynthesis, is another six-carbon sugar. Simple sugars can be bonded to make larger carbohydrates. For example, two sugars bonded together make the disaccharide you know as table sugar, shown in **FIGURE 2.11.** Many glucose molecules can be linked to make polysaccharides (PAHL-ee-SAK-uh-RYDZ), which are polymers of monosaccharides.

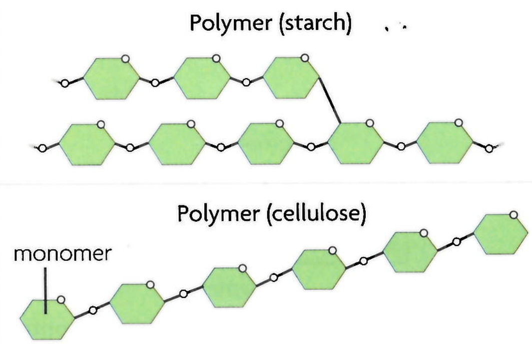


Glucose ($C_6H_{12}O_6$) can be ring shaped and is often shown as a simplified hexagon.

Starches, glycogen, and cellulose are polysaccharides. Starches and glycogen are similar, but they differ from cellulose because their glucose monomers are bonded together differently. Most starches are branched chains of glucose molecules. Starches are made and stored by plants, and they can be broken down as a source of energy by plant and animal cells. Glycogen, which is made and stored in animals, is more highly branched than plant starches.

FIGURE 2.11 Household sugar (sucrose) is a disaccharide, or two-sugar molecule, of glucose (inset) and fructose.

FIGURE 2.12 CARBOHYDRATE STRUCTURE

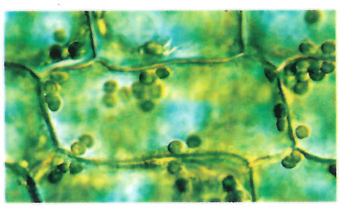


Starch is a polymer of glucose monomers that often has a branched structure.

Cellulose is a polymer of glucose monomers that has a straight, rigid structure.

Connecting CONCEPTS

Cell Structure A cell wall made of cellulose surrounds the membrane of plant cells. You will learn more about cell walls in **Chapter 3.**



Cellulose is somewhat different from starch and glycogen. Its straight, rigid structure, shown in **FIGURE 2.12,** makes the cellulose molecule a major building block in plant cell structure. Cellulose makes up the cell wall that is the tough outer covering of plant cells. You have eaten cellulose in the stringy fibers of vegetables such as celery, so you know that it is tough to chew and break up.

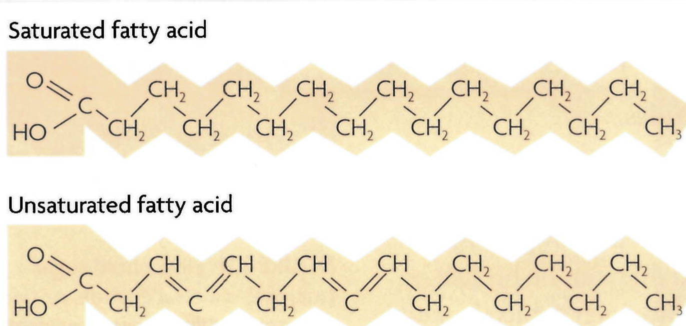
Lipids

Lipids are nonpolar molecules that include fats, oils, and cholesterol. Like carbohydrates, most lipids contain chains of carbon atoms bonded to oxygen and hydrogen atoms. Some lipids are broken down as a source of usable energy for cells. Other lipids are parts of a cell's structure.

Fats and oils are two familiar types of lipids. They store large amounts of chemical energy in organisms. Animal fats are found in foods such as meat and butter. You know plant fats as oils, such as olive oil and peanut oil. The structures of fats and oils are similar. They both consist of a molecule called glycerol (GLIHS-uh-RAWL) bonded to molecules called fatty acids. **Fatty acids** are chains of carbon atoms bonded to hydrogen atoms. Two different types of fatty acids are shown in **FIGURE 2.13.**

Many lipids, both fats and oils, contain three fatty acids bonded to glycerol. They are called triglycerides. Most animal fats are saturated fats, which means they have the maximum number of hydrogen atoms possible. That is, every place that a hydrogen atom can bond to a carbon atom is filled with a hydrogen atom, and all carbon–carbon bonds are single bonds. You can think of the fatty acid as being "saturated" with hydrogen atoms. In contrast, fatty acids in oils have fewer hydrogen atoms because there is at least one double bond between carbon atoms. These lipids are called unsaturated fats because the fatty acids are not saturated with hydrogen atoms. Fats and oils are very similar, but why are animal fats solid and plant oils liquid? The double bonds in unsaturated fats make kinks in the fatty acids. As a result, the molecules cannot pack together tightly enough to form a solid.

FIGURE 2.13 Fatty acids can be either saturated or unsaturated.



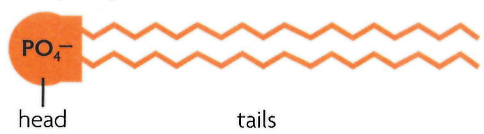
Saturated fats contain fatty acids in which all carbon–carbon bonds are single bonds.

Unsaturated fats have fatty acids with at least one carbon–carbon double bond.

All cell membranes are made mostly of another type of lipid, called a phospholipid (FAHS-foh-LIHP-ihd). A phospholipid consists of glycerol, two fatty acids, and a phosphate group (PO_4^-) that is part of the polar "head" of the molecule. The fatty acids are the nonpolar "tails" of a phospholipid. Compare the structure of a phospholipid to the structure of a triglyceride in **FIGURE 2.14.**

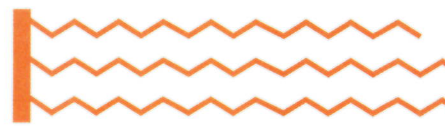
FIGURE 2.14 LIPID STRUCTURE

Phospholipid



A phospholipid has nonpolar fatty acid "tails" and a polar "head" that contains a phosphate group.

Triglyceride



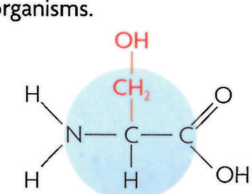
A triglyceride has three fatty acids and a molecule of glycerol, but no phosphate group.

Cholesterol (kuh-LEHS-tuh-RAWL) is a lipid that has a ring structure. You may hear about dangers of eating foods that contain a lot of cholesterol, such as eggs, but your body needs a certain amount of it to function. For example, cholesterol is a part of cell membranes, and your body uses it to make chemicals called steroid hormones. Cholesterol-based steroids have many functions. Some regulate your body's response to stress. Others, such as testosterone and estrogen, control sexual development and the reproductive system.

Proteins

Proteins are the most varied of the carbon-based molecules in organisms. In movement, eyesight, or digestion, proteins are at work. A **protein** is a polymer made of monomers called amino acids. **Amino acids** are molecules that contain carbon, hydrogen, oxygen, nitrogen, and sometimes sulfur. Organisms use 20 different amino acids to build proteins. Your body can make 12 of the amino acids. The others come from foods you eat, such as meat, beans, and nuts.

FIGURE 2.15 Serine is one of 20 amino acids that make up proteins in organisms.

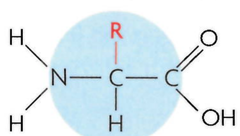


Look at **FIGURE 2.15** to see the amino acid serine. All amino acids have similar structures. As **FIGURE 2.16** shows, each amino acid monomer has a carbon atom that is bonded to four other parts. Three of these parts are the same in every amino acid: a hydrogen atom, an amino group (NH_2), and a carboxyl group (COOH). Amino acids differ only in their side group, or the R-group.

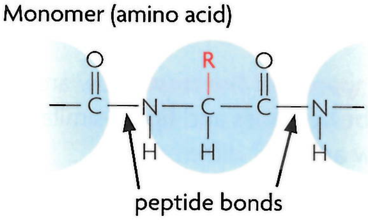
Amino acids form covalent bonds, called peptide bonds, with each other. The bonds form between the amino group of one amino acid and the carboxyl group of another amino acid. Through peptide bonds, amino acids are linked into chains called polypeptides. A protein is one or more polypeptides.

FIGURE 2.16 AMINO ACID AND PROTEIN STRUCTURE

All amino acids have a carbon atom bonded to a hydrogen atom, an amino group (NH_2), and a carboxyl group (COOH). Different amino acids have different side groups (R).

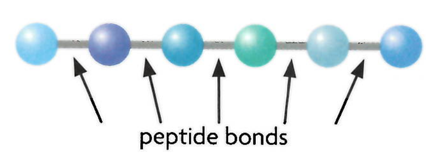


Monomer (amino acid)



Peptide bonds form between the amino group of one amino acid and the carboxyl group of another amino acid.

Polymer (protein)



A polypeptide is a chain of precisely ordered amino acids linked by peptide bonds. A protein is made of one or more polypeptides.

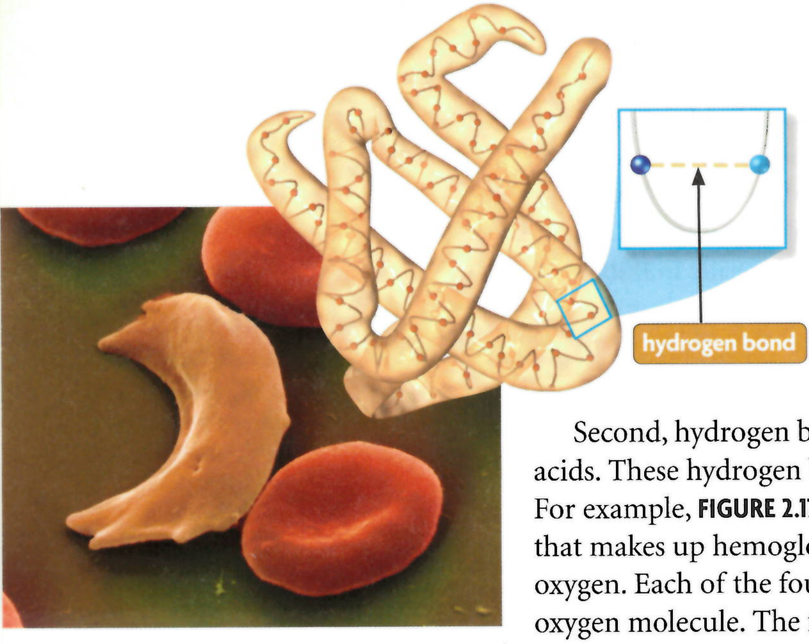


FIGURE 2.17 Hemoglobin in red blood cells transports oxygen. The structure of hemoglobin depends on hydrogen bonds between specific amino acids. Just one amino acid change causes red blood cells to have the curved shape characteristic of sickle cell anemia. (colored SEM; magnification 3500×)

Proteins differ in the number and order of amino acids. The specific sequence of amino acids determines a protein's structure and function. Two types of interactions between the side groups of some amino acids are especially important in protein structure. First, some side groups contain sulfur atoms. The sulfur atoms can form covalent bonds that force the protein to bend into a certain shape.

Second, hydrogen bonds can form between the side groups of some amino acids. These hydrogen bonds cause the protein to fold into a specific shape. For example, **FIGURE 2.17** shows the structure of one of the four polypeptides that makes up hemoglobin, the protein in your red blood cells that transports oxygen. Each of the four polypeptides contains an iron atom that bonds to an oxygen molecule. The four polypeptides are folded in a way that puts the four oxygen-carrying sites together in a pocketlike structure inside the molecule. If a protein has incorrect amino acids, the structure may change in a way that prevents the protein from working properly. Just one wrong amino acid of the 574 amino acids in hemoglobin causes the disorder sickle cell anemia.

Nucleic Acids

Detailed instructions to build proteins are stored in extremely long carbon-based molecules called nucleic acids. **Nucleic acids** are polymers that are made up of monomers called nucleotides. A nucleotide is composed of a sugar, a phosphate group, and a nitrogen-containing molecule called a base. There are two general types of nucleic acids: DNA and RNA.

Nucleic acids differ from the other types of carbon-based molecules. Carbohydrates, lipids, and proteins have a large number of structures and functions. Nucleic acids have just one function. They work together to make proteins. DNA stores the information for putting amino acids together to make proteins, and RNA helps to build proteins. DNA is the basis of genes and heredity, but cannot do anything by itself. Instead, the structure of DNA—the order of nucleotides—provides the code for the proper assembly of proteins. You will learn more about nucleic acids and how they build proteins in Unit 3.

NSTA SCILINKS scilinks.org
For more information on carbon-based molecules, visit scilinks.org.
Keycode: MLB002

Apply **What is the relationship between proteins and nucleic acids?**

2.3 ASSESSMENT

ONLINE QUIZ ClassZone.com

REVIEWING MAIN IDEAS

1. What is the relationship between a **polymer** and a **monomer**?
2. Explain how both **nucleic acids** and **proteins** are polymers. Be sure to describe the monomers that make up the polymers.

CRITICAL THINKING

3. **Compare and Contrast** How are **carbohydrates** and **lipids** similar? How are they different?
4. **Infer** Explain how the bonding properties of carbon atoms result in the large variety of carbon-based molecules in living things.

Connecting CONCEPTS

5. **Biochemistry** Why might **fatty acids, amino acids,** and nucleic acids increase the hydrogen ion (H^+) concentration of a solution? Explain your answer.

DATA ANALYSIS ClassZone.com

Independent and Dependent Variables

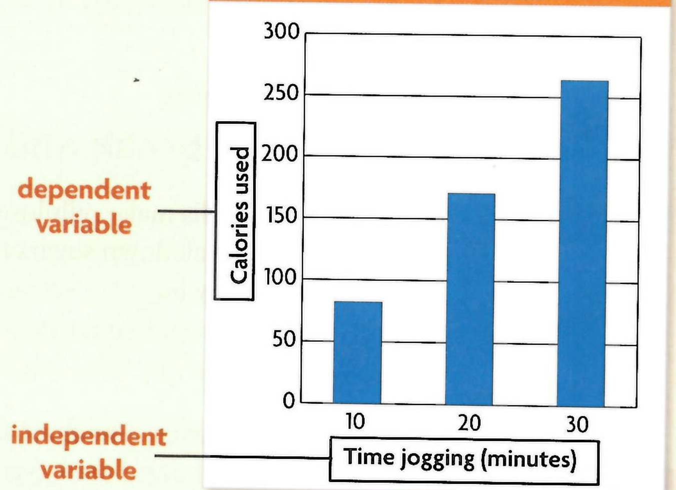
In an experiment, a scientist determines the effect one variable has on another. A scientist changes, or manipulates, the **independent variable** and measures or observes the **dependent variables.** Therefore, data from an experiment are measurements of dependent variables. Changes in dependent variables "depend upon" the independent variable.

EXAMPLE

A scientist studied the effect of jogging on the number of Calories used. (The Calories in food are kilocalories, or 1000 calories.) People jogged for three different lengths of time—10 minutes, 20 minutes, and 30 minutes. The number of Calories used was measured, recorded, and plotted on a graph like the one shown on the right. What are the independent and dependent variables?

- The independent variable is the length of time spent jogging (10 minutes, 20 minutes, or 30 minutes).
- The dependent variable is the number of Calories used while jogging—the number of Calories "depends on" time.

GRAPH 1. JOGGING AND CALORIES



IDENTIFY VARIABLES

A company that makes nutritional products is developing a new type of protein drink for athletes. A scientist at the company is studying the pH at which a digestive enzyme best breaks down the different proteins in the drink. The scientist uses the following experimental procedure:

- Five test tubes each contain 2 mL of the protein drink.
- Five different solutions contain the digestive enzyme, but each solution has a different pH—1.5, 2.0, 2.5, 3.0, and 3.5. One enzyme solution is added to each test tube of protein drink.
- Protein levels are measured in each of the five test tubes.

1. **Identify** What are the independent and dependent variables in the experiment? Explain your answers.
2. **Apply** Time is often used as a dependent variable in experiments. Describe how time could be used as a dependent variable in this experiment.

2.4 Chemical Reactions

KEY CONCEPT Life depends on chemical reactions.

MAIN IDEAS

- Bonds break and form during chemical reactions.
- Chemical reactions release or absorb energy.

VOCABULARY

chemical reaction, p. 50
reactant, p. 50
product, p. 50
bond energy, p. 51
equilibrium, p. 51
activation energy, p. 53
exothermic, p. 53
endothermic, p. 53

Review
atom, molecule

REVIEW AT CLASSZONE.COM

Connect When you hear the term *chemical reaction,* what comes to mind? Maybe you think of liquids bubbling in beakers. You probably do not think of the air in your breath, but most of the carbon dioxide and water vapor that you breathe out are made by chemical reactions in your cells.

MAIN IDEA

Bonds break and form during chemical reactions.

Plant cells make cellulose by linking simple sugars together. Plant and animal cells break down sugars to get usable energy. And all cells build protein molecules by bonding amino acids together. These are just a few of the chemical reactions in living things. **Chemical reactions** change substances into different substances by breaking and forming chemical bonds.

Reactants, Products, and Bond Energy

Your cells need the oxygen molecules that you breathe in. Oxygen (O_2) plays a part in a series of chemical reactions that provides usable energy for your cells. These reactions, which are described in detail in Chapter 4, break down the simple sugar glucose ($C_6H_{12}O_6$). The process uses oxygen and glucose and results in carbon dioxide (CO_2), water (H_2O), and usable energy. Oxygen and glucose are the reactants. **Reactants** are the substances changed during a chemical reaction. Carbon dioxide and water are the products. **Products** are the substances made by a chemical reaction. Chemical equations are used to show what happens during a reaction. The overall equation for the process that changes oxygen and glucose into carbon dioxide and water is

$$\underbrace{6O_2 + C_6H_{12}O_6}_{\text{Reactants}} \underbrace{\longrightarrow}_{\text{Direction}} \underbrace{6CO_2 + 6H_2O}_{\text{Products}}$$

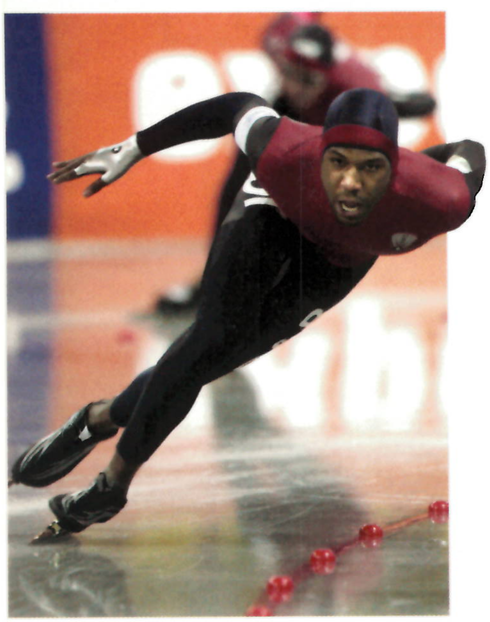


FIGURE 2.18 The breakdown of glucose provides chemical energy for all activities, including speed skating.

The reactants are on the left side of the equation, and the products are on the right side. The arrow shows the direction of the reaction. This process, which is called cellular respiration, makes the carbon dioxide and water vapor that you breathe out. But for carbon dioxide and water to be made, bonds must be broken in the reactants, and bonds must form in the products. What causes bonds in oxygen and glucose molecules to break? And what happens when new bonds form in carbon dioxide and water?

QUICK LAB **MODELING**

Chemical Bonding

You use energy to put things together, but chemical bonding is different. Energy is added to break bonds, and energy is released when bonds form.

MATERIALS
2 flat magnets

PROBLEM How is chemical bonding similar to the interaction between two magnets?

PROCEDURE

1. Bring the magnets close to each other until they snap together.
2. Pull the magnets away from each other.

ANALYZE AND CONCLUDE

1. **Infer** How is bond formation represented by the snapping sound?
2. **Apply** How is bond energy related to your separation of the magnets?

First, energy is added to break bonds in molecules of oxygen and glucose. **Bond energy** is the amount of energy that will break a bond between two atoms. Bonds between different types of atoms have different bond energies. A certain amount of energy is needed to break bonds in an oxygen molecule. A different amount of energy is needed to break bonds in a glucose molecule.

Energy is released when bonds form, such as when molecules of water and carbon dioxide are made. When a bond forms, the amount of energy released is equal to the amount of energy that breaks the same bond. For example, energy is released when hydrogen and oxygen atoms bond to form a water molecule. The same amount of energy is needed to break apart a water molecule.

Chemical Equilibrium

Some reactions go from reactants to products until the reactants are used up. However, many reactions in living things are reversible. They move in both directions at the same time. These reactions tend to go in one direction or the other depending on the concentrations of the reactants and products. One such reaction lets blood, shown in **FIGURE 2.19**, carry carbon dioxide. Carbon dioxide reacts with water in blood to form a compound called carbonic acid (H_2CO_3). Your body needs this reaction to get rid of carbon dioxide waste from your cells.

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

The arrows in the equation above show that the reaction goes in both directions. When the carbon dioxide concentration is high, as it is around your cells, the reaction moves toward the right and carbonic acid forms. In your lungs, the carbon dioxide concentration is low. The reaction goes in the other direction, and carbonic acid breaks down.

When a reaction takes place at an equal rate in both directions, the reactant and product concentrations stay the same. This state is called equilibrium. **Equilibrium** (EE-kwuh-LIHB-ree-uhm) is reached when both the reactants and products are made at the same rate.

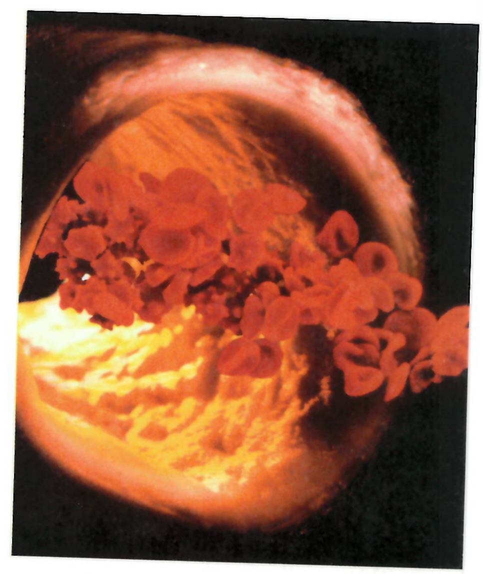


FIGURE 2.19 Blood cells and plasma transport materials throughout the body. Carbonic acid dissolves in the blood so that carbon dioxide can be transported to the lungs. (composite colored SEM; magnification 1000×)

Apply **Explain why concentration is important in a chemical reaction.**

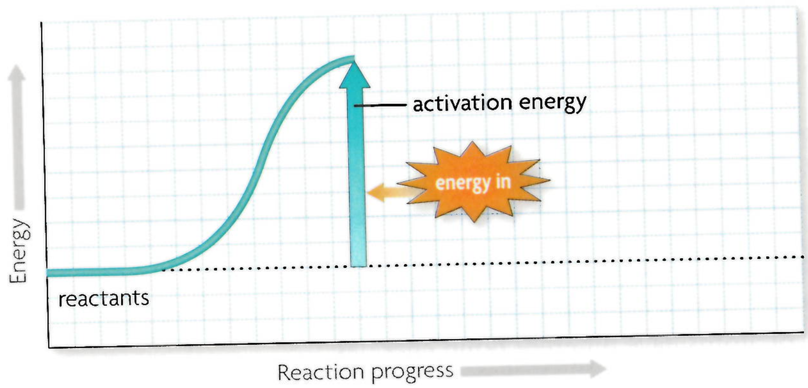
Animated BIOLOGY Watch exothermic and endothermic reactions at ClassZone.com.

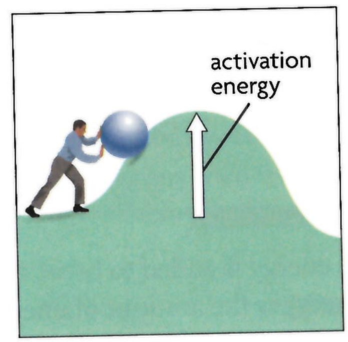
FIGURE 2.20 Energy and Chemical Reactions

Energy is required to break bonds in reactants, and energy is released when bonds form in products. Overall, a chemical reaction either absorbs or releases energy.

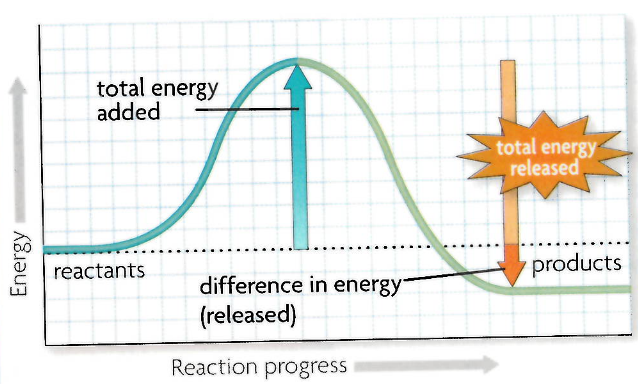
ACTIVATION ENERGY

When enough activation energy is added to the reactants, bonds in the reactants break and the reaction begins.



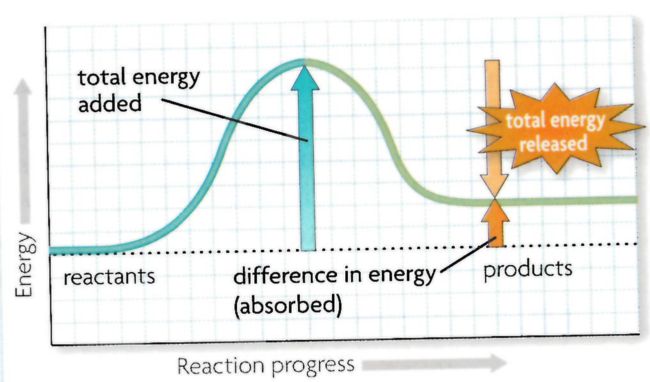


EXOTHERMIC REACTION Energy Released



The products in an exothermic reaction have a lower bond energy than the reactants, and the difference in bond energy is released to the surroundings.

ENDOTHERMIC REACTION Energy Absorbed



The products in an endothermic reaction have a higher bond energy than the reactants, and the difference in bond energy is absorbed from the surroundings.

CRITICAL VIEWING **Is the amount of activation energy related to whether a reaction is exothermic or endothermic? Why or why not?**

MAIN IDEA

Chemical reactions release or absorb energy.

All chemical reactions involve changes in energy. Energy that is added to the reactants breaks their chemical bonds. When new bonds form in the products, energy is released. This means that energy is both absorbed and released during a chemical reaction. Some chemical reactions release more energy than they absorb. Other chemical reactions absorb more energy than they release. Whether a reaction releases or absorbs energy depends on bond energy.

Some energy must be absorbed by the reactants in any chemical reaction. **Activation energy** is the amount of energy that needs to be absorbed for a chemical reaction to start. Activation energy is like the energy you would need to push a rock up a hill. Once the rock is at the top of the hill, it rolls down the other side by itself. A graph of the activation energy that is added to start a chemical reaction is shown at the top of **FIGURE 2.20.**

An **exothermic** chemical reaction releases more energy than it absorbs. If the products have a lower bond energy than the reactants, the reaction is exothermic. The excess energy—the difference in bond energy between the reactants and products—is often given off as heat or light. Some animals, such as squids and fireflies, give off light that comes from exothermic reactions, as shown in **FIGURE 2.21.** Cellular respiration, the process that uses glucose and oxygen to provide usable energy for cells, is also exothermic. Cellular respiration releases not only usable energy for your cells but also heat that keeps your body warm.

An **endothermic** chemical reaction absorbs more energy than it releases. If products have a higher bond energy than reactants, the reaction is endothermic. Energy must be absorbed to make up the difference. One of the most important processes for life on Earth, photosynthesis, is endothermic. During photosynthesis, plants absorb energy from sunlight and use that energy to make simple sugars and complex carbohydrates.

Analyze **How is activation energy related to bond energy?**

VOCABULARY

The prefix *exo-* means "out," and the prefix *endo-* means "in." Energy "moves out of" an exothermic reaction, and energy "moves into" an endothermic reaction.

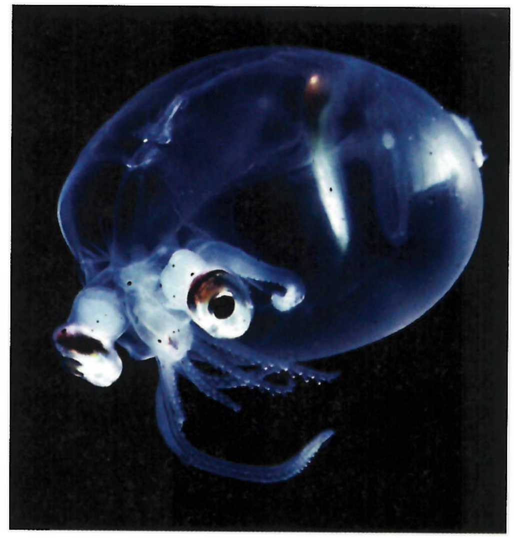


FIGURE 2.21 The glow of the bugeye squid comes from an exothermic reaction that releases light.

2.4 ASSESSMENT

ONLINE QUIZ ClassZone.com

REVIEWING MAIN IDEAS

1. Hydrogen peroxide (H_2O_2) breaks down into water (H_2O) and oxygen (O_2). Explain why this is a **chemical reaction.** What are the **reactants** and the **products** in the reaction?
2. How do **endothermic** and **exothermic** reactions differ?

CRITICAL THINKING

3. **Infer** The process below is exothermic. What must be true about the **bond energies** of the reactants and the products? Explain.

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

4. **Evaluate** Why might it not always be possible to determine the reactants and the products in a reaction? Explain your answer in terms of chemical **equilibrium.**

Connecting CONCEPTS

5. **Biochemistry** A chemical reaction can start when enough **activation energy** is added to the reactants. Do you think the activation energy for chemical reactions in living things is high or low? Explain your answer.

2.5 Enzymes

KEY CONCEPT Enzymes are catalysts for chemical reactions in living things.

MAIN IDEAS

- A catalyst lowers activation energy.
- Enzymes allow chemical reactions to occur under tightly controlled conditions.

VOCABULARY

catalyst, p. 54
enzyme, p. 55
substrate, p. 56

Review
chemical reaction, activation energy, protein, hydrogen bond

REVIEW AT CLASSZONE.COM

Connect Just how can a Venus flytrap digest a frog? It happens through the action of proteins called enzymes. Enzymes help to start and run chemical reactions in living things. For example, enzymes are needed to break down food into smaller molecules that cells can use. Without enzymes, a Venus flytrap couldn't break down its food, and neither could you.

MAIN IDEA

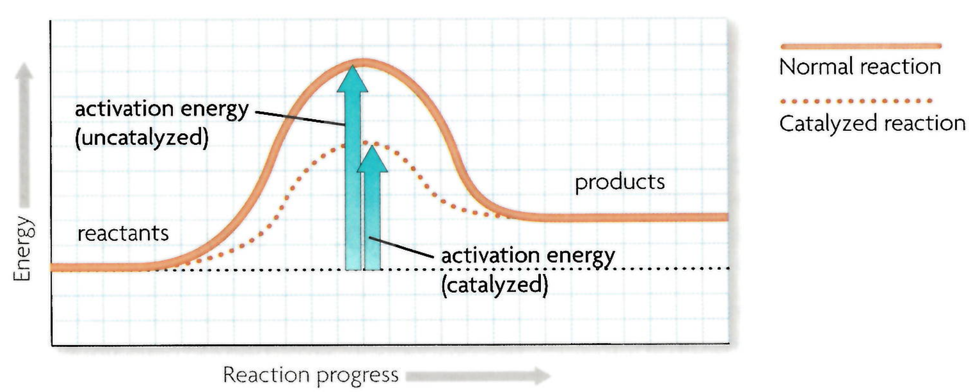
A catalyst lowers activation energy.

Remember what you learned about activation energy in Section 2.4. Activation energy for a chemical reaction is like the energy that is needed to push a rock up a hill. When enough energy is added to get the rock to the top of a hill, the rock can roll down the other side by itself. Activation energy gives a similar push to a chemical reaction. Once a chemical reaction starts, it can continue by itself, and it will go at a certain rate.

Often, the activation energy for a chemical reaction comes from an increase in temperature. But even after a chemical reaction starts, it may happen very slowly. The reactants may not interact enough, or they may not be at a high enough concentration, to quickly form the products of the reaction. However, both the activation energy and rate of a chemical reaction can be changed by a chemical catalyst, as shown in **FIGURE 2.22.** A **catalyst** (KAT-l-ihst) is a substance that decreases the activation energy needed to start a chemical reaction and, as a result, also increases the rate of the chemical reaction.

FIGURE 2.22 CATALYSTS AND ACTIVATION ENERGY

Under normal conditions, a certain amount of activation energy is needed to start a chemical reaction. A catalyst decreases the activation energy needed.



Compare the activation energies and the reaction rates in the graph in **FIGURE 2.22.** Under normal conditions, the reaction requires a certain amount of activation energy, and it occurs at a certain rate. When a catalyst is present, less energy is needed and the products form faster. Although catalysts take part in chemical reactions, catalysts are not considered to be either reactants or products because catalysts are not changed or used up during a reaction.

Summarize **Describe two functions of catalysts in chemical reactions.**

MAIN IDEA

Enzymes allow chemical reactions to occur under tightly controlled conditions.

Chemical reactions in organisms have to take place at an organism's body temperature. Often, reactants are found in low concentrations. Because the reactions must take place very quickly, they usually need a catalyst. **Enzymes** are catalysts for chemical reactions in living things. Enzymes, like other catalysts, lower the activation energy and increase the rate of chemical reactions. In reactions that are reversible, such as the carbon dioxide and carbonic acid reaction described in Section 2.4, enzymes do not affect chemical equilibrium. This means that enzymes do not change the direction of a reaction—they just change the amount of time needed for equilibrium to be reached.

Enzymes are involved in almost every process in organisms. From breaking down food to building proteins, enzymes are needed. For example, amylase is an enzyme in saliva that breaks down starch into simpler sugars. This reaction occurs up to a million times faster with amylase than without it. Enzymes are also an important part of your immune system, as shown in **FIGURE 2.23.**

Almost all enzymes are proteins. These enzymes, like other proteins, are long chains of amino acids. Each enzyme also depends on its structure to function properly. Conditions such as temperature and pH can affect the shape and function, or activity, of an enzyme. Enzymes work best in a small temperature range around the organism's normal body temperature. At only slightly higher temperatures, the hydrogen bonds in an enzyme may begin to break apart. The enzyme's structure changes and it loses its ability to function. This is one reason why a very high fever is so dangerous to a person. A change in pH can also affect the hydrogen bonds in enzymes. Many enzymes in humans work best at the nearly neutral pH that is maintained within cells of the human body.

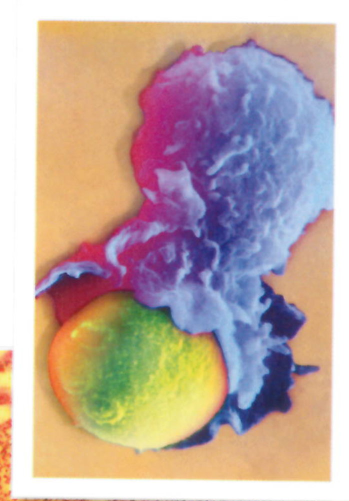
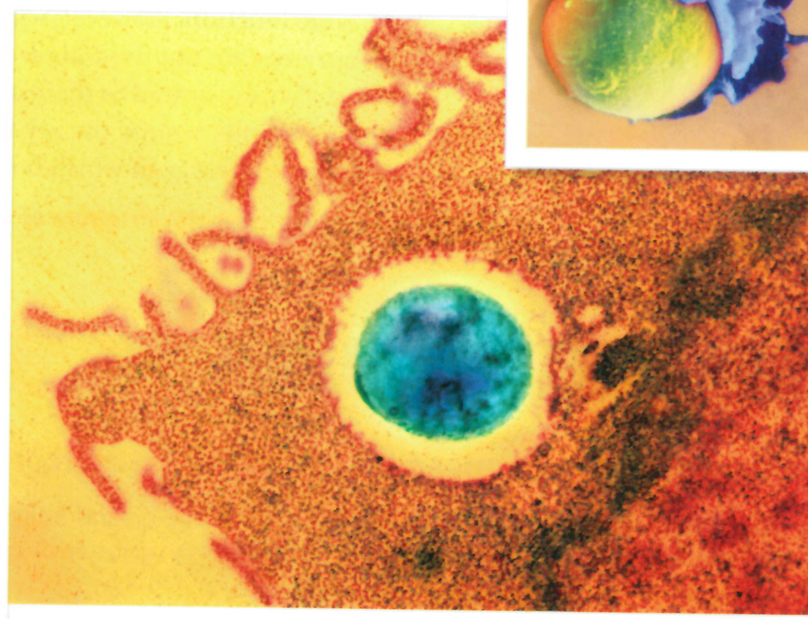
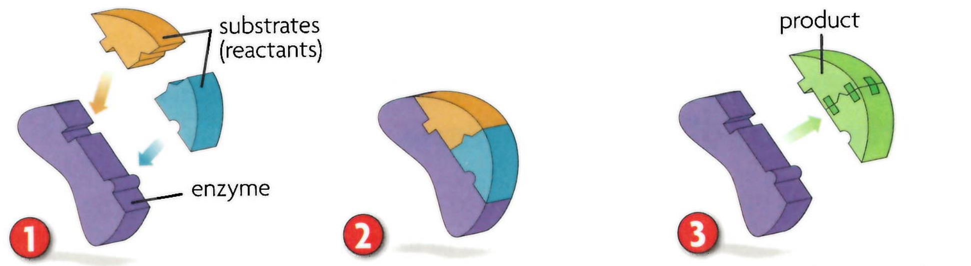



FIGURE 2.23 The inset micrograph (top) shows a white blood cell engulfing an invading pathogen. The larger micrograph shows a pathogen after it has been captured. Once inside a white blood cell, enzymes are used to destroy the pathogen. (inset image: colored SEM; magnification about 3000×; large image: colored TEM; magnification 11,000×)

Connecting CONCEPTS

Biochemistry The order of amino acids determines the structure and function of an enzyme. An enzyme's structure often depends on hydrogen bonds between amino acids.

Enzyme structure is important because each enzyme's shape allows only certain reactants to bind to the enzyme. The specific reactants that an enzyme acts on are called **substrates.** For example, amylase only breaks down starch. Therefore, starch is the substrate for amylase. Substrates temporarily bind to enzymes at specific places called active sites. Like a key fits into a lock, substrates exactly fit the active sites of enzymes. This is why if an enzyme's structure changes, it may not work at all. This idea of enzyme function, which is called the lock-and-key model, is shown below.



1 Substrates bind to an enzyme at certain places called active sites.

2 The enzyme brings substrates together and weakens their bonds.

3 The catalyzed reaction forms a product that is released from the enzyme.

The lock-and-key model helps explain how enzymes work. First, enzymes bring substrate molecules close together. Because of the low concentrations of reactants in cells, many reactions would be unlikely to take place without enzymes bringing substrates together. Second, enzymes decrease activation energy. When substrates bind to the enzyme at the enzyme's active site, the bonds inside these molecules become strained. If bonds are strained, or stretched slightly out of their normal positions, they become weaker. Less activation energy is needed for these slightly weakened bonds to be broken.

The lock-and-key model is a good starting point for understanding enzyme function. However, scientists have recently found that the structures of enzymes are not fixed in place. Instead, enzymes actually bend slightly when they are bound to their substrates. In terms of a lock and key, it is as if the lock bends around the key to make the key fit better. The bending of the enzyme is one way in which bonds in the substrates are weakened.

Apply How does the structure of an enzyme affect its function?

2.5 ASSESSMENT

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REVIEWING MAIN IDEAS

1. How does a **catalyst** affect the activation energy of a chemical reaction?
2. Describe how the interaction between an **enzyme** and its **substrates** changes a chemical reaction.

CRITICAL THINKING

3. **Infer** Some organisms live in very hot or very acidic environments. Would their enzymes function in a person's cells? Why or why not?
4. **Predict** Suppose that the amino acids that make up an enzyme's active site are changed. How might this change affect the enzyme?

Connecting CONCEPTS

5. **Homeostasis** Organisms need to maintain homeostasis, or stable internal conditions. Why is homeostasis important for the function of enzymes?