

2 The Chemistry of Life

**Big
idea**

Matter and Energy

Q: What are the basic chemical principles that affect living things?



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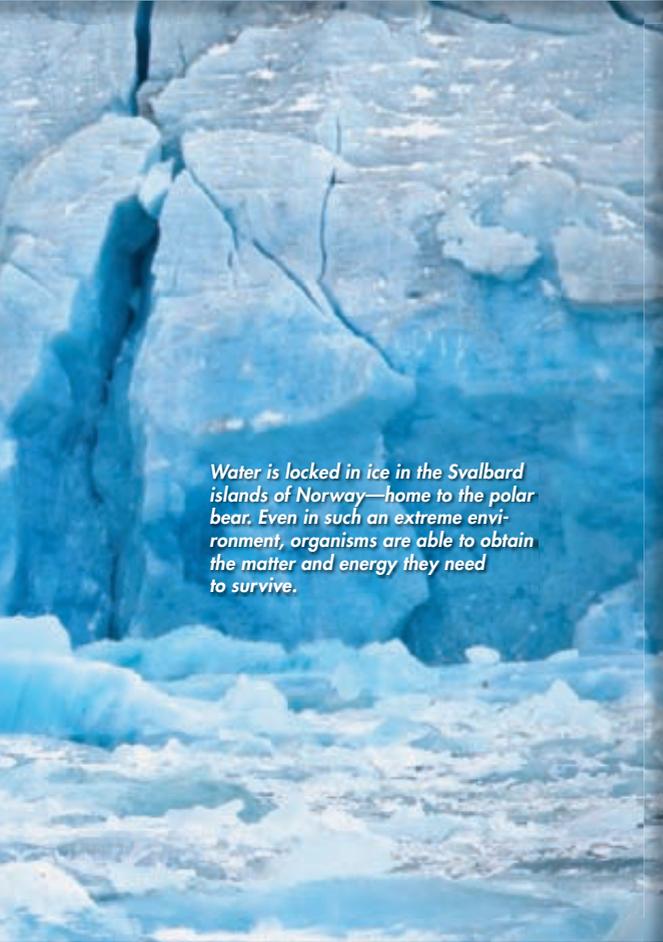
Chapter 2

GO

• Flash Cards

INSIDE:

- 2.1 The Nature of Matter
- 2.2 Properties of Water
- 2.3 Carbon Compounds
- 2.4 Chemical Reactions and Enzymes



Water is locked in ice in the Svalbard islands of Norway—home to the polar bear. Even in such an extreme environment, organisms are able to obtain the matter and energy they need to survive.

• Untamed Science Video • Chapter Mystery



CHAPTER MYSTERY

THE GHOSTLY FISH

Most fish, just like you and other vertebrates, have red blood. Red blood cells carry oxygen, a gas essential for life. The cells' red color comes from an oxygen-binding protein called hemoglobin.

But a very small number of fish don't have such cells. Their blood is clear—almost transparent. Because they live in cold antarctic waters and have a ghostly appearance, they are nicknamed "ice fish." How do these animals manage to survive without red blood cells?

As you read this chapter, look for clues to help you explain the ice fish's unusual feature. Think about the chemistry that might be involved. Then, solve the mystery.

Never Stop Exploring Your World.

Finding the solution to the fishy mystery is only the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where this mystery leads.





2.1

The Nature of Matter

Key Questions

 What three subatomic particles make up atoms?

 How are all of the isotopes of an element similar?

 In what ways do compounds differ from their component elements?

 What are the main types of chemical bonds?

Vocabulary

atom • nucleus • electron • element • isotope • compound • ionic bond • ion • covalent bond • molecule • van der Waals forces

Taking Notes

Outline Before you read, make an outline of the major headings in the lesson. As you read, fill in main ideas and supporting details under each head.

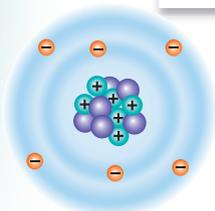


FIGURE 2-1 A Carbon Atom

THINK ABOUT IT What are you made of? Just as buildings are made from bricks, steel, glass, and wood, living things are made from chemical compounds. But it doesn't stop there. When you breathe, eat, or drink, your body uses the substances in air, food, and water to carry out chemical reactions that keep you alive. If the first task of an architect is to understand building materials, then what would be the first job of a biologist? Clearly, it is to understand the chemistry of life.

Atoms

 What three subatomic particles make up atoms?

The study of chemistry begins with the basic unit of matter, the **atom**. The concept of the atom came first from the Greek philosopher Democritus, nearly 2500 years ago. Democritus asked a simple question: If you take an object like a stick of chalk and break it in half, are both halves still chalk? The answer, of course, is yes. But what happens if you break it in half again and again and again? Can you continue to divide without limit, or does there come a point at which you cannot divide the fragment of chalk without changing it into something else? Democritus thought that there had to be a limit. He called the smallest fragment the atom, from the Greek word *atomos*, which means “unable to be cut.”

Atoms are incredibly small. Placed side by side, 100 million atoms would make a row only about 1 centimeter long—about the width of your little finger! Despite its extremely small size, an atom contains subatomic particles that are even smaller. **Figure 2-1** shows the subatomic particles in a carbon atom.  **The subatomic particles that make up atoms are protons, neutrons, and electrons.**

Protons and Neutrons Protons and neutrons have about the same mass. However, protons are positively charged particles (+) and neutrons carry no charge at all. Strong forces bind protons and neutrons together to form the **nucleus**, at the center of the atom.

Electrons The **electron** is a negatively charged particle (–) with only 1/1840 the mass of a proton. Electrons are in constant motion in the space surrounding the nucleus. They are attracted to the positively charged nucleus but remain outside the nucleus because of the energy of their motion. Because atoms have equal numbers of electrons and protons, their positive and negative charges balance out, and atoms themselves are electrically neutral.

Elements and Isotopes

 **How are all of the isotopes of an element similar?**

A chemical **element** is a pure substance that consists entirely of one type of atom. More than 100 elements are known, but only about two dozen are commonly found in living organisms. Elements are represented by one- or two-letter symbols. C, for example, stands for carbon, H for hydrogen, Na for sodium, and Hg for mercury. The number of protons in the nucleus of an element is called its atomic number. Carbon's atomic number is 6, meaning that each atom of carbon has six protons and, consequently, six electrons. See Appendix E, The Periodic Table, which shows the elements.

Isotopes Atoms of an element may have different numbers of neutrons. For example, although all atoms of carbon have six protons, some have six neutrons, some seven, and a few have eight. Atoms of the same element that differ in the number of neutrons they contain are known as **isotopes**. The total number of protons and neutrons in the nucleus of an atom is called its mass number. Isotopes are identified by their mass numbers. **Figure 2–3** shows the subatomic composition of carbon-12, carbon-13, and carbon-14 atoms. The weighted average of the masses of an element's isotopes is called its atomic mass. “Weighted” means that the abundance of each isotope in nature is considered when the average is calculated.  **Because they have the same number of electrons, all isotopes of an element have the same chemical properties.**

Isotopes of Carbon			
Isotope	Number of Protons	Number of Electrons	Number of Neutrons
Carbon-12 (nonradioactive)	6	6	6
Carbon-13 (nonradioactive)	6	6	7
Carbon-14 (radioactive)	6	6	8

Radioactive Isotopes Some isotopes are radioactive, meaning that their nuclei are unstable and break down at a constant rate over time. The radiation these isotopes give off can be dangerous, but radioactive isotopes have a number of important scientific and practical uses.

Geologists can determine the ages of rocks and fossils by analyzing the isotopes found in them. Radiation from certain isotopes can be used to detect and treat cancer and to kill bacteria that cause food to spoil. Radioactive isotopes can also be used as labels or “tracers” to follow the movements of substances within organisms.

 **In Your Notebook** Draw a diagram of a helium atom, which has an atomic number of 2.



FIGURE 2–2 Droplets of Mercury Mercury, a silvery-white metallic element, is liquid at room temperature and forms droplets. It is extremely poisonous.

FIGURE 2–3 Carbon Isotopes Isotopes of carbon all have 6 protons but different numbers of neutrons—6, 7, or 8. They are identified by the total number of protons and neutrons in the nucleus: carbon-12, carbon-13, and carbon-14. **Classify** Which isotope of carbon is radioactive?

Chemical Compounds

 **In what ways do compounds differ from their component elements?**

In nature, most elements are found combined with other elements in compounds. A chemical **compound** is a substance formed by the chemical combination of two or more elements in definite proportions. Scientists show the composition of compounds by a kind of shorthand known as a chemical formula. Water, which contains two atoms of hydrogen for each atom of oxygen, has the chemical formula H_2O . The formula for table salt, $NaCl$, indicates that the elements that make up table salt—sodium and chlorine—combine in a 1 : 1 ratio.

 **The physical and chemical properties of a compound are usually very different from those of the elements from which it is formed.** For example, hydrogen and oxygen, which are gases at room temperature, can combine explosively and form liquid water. Sodium is a silver-colored metal that is soft enough to cut with a knife. It reacts explosively with water. Chlorine is very reactive, too. It is a poisonous, yellow-greenish gas that was used in battles during World War I. Sodium chloride, table salt, is a white solid that dissolves easily in water. As you know, sodium chloride is not poisonous. In fact, it is essential for the survival of most living things.

BUILD Vocabulary

RELATED WORD FORMS The verb *react* means to act in response to something. The adjective *reactive* describes the tendency to respond or react.

Chemical Bonds

 **What are the main types of chemical bonds?**

The atoms in compounds are held together by various types of chemical bonds. Much of chemistry is devoted to understanding how and when chemical bonds form. Bond formation involves the electrons that surround each atomic nucleus. The electrons that are available to form bonds are called valence electrons.  **The main types of chemical bonds are ionic bonds and covalent bonds.**



Model an Ionic Compound

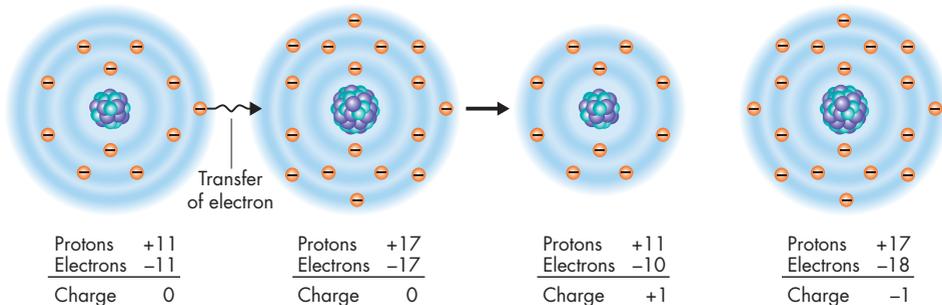
- 1 You will be assigned to represent either a sodium atom or a chlorine atom.
- 2 Obtain the appropriate number of popcorn kernels to represent your electrons.
- 3 Find a partner with whom you can form the ionic compound sodium chloride—table salt.
- 4 In table salt, the closely packed sodium and chloride ions form an orderly structure called a crystal. With all your classmates, work as a class to model a sodium chloride crystal.

Analyze and Conclude

1. **Relate Cause and Effect** Describe the exchange of popcorn kernels (electrons) that took place as you formed the ionic bond. What electrical charges resulted from the exchange?
2. **Use Models** How were the “ions” arranged in the model of the crystal? Why did you and your classmates choose this arrangement?

A. Ionic Bonding

Sodium atom (Na) + Chlorine atom (Cl) → Sodium ion (Na⁺) + Chloride ion (Cl⁻)



Ionic Bonds An **ionic bond** is formed when one or more electrons are transferred from one atom to another. Recall that atoms are electrically neutral because they have equal numbers of protons and electrons. An atom that loses electrons becomes positively charged. An atom that gains electrons has a negative charge. These positively and negatively charged atoms are known as **ions**.

Figure 2-4A shows how ionic bonds form between sodium and chlorine in table salt. A sodium atom easily loses its one valence electron and becomes a sodium ion (Na⁺). A chlorine atom easily gains an electron and becomes a chloride ion (Cl⁻). In a salt crystal, there are trillions of sodium and chloride ions. These oppositely charged ions have a strong attraction, forming an ionic bond.

Covalent Bonds Sometimes electrons are shared by atoms instead of being transferred. What does it mean to share electrons? It means that the moving electrons actually travel about the nuclei of both atoms, forming a **covalent bond**. When the atoms share two electrons, the bond is called a single covalent bond. Sometimes the atoms share four electrons and form a double bond. In a few cases, atoms can share six electrons, forming a triple bond. The structure that results when atoms are joined together by covalent bonds is called a molecule. The **molecule** is the smallest unit of most compounds. The diagram of a water molecule in Figure 2-4B shows that each hydrogen atom is joined to water's lone oxygen atom by a single covalent bond. When atoms of the same element join together, they also form a molecule. Oxygen molecules in the air you breathe consist of two oxygen atoms joined by covalent bonds.

B. Covalent Bonding

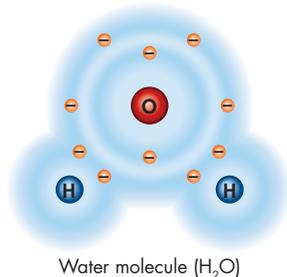
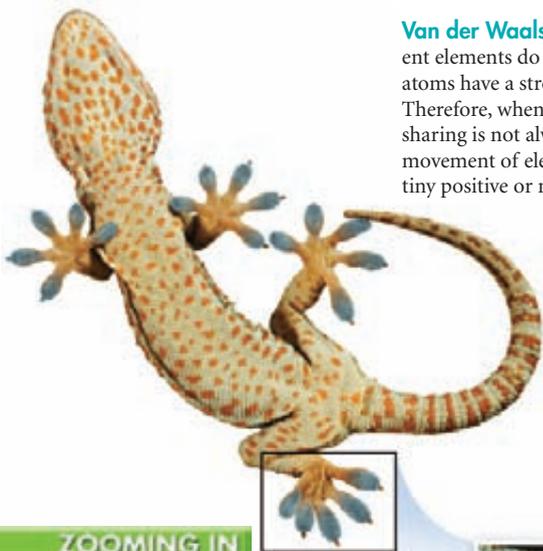


FIGURE 2-4 Ionic Bonding and Covalent Bonding A. The compound sodium chloride forms when sodium loses its valence electron to chlorine. B. In a water molecule, each hydrogen atom shares two electrons with the oxygen atom.

In Your Notebook In your own words, describe the differences between ionic and covalent bonds.

MYSTERY CLUE

Fish do not break water molecules into their component atoms to obtain oxygen. Rather, they use oxygen gas dissolved in the water. How are the atoms in an oxygen molecule (O₂) joined together?



ZOOMING IN

VAN DER WAALS FORCES AT WORK

FIGURE 2-5 The underside of each foot on this Tokay gecko is covered by millions of tiny hairlike projections. The projections themselves are made of even finer fibers, creating more surface area for “sticking” to surfaces at the molecular level. This allows geckos to scurry up walls and across ceilings.



SEM 950X

Van der Waals Forces Because of their structures, atoms of different elements do not all have the same ability to attract electrons. Some atoms have a stronger attraction for electrons than do other atoms. Therefore, when the atoms in a covalent bond share electrons, the sharing is not always equal. Even when the sharing is equal, the rapid movement of electrons can create regions on a molecule that have a tiny positive or negative charge.

When molecules are close together, a slight attraction can develop between the oppositely charged regions of nearby molecules. Chemists call such intermolecular forces of attraction **van der Waals forces**, after the scientist who discovered them. Although van der Waals forces are not as strong as ionic bonds or covalent bonds, they can hold molecules together, especially when the molecules are large.

2.1 Assessment

Review Key Concepts

- a. Review** Describe the structure of an atom.
b. Infer An atom of calcium contains 20 protons. How many electrons does it have?
- a. Review** Why do all isotopes of an element have the same chemical properties?
b. Compare and Contrast Compare the structure of carbon-12 and carbon-14.
- a. Review** What is a compound?
b. Apply Concepts Water (H_2O) and hydrogen peroxide (H_2O_2) both consist of hydrogen and oxygen atoms. Explain why they have different chemical and physical properties.

- a. Review** What are two types of bonds that hold the atoms within a compound together?
b. Classify A potassium atom easily loses its one valence electron. What type of bond will it form with a chlorine atom?

Apply the Big Idea

Matter and Energy

- Why do you think it is important that biologists have a good understanding of chemistry?

Technology & BIOLOGY

A Nature-Inspired Adhesive

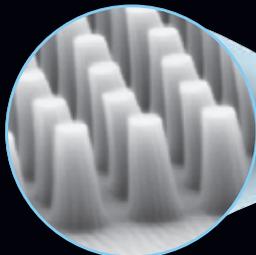
People who keep geckos as pets have always marveled at the way these little lizards can climb up vertical surfaces, even smooth glass walls, and then hang on by a single toe despite the pull of gravity. How do they do it? No, they do not have some sort of glue on their feet and they don't have suction cups. Incredibly, they use van der Waals forces.

A gecko foot is covered by as many as half a million tiny hairlike projections. Each projection is further divided into hundreds of tiny, flat-surfaced fibers. This design allows the gecko's foot to come in contact with an extremely large area of the wall at the molecular level. Van der Waals forces form between molecules on the surface of the gecko's foot and molecules on the surface of the wall. This allows the gecko to actually balance the pull of gravity.

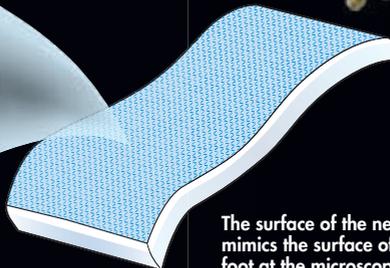
If it works for the gecko, why not for us? That's the thinking of researchers at the Massachusetts Institute of Technology, who have now used the same principle to produce a bandage. This new bandage is held to tissue by van der Waals forces alone. Special materials make it possible for the new bandage to work even on moist surfaces, which means that it may be used to reseal internal tissues after surgery. By learning a trick or two from the gecko, scientists may have found a way to help heal wounds, and even save lives in the process.

WRITING

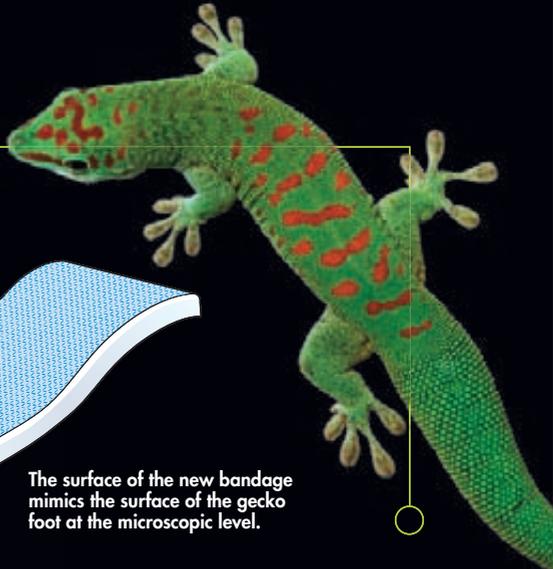
Suppose you are a doctor reviewing this new bandage for its potential applications. In what ways might you use such a bandage? Present your ideas as a list.



SEM 12,000×



The surface of the new bandage mimics the surface of the gecko foot at the microscopic level.





2.2

Properties of Water

Key Questions

Key How does the structure of water contribute to its unique properties?

Key How does water's polarity influence its properties as a solvent?

Key Why is it important for cells to buffer solutions against rapid changes in pH?

Vocabulary

hydrogen bond • cohesion • adhesion • mixture • solution • solute • solvent • suspension • pH scale • acid • base • buffer

Taking Notes

Venn Diagram As you read, draw a Venn diagram showing the differences between solutions and suspensions and the properties that they share.

THINK ABOUT IT Looking back at our beautiful planet, an astronaut in space said that if other beings have seen the Earth, they must surely call it “the blue planet.” He referred, of course, to the oceans of water that cover nearly three fourths of Earth’s surface. The very presence of liquid water tells a scientist that life may also be present on such a planet. Why should this be so? Why should life itself be connected so strongly to something so ordinary that we often take it for granted? The answers to those questions suggest that there is something very special about water and the role it plays in living things.

The Water Molecule

Key How does the structure of water contribute to its unique properties?

Water is one of the few compounds found in a liquid state over most of the Earth’s surface. Like other molecules, water (H₂O) is neutral. The positive charges on its 10 protons balance out the negative charges on its 10 electrons. However, there is more to the story.

Polarity With 8 protons in its nucleus, an oxygen atom has a much stronger attraction for electrons than does a hydrogen atom with its single proton. Thus, at any moment, there is a greater probability of finding the shared electrons in water close to its oxygen atom than near its hydrogen atoms. Because of the angles of its chemical bonds, the oxygen atom is on one end of the molecule and the hydrogen atoms are on the other, as shown in **Figure 2-6**. As a result, the oxygen end of the molecule has a slight negative charge and the hydrogen end of the molecule has a slight positive charge.

A molecule in which the charges are unevenly distributed is said to be “polar,” because the molecule is a bit like a magnet with two poles. The charges on a polar molecule are written in parentheses, (–) or (+), to show that they are weaker than the charges on ions such as Na⁺ and Cl[–].

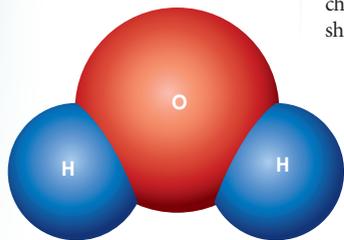


FIGURE 2-6 A Water Molecule

A water molecule is polar because there is an uneven distribution of electrons between the oxygen and hydrogen atoms. The negative pole is near the oxygen atom and the positive pole is between the hydrogen atoms.

Hydrogen Bonding Because of their partial positive and negative charges, polar molecules such as water can attract each other. The attraction between a hydrogen atom on one water molecule and the oxygen atom on another is known as a **hydrogen bond**. Hydrogen bonds are not as strong as covalent or ionic bonds, and they can form in other compounds as well.  Because water is a polar molecule, it is able to form multiple hydrogen bonds, which account for many of water's special properties.

► **Cohesion** **Cohesion** is an attraction between molecules of the same substance. Because a single water molecule may be involved in as many as four hydrogen bonds at the same time, water is extremely cohesive. Cohesion causes water molecules to be drawn together, which is why drops of water form beads on a smooth surface. Cohesion also produces surface tension, explaining why some insects and spiders can walk on a pond's surface, as shown in **Figure 2-7**.

► **Adhesion** On the other hand, **adhesion** is an attraction between molecules of different substances. Have you ever been told to read the volume in a graduated cylinder at eye level? As shown in **Figure 2-8**, the surface of the water in the graduated cylinder dips slightly in the center because the adhesion between water molecules and glass molecules is stronger than the cohesion between water molecules. Adhesion between water and glass also causes water to rise in a narrow tube against the force of gravity. This effect is called capillary action. Capillary action is one of the forces that draws water out of the roots of a plant and up into its stems and leaves. Cohesion holds the column of water together as it rises.

► **Heat Capacity** Another result of the multiple hydrogen bonds between water molecules is that it takes a large amount of heat energy to cause those molecules to move faster, which raises the temperature of the water. Therefore, water's heat capacity, the amount of heat energy required to increase its temperature, is relatively high. This allows large bodies of water, such as oceans and lakes, to absorb large amounts of heat with only small changes in temperature. The organisms living within are thus protected from drastic changes in temperature. At the cellular level, water absorbs the heat produced by cell processes, regulating the temperature of the cell.

In Your Notebook Draw a diagram of a meniscus. Label where cohesion and adhesion occur.

FIGURE 2-8 Adhesion Adhesion between water and glass molecules is responsible for causing the water in these columns to rise. The surface of the water in the glass column dips slightly in the center, forming a curve called a meniscus.

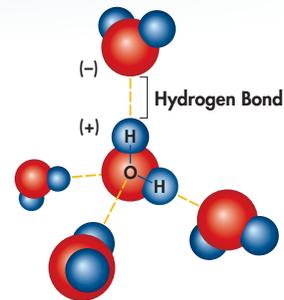


FIGURE 2-7 Hydrogen Bonding and Cohesion Each molecule of water can form multiple hydrogen bonds with other water molecules. The strong attraction between water molecules produces a force sometimes called "surface tension," which can support very lightweight objects, such as this raft spider.

Apply Concepts Why are water molecules attracted to one another?

MYSTERY CLUE

The solubility of gases increases as temperatures decrease. Think about when a can of warm soda is opened—the carbon dioxide dissolved in it fizzes out more rapidly because the gas is less soluble at warm temperatures. How might the temperature of antarctic waters affect the amount of dissolved oxygen available for ice fish?



Solutions and Suspensions

How does water's polarity influence its properties as a solvent?

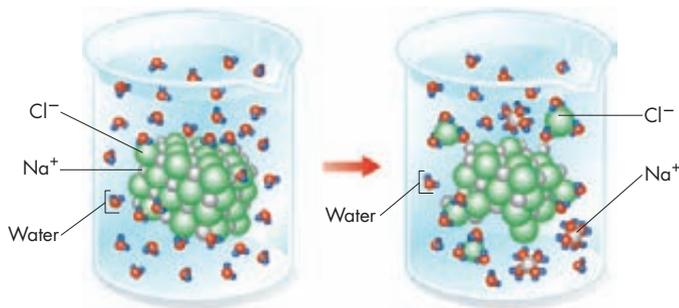
Water is not always pure; it is often found as part of a mixture. A **mixture** is a material composed of two or more elements or compounds that are physically mixed together but not chemically combined. Salt and pepper stirred together constitute a mixture. So do sugar and sand. Earth's atmosphere is a mixture of nitrogen, oxygen, carbon dioxide, and other gases. Living things are in part composed of mixtures involving water. Two types of mixtures that can be made with water are solutions and suspensions.

Solutions If a crystal of table salt is placed in a glass of warm water, sodium and chloride ions on the surface of the crystal are attracted to the polar water molecules. Ions break away from the crystal and are surrounded by water molecules, as illustrated in **Figure 2–9**. The ions gradually become dispersed in the water, forming a type of mixture called a solution. All the components of a **solution** are evenly distributed throughout the solution. In a saltwater solution, table salt is the **solute**—the substance that is dissolved. Water is the **solvent**—the substance in which the solute dissolves. **Water's polarity gives it the ability to dissolve both ionic compounds and other polar molecules.**

Water easily dissolves salts, sugars, minerals, gases, and even other solvents such as alcohol. Without exaggeration, water is the greatest solvent on Earth. But even water has limits. When a given amount of water has dissolved all of the solute it can, the solution is said to be saturated.

FIGURE 2–9 A Salt Solution When an ionic compound such as sodium chloride is placed in water, water molecules surround and separate the positive and negative ions.

Interpret Visuals What happens to the sodium ions and chloride ions in the solution?

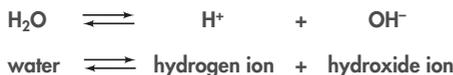


Suspensions Some materials do not dissolve when placed in water, but separate into pieces so small that they do not settle out. The movement of water molecules keeps the small particles suspended. Such mixtures of water and nondissolved material are known as **suspensions**. Some of the most important biological fluids are both solutions and suspensions. The blood that circulates through your body is mostly water. The water in the blood contains many dissolved compounds. However, blood also contains cells and other undissolved particles that remain in suspension as the blood moves through the body.

Acids, Bases, and pH

🔑 Why is it important for cells to buffer solutions against rapid changes in pH?

Water molecules sometimes split apart to form ions. This reaction can be summarized by a chemical equation in which double arrows are used to show that the reaction can occur in either direction.



How often does this happen? In pure water, about 1 water molecule in 550 million splits to form ions in this way. Because the number of positive hydrogen ions produced is equal to the number of negative hydroxide ions produced, pure water is neutral.

The pH Scale Chemists devised a measurement system called the **pH scale** to indicate the concentration of H^+ ions in solution. As **Figure 2–10** shows, the pH scale ranges from 0 to 14. At a pH of 7, the concentration of H^+ ions and OH^- ions is equal. Pure water has a pH of 7. Solutions with a pH below 7 are called acidic because they have more H^+ ions than OH^- ions. The lower the pH, the greater the acidity. Solutions with a pH above 7 are called basic because they have more OH^- ions than H^+ ions. The higher the pH, the more basic the solution. Each step on the pH scale represents a factor of 10. For example, a liter of a solution with a pH of 4 has 10 times as many H^+ ions as a liter of a solution with a pH of 5.

In Your Notebook Order these items in order of increasing acidity: soap, lemon juice, milk, acid rain.

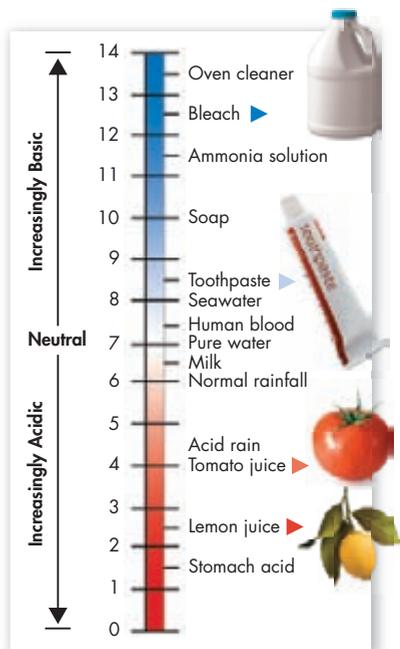


FIGURE 2–10 The pH Scale The concentration of H^+ ions determines whether solutions are acidic or basic. The most acidic material on this pH scale is stomach acid. The most basic material on this scale is oven cleaner.

Quick Lab

GUIDED INQUIRY

Acidic and Basic Foods



- 1 Predict whether the food samples provided are acidic or basic.
- 2 Tear off a 2-inch piece of pH paper for each sample you will test. Place these pieces on a paper towel.
- 3 Construct a data table in which you will record the name and pH of each food sample.

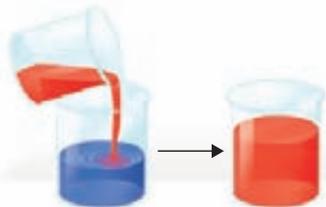
- 4 Use a scalpel to cut a piece off each solid.

CAUTION: Be careful not to cut yourself. Do not eat the food. Touch the cut surface of each sample to a square of pH paper. Use a dropper pipette to place a drop of any liquid sample on a square of pH paper. Record the pH of each sample in your data table.

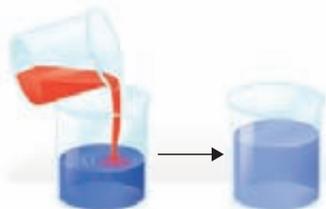
Analyze and Conclude

1. **Analyze Data** Were most of the samples acidic or basic?
2. **Evaluate** Was your prediction correct?

FIGURE 2-11 Buffers Buffers help prevent drastic changes in pH. Adding acid to an unbuffered solution causes the pH of the unbuffered solution to drop. If the solution contains a buffer, however, adding the acid will cause only a slight change in pH.



Unbuffered base + acid = acidic pH



Buffered base + acid = basic pH

Acids Where do all those extra H^+ ions in a low-pH solution come from? They come from acids. An **acid** is any compound that forms H^+ ions in solution. Acidic solutions contain higher concentrations of H^+ ions than pure water and have pH values below 7. Strong acids tend to have pH values that range from 1 to 3. The hydrochloric acid (HCl) produced by the stomach to help digest food is a strong acid.

Bases A **base** is a compound that produces hydroxide (OH^-) ions in solution. Basic, or alkaline, solutions contain lower concentrations of H^+ ions than pure water and have pH values above 7. Strong bases, such as the lye (commonly NaOH) used in soapmaking, tend to have pH values ranging from 11 to 14.

Buffers The pH of the fluids within most cells in the human body must generally be kept between 6.5 and 7.5. If the pH is lower or higher, it will affect the chemical reactions that take place within the cells. Thus, controlling pH is important for maintaining homeostasis. One of the ways that organisms control pH is through dissolved compounds called buffers. **Buffers** are weak acids or bases that can react with strong acids or bases to prevent sharp, sudden changes in pH. Blood, for example, has a normal pH of 7.4. Sudden changes in blood pH are usually prevented by a number of chemical buffers, such as bicarbonate and phosphate ions.

Key Concept Buffers dissolved in life's fluids play an important role in maintaining homeostasis in organisms.

2.2 Assessment

Review Key Concepts

- a. Review** What does it mean when a molecule is said to be “polar”?

b. Explain How do hydrogen bonds between water molecules occur?

c. Use Models Use the structure of a water molecule to explain why it is polar.
- a. Review** Why is water such a good solvent?

b. Compare and Contrast What is the difference between a solution and a suspension?
- a. Review** What is an acid? What is a base?

b. Explain The acid hydrogen fluoride (HF) can be dissolved in pure water. Will the pH of the solution be greater or less than 7?

- c. Infer** During exercise, many chemical changes occur in the body, including a drop in blood pH, which can be very serious. How is the body able to cope with such changes?

WRITE ABOUT SCIENCE

Creative Writing

- Suppose you are a writer for a natural history magazine for children. This month's issue will feature insects. Write a paragraph explaining why some bugs, such as the water strider, can walk on water.



2.3

Carbon Compounds

THINK ABOUT IT In the early 1800s, many chemists called the compounds created by organisms “organic,” believing they were fundamentally different from compounds in nonliving things. Today we understand that the principles governing the chemistry of living and nonliving things are the same, but the term “organic chemistry” is still around. Today, organic chemistry means the study of compounds that contain bonds between carbon atoms, while inorganic chemistry is the study of all other compounds.

The Chemistry of Carbon

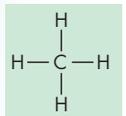
🔑 *What elements does carbon bond with to make up life’s molecules?*

Why is carbon so interesting that a whole branch of chemistry should be set aside just to study carbon compounds? There are two reasons for this. First, carbon atoms have four valence electrons, allowing them to form strong covalent bonds with many other elements.

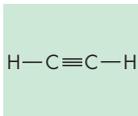
🔑 *Carbon can bond with many elements, including hydrogen, oxygen, phosphorus, sulfur, and nitrogen to form the molecules of life. Living organisms are made up of molecules that consist of carbon and these other elements.*

Even more important, one carbon atom can bond to another, which gives carbon the ability to form chains that are almost unlimited in length. These carbon-carbon bonds can be single, double, or triple covalent bonds. Chains of carbon atoms can even close up on themselves to form rings, as shown in **Figure 2–12**. Carbon has the ability to form millions of different large and complex structures. No other element even comes close to matching carbon’s versatility.

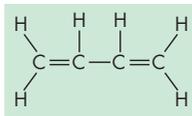
FIGURE 2–12 Carbon Structures Carbon can form single, double, or triple bonds with other carbon atoms. Each line between atoms in a molecular drawing represents one covalent bond. **Observing** *How many covalent bonds are there between the two carbon atoms in acetylene?*



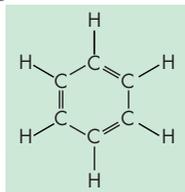
Methane



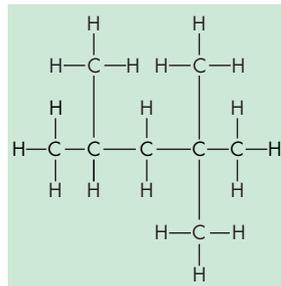
Acetylene



Butadiene



Benzene



Isooctane

Key Questions

🔑 *What elements does carbon bond with to make up life’s molecules?*

🔑 *What are the functions of each of the four groups of macromolecules?*

Vocabulary

- monomer • polymer •
- carbohydrate •
- monosaccharide •
- lipid • nucleic acid •
- nucleotide • protein •
- amino acid

Taking Notes

Compare/Contrast Table As you read, make a table that compares and contrasts the four groups of organic compounds.

Macromolecules

🔑 What are the functions of each of the four groups of macromolecules?

BUILD Vocabulary

WORD ORIGINS **Monomer** comes from the Greek words *monos*, meaning “single,” and *meros*, meaning “part.” *Monomer* means “single part.” The prefix *poly-* comes from the Greek word *polus*, meaning “many,” so **polymer** means “many parts.”

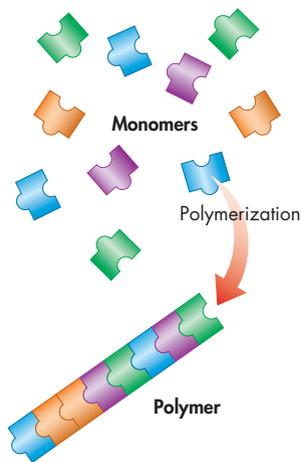


FIGURE 2-13 Polymerization When monomers join together, they form polymers. **Using Analogies** How are monomers similar to links in a chain?

Many of the organic compounds in living cells are so large that they are known as macromolecules, which means “giant molecules.” Macromolecules are made from thousands or even hundreds of thousands of smaller molecules.

Most macromolecules are formed by a process known as polymerization (pah lih mur ih ZAY shun), in which large compounds are built by joining smaller ones together. The smaller units, or **monomers**, join together to form **polymers**. The monomers in a polymer may be identical, like the links on a metal watch band; or the monomers may be different, like the beads in a multicolored necklace. **Figure 2-13** illustrates the process of polymerization.

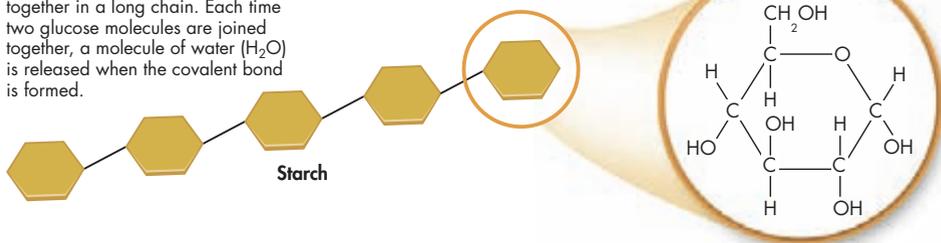
Biochemists sort the macromolecules found in living things into groups based on their chemical composition. The four major groups of macromolecules found in living things are carbohydrates, lipids, nucleic acids, and proteins. As you read about these molecules, compare their structures and functions.

Carbohydrates **Carbohydrates** are compounds made up of carbon, hydrogen, and oxygen atoms, usually in a ratio of 1 : 2 : 1. **🔑** Living things use carbohydrates as their main source of energy. Plants, some animals, and other organisms also use carbohydrates for structural purposes. The breakdown of sugars, such as glucose, supplies immediate energy for cell activities. Many organisms store extra sugar as complex carbohydrates known as starches. As shown in **Figure 2-14**, the monomers in starch polymers are sugar molecules.

▶ **Simple Sugars** Single sugar molecules are also known as **monosaccharides** (mahn oh SAK uh rydz). Besides glucose, monosaccharides include galactose, which is a component of milk, and fructose, which is found in many fruits. Ordinary table sugar, sucrose, consists of glucose and fructose. Sucrose is a disaccharide, a compound made by joining two simple sugars together.

FIGURE 2-14 Carbohydrates

Starches form when sugars join together in a long chain. Each time two glucose molecules are joined together, a molecule of water (H_2O) is released when the covalent bond is formed.



Comparing Fatty Acids

The table compares four different fatty acids. Although they all have the same number of carbon atoms, their properties vary.

- Interpret Data** Which of the four fatty acids is saturated? Which are unsaturated?
- Observe** How does melting point change as the number of carbon-carbon double bonds increases?

Effect of Carbon Bonds on Melting Point			
Fatty Acid	Number of Carbons	Number of Double Bonds	Melting Point (°C)
Stearic acid	18	0	69.6
Oleic acid	18	1	14
Linoleic acid	18	2	-5
Linolenic acid	18	3	-11

- Infer** If room temperature is 25°C, which fatty acid is a solid at room temperature? Which is liquid at room temperature?

FIGURE 2-16 Nucleic Acids The monomers that make up a nucleic acid are nucleotides. Each nucleotide has a 5-carbon sugar, a phosphate group, and a nitrogenous base.

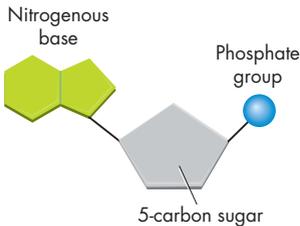
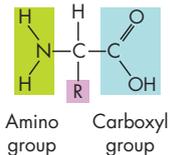
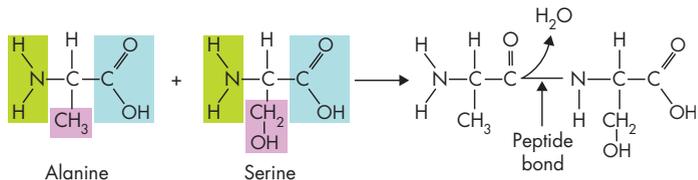


FIGURE 2-17 Amino Acids and Peptide Bonding Peptide bonds form between the amino group of one amino acid and the carboxyl group of another amino acid. A molecule of water (H_2O) is released when the bond is formed. Note that it is the variable R-group section of the molecule that distinguishes one amino acid from another.

General Structure of Amino Acids



Formation of Peptide Bond



Nucleic Acids Nucleic acids are macromolecules containing hydrogen, oxygen, nitrogen, carbon, and phosphorus. Nucleic acids are polymers assembled from individual monomers known as nucleotides. Nucleotides consist of three parts: a 5-carbon sugar, a phosphate group ($-PO_4$), and a nitrogenous base, as shown in Figure 2-16. Some nucleotides, including the compound known as adenosine triphosphate (ATP), play important roles in capturing and transferring chemical energy. Individual nucleotides can be joined by covalent bonds to form a polynucleotide, or nucleic acid.

Nucleic acids store and transmit hereditary, or genetic, information. There are two kinds of nucleic acids: ribonucleic acid (RNA) and deoxyribonucleic acid (DNA). As their names indicate, RNA contains the sugar ribose and DNA contains the sugar deoxyribose.

Protein Proteins are macromolecules that contain nitrogen as well as carbon, hydrogen, and oxygen. Proteins are polymers of molecules called amino acids, shown in Figure 2-17. Amino acids are compounds with an amino group ($-NH_2$) on one end and a carboxyl group ($-COOH$) on the other end. Covalent bonds called peptide bonds link amino acids together to form a polypeptide. A protein is a functional molecule built from one or more polypeptides. **Some proteins control the rate of reactions and regulate cell processes. Others form important cellular structures, while still others transport substances into or out of cells or help to fight disease.**

► **Structure and Function** More than 20 different amino acids are found in nature. All amino acids are identical in the regions where they may be joined together by covalent bonds. This uniformity allows any amino acid to be joined to any other amino acid—by bonding an amino group to a carboxyl group. Proteins are among the most diverse macromolecules. The reason is that amino acids differ from each other in a side chain called the R-group, which have a range of different properties. Some R-groups are acidic and some are basic. Some are polar, some are nonpolar, and some even contain large ring structures.

► **Levels of Organization** Amino acids are assembled into polypeptide chains according to instructions coded in DNA. To help understand these large molecules, scientists describe proteins as having four levels of structure. A protein's primary structure is the sequence of its amino acids. Secondary structure is the folding or coiling of the polypeptide chain. Tertiary structure is the complete, three-dimensional arrangement of a polypeptide chain. Proteins with more than one chain are said to have a fourth level of structure, describing the way in which the different polypeptides are arranged with respect to each other. **Figure 2–18** shows these four levels of structure in hemoglobin, a protein found in red blood cells that helps to transport oxygen in the bloodstream. The shape of a protein is maintained by a variety of forces, including ionic and covalent bonds, as well as van der Waals forces and hydrogen bonds. In the next lesson, you will learn why a protein's shape is so important.

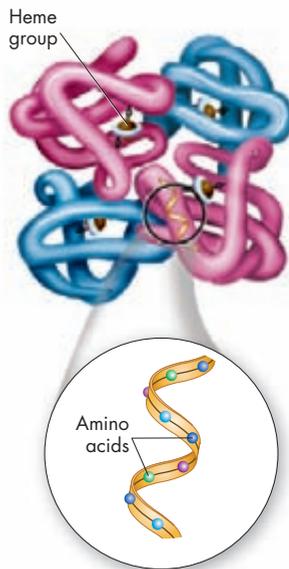


FIGURE 2–18 Protein Structure

The protein hemoglobin consists of four subunits. The iron-containing heme group in the center of each subunit gives hemoglobin its red color. An oxygen molecule binds tightly to each heme molecule. **Interpret Visuals** How many levels of organization does hemoglobin have?

2.3 Assessment

Review Key Concepts

- a. Review** What are the major elements of life?

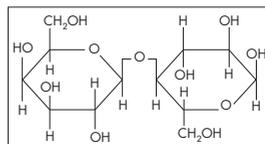
b. Relate Cause and Effect What properties of carbon explain carbon's ability to form different large and complex structures?
- a. Review** Name four groups of organic compounds found in living things.

b. Explain Describe at least one function of each group of organic compound.

c. Infer Why are proteins considered polymers but lipids not?

VISUAL THINKING

- A structural formula shows how the atoms in a compound are arranged.



- Observe** What atoms constitute the compound above?
- Classify** What class of macromolecule does the compound belong to?



2.4

Chemical Reactions and Enzymes

Key Questions

🔑 What happens to chemical bonds during chemical reactions?

🔑 How do energy changes affect whether a chemical reaction will occur?

🔑 What role do enzymes play in living things and what affects their function?

Vocabulary

chemical reaction • reactant • product • activation energy • catalyst • enzyme • substrate

Taking Notes

Concept Map As you read, make a concept map that shows the relationship among the vocabulary terms in this lesson.



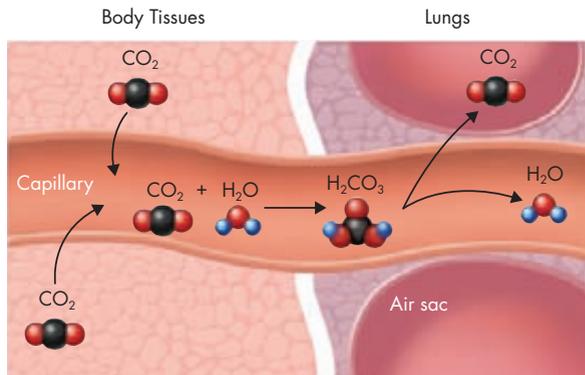
FIGURE 2-19 Carbon Dioxide in the Bloodstream As it enters the blood, carbon dioxide reacts with water to produce carbonic acid (H_2CO_3), which is highly soluble. This reaction enables the blood to carry carbon dioxide to the lungs. In the lungs, the reaction is reversed and produces carbon dioxide gas, which you exhale.

THINK ABOUT IT Living things, as you have seen, are made up of chemical compounds—some simple and some complex. But chemistry isn't just what life is made of—chemistry is also what life does. Everything that happens in an organism—its growth, its interaction with the environment, its reproduction, and even its movement—is based on chemical reactions.

Chemical Reactions

🔑 What happens to chemical bonds during chemical reactions?

A **chemical reaction** is a process that changes, or transforms, one set of chemicals into another. An important scientific principle is that mass and energy are conserved during chemical transformations. This is also true for chemical reactions that occur in living organisms. Some chemical reactions occur slowly, such as the combination of iron and oxygen to form an iron oxide called rust. Other reactions occur quickly. The elements or compounds that enter into a chemical reaction are known as **reactants**. The elements or compounds produced by a chemical reaction are known as **products**. **🔑** Chemical reactions involve changes in the chemical bonds that join atoms in compounds. An important chemical reaction in your bloodstream that enables carbon dioxide to be removed from the body is shown in **Figure 2-19**.



Energy in Reactions

 **How do energy changes affect whether a chemical reaction will occur?**

Energy is released or absorbed whenever chemical bonds are formed or broken. This means that chemical reactions also involve changes in energy.

Energy Changes Some chemical reactions release energy, and other reactions absorb it. Energy changes are one of the most important factors in determining whether a chemical reaction will occur.

 **Chemical reactions that release energy often occur on their own, or spontaneously. Chemical reactions that absorb energy will not occur without a source of energy.** An example of an energy-releasing reaction is the burning of hydrogen gas, in which hydrogen reacts with oxygen to produce water vapor.



The energy is released in the form of heat, and sometimes—when hydrogen gas explodes—light and sound.

The reverse reaction, in which water is changed into hydrogen and oxygen gas, absorbs so much energy that it generally doesn't occur by itself. In fact, the only practical way to reverse the reaction is to pass an electrical current through water to decompose water into hydrogen gas and oxygen gas. Thus, in one direction the reaction produces energy, and in the other direction the reaction requires energy.

Energy Sources In order to stay alive, organisms need to carry out reactions that require energy. Because matter and energy are conserved in chemical reactions, every organism must have a source of energy to carry out chemical reactions. Plants get that energy by trapping and storing the energy from sunlight in energy-rich compounds. Animals get their energy when they consume plants or other animals. Humans release the energy needed to grow tall, to breathe, to think, and even to dream through the chemical reactions that occur when we metabolize, or break down, digested food.

Activation Energy Chemical reactions that release energy do not always occur spontaneously. That's a good thing because if they did, the pages of this book might burst into flames. The cellulose in paper burns in the presence of oxygen and releases heat and light. However, paper burns only if you light it with a match, which supplies enough energy to get the reaction started. Chemists call the energy that is needed to get a reaction started the **activation energy**. As Figure 2–20 shows, activation energy is involved in chemical reactions regardless of whether the overall chemical reaction releases energy or absorbs energy.

FIGURE 2–20 Activation Energy

The peak of each graph represents the energy needed for the reaction to go forward. The difference between this required energy and the energy of the reactants is the activation energy. **Interpret Graphs** How do the energy of the reactants and products differ between an energy-absorbing reaction and an energy-releasing reaction?

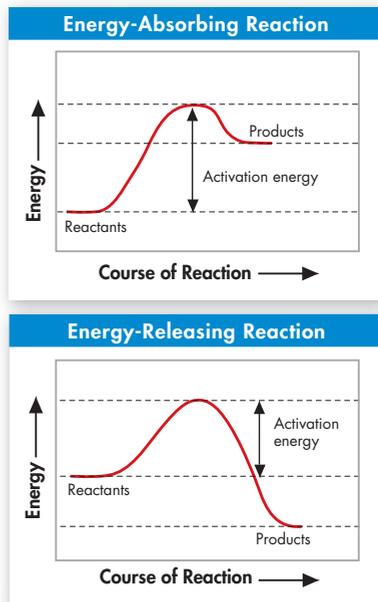
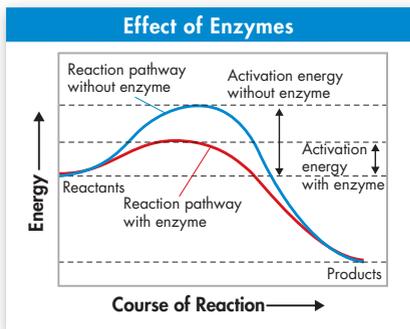


FIGURE 2-21 Effect of Enzymes

Notice how the addition of an enzyme lowers the activation energy in this reaction. The enzyme speeds up the reaction.



Enzymes

🔑 *What role do enzymes play in living things and what affects their function?*

Some chemical reactions that make life possible are too slow or have activation energies that are too high to make them practical for living tissue. These chemical reactions are made possible by a process that would make any chemist proud—cells make catalysts. A **catalyst** is a substance that speeds up the rate of a chemical reaction. Catalysts work by lowering a reaction's activation energy.

Nature's Catalysts **Enzymes** are proteins that act as biological catalysts. **🔑** **Enzymes speed up chemical reactions that take place in cells.** Like other catalysts, enzymes act by lowering the activation energies, as illustrated by the graph in Figure 2-21. Lowering the activation energy has a dramatic effect on how quickly the reaction is completed. How big an effect does it have? Consider the reaction in which carbon dioxide combines with water to produce carbonic acid.



Left to itself, this reaction is so slow that carbon dioxide might build up in the body faster than the bloodstream could remove it. Your bloodstream contains an enzyme called carbonic anhydrase that speeds up the reaction by a factor of 10 million. With carbonic anhydrase on the job, the reaction takes place immediately and carbon dioxide is removed from the blood quickly.

Enzymes are very specific, generally catalyzing only one chemical reaction. For this reason, part of an enzyme's name is usually derived from the reaction it catalyzes. Carbonic anhydrase gets its name because it also catalyzes the reverse reaction that removes water from carbonic acid.

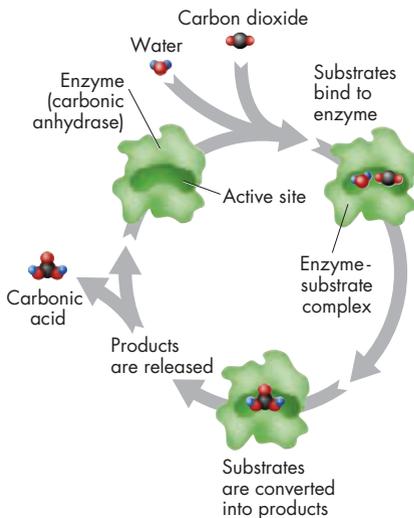
The Enzyme-Substrate Complex How do enzymes do their jobs? For a chemical reaction to take place, the reactants must collide with enough energy so that existing bonds will be broken and new bonds will be formed. If the reactants do not have enough energy, they will be unchanged after the collision.

Enzymes provide a site where reactants can be brought together to react. Such a site reduces the energy needed for reaction. The reactants of enzyme-catalyzed reactions are known as **substrates**. Figure 2-22 provides an example of an enzyme-catalyzed reaction.

FIGURE 2-22 An Enzyme-Catalyzed Reaction

The enzyme carbonic anhydrase converts the substrates carbon dioxide and water into carbonic acid (H_2CO_3).

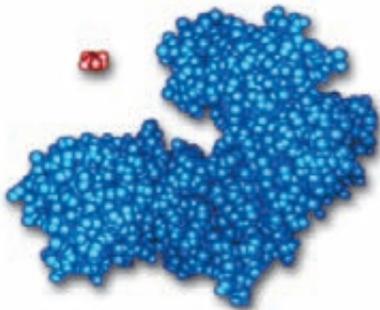
Predicting *What happens to the carbonic anhydrase after the products are released?*



The substrates bind to a site on the enzyme called the active site. The active site and the substrates have complementary shapes. The fit is so precise that the active site and substrates are often compared to a lock and key, as shown in **Figure 2–23**.

Regulation of Enzyme Activity Enzymes play essential roles in controlling chemical pathways, making materials that cells need, releasing energy, and transferring information. Because they are catalysts for reactions, enzymes can be affected by any variable that influences a chemical reaction.  **Temperature, pH, and regulatory molecules can affect the activity of enzymes.**

Many enzymes are affected by changes in temperature. Not surprisingly, those enzymes produced by human cells generally work best at temperatures close to 37°C, the normal temperature of the human body. Enzymes work best at certain ionic conditions and pH values. For example, the stomach enzyme pepsin, which begins protein digestion, works best under acidic conditions. In addition, the activities of most enzymes are regulated by molecules that carry chemical signals within cells, switching enzymes “on” or “off” as needed.



MYSTERY CLUE

The chemical reactions of living things, including those that require oxygen, occur more slowly at low temperatures. How would frigid antarctic waters affect the ice fish's need for oxygen?

VISUAL ANALOGY

UNLOCKING ENZYMES

FIGURE 2–23 This space-filling model shows how a substrate binds to an active site on an enzyme. The fit between an enzyme and its substrates is so specific it is often compared to a lock and key.

2.4 Assessment

Review Key Concepts

- a. Review** What happens to chemical bonds during chemical reactions?
b. Apply Concepts Why is the melting of ice not a chemical reaction?
- a. Review** What is activation energy?
b. Compare and Contrast Describe the difference between a reaction that occurs spontaneously and one that does not.
- a. Review** What are enzymes?
b. Explain Explain how enzymes work, including the role of the enzyme-substrate complex.

c. Use Analogies A change in pH can change the shape of a protein. How might a change in pH affect the function of an enzyme such as carbonic anhydrase? (*Hint*: Think about the analogy of the lock and key.)

VISUAL THINKING

- Make a model that demonstrates the fit between an enzyme and its substrate. Show your model to a friend or family member and explain how enzymes work using your model.

Pre-Lab: Temperature Affects Enzymes

Problem How does temperature affect the rate of an enzyme-catalyzed reaction?

Materials raw liver, forceps, petri dish, dropper pipette, 1% hydrogen peroxide solution, 25-mL graduated cylinder, 50-mL beaker, puréed liver, filter paper disks, paper towels, clock or watch with a second hand, water baths, thermometers, beaker tongs



Lab Manual Chapter 2 Lab

Skills Focus Form a Hypothesis, Design an Experiment, Measure, Interpret Graphs

Connect to the Big Idea Many chemical reactions in living organisms could not take place without enzymes. Enzymes catalyze the reactions that release energy from nutrients. They also catalyze the synthesis of the complex molecules that organisms need to grow and stay healthy. One factor that affects the action of enzymes is temperature. Think about why people store some foods in a refrigerator. The cold temperature limits the ability of enzymes to break down, or spoil, those foods.

Do high temperatures have the opposite effect on enzymes? Do they become more and more active as the temperature rises? In this lab, you will investigate the effect of temperature on an enzyme-catalyzed reaction.

Background Questions

- Review** Why do many reactions that occur in cells require enzymes? How do enzymes speed up chemical reactions?
- Review** Name three variables that can affect enzyme activity.
- Use Analogies** Use eggs and a frying pan on a stove as an analogy for reactants and an enzyme. Use the control knob on the stove burner as an analogy for how a variable can affect the action of an enzyme.

Pre-Lab Questions

Preview the procedure in the lab manual.

- Relate Cause and Effect** How will you know that a chemical reaction is taking place in Part A? How will you know in Part B?
- Control Variables** In Part B of the lab, which variable will you manipulate? Which variable is the dependent variable?
- Relate Cause and Effect** How is the time required for the filter-paper disk to float related to the activity of the enzyme?

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Untamed Science Watch the Untamed Science crew find answers to the mystery of why water is such a special compound.

Art Review Learn about ionic and covalent bonding.

Art in Motion View an animation that shows the process of a salt crystal dissolving in water.

Data Analysis Analyze data that explains the physiological effects of low pH, and the ecological impact of acid rain.

Visual Analogy Compare enzymes and substrates to a lock and key.

2 Study Guide

Big idea Matter and Energy

Chemical bonds join together the molecules and compounds of life. Water and carbon compounds play essential roles in organisms, which carry out chemical reactions in their daily life processes.

2.1 The Nature of Matter

The subatomic particles that make up atoms are protons, neutrons, and electrons.

All isotopes of an element have the same chemical properties, because they have the same number of electrons.

The physical and chemical properties of a compound are usually very different from those of the elements from which it is formed.

The main types of chemical bonds are ionic bonds and covalent bonds.

atom (34)	ionic bond (37)
nucleus (34)	ion (37)
electron (34)	covalent bond (37)
element (35)	molecule (37)
isotope (35)	van der Waals forces (38)
compound (36)	

2.2 Properties of Water

Water is a polar molecule. Therefore, it is able to form multiple hydrogen bonds, which account for many of its special properties.

Water's polarity gives it the ability to dissolve both ionic compounds and other polar molecules.

Buffers play an important role in maintaining homeostasis in organisms.

hydrogen bond (41)	solution (42)	pH scale (43)
cohesion (41)	solute (42)	acid (44)
adhesion (41)	solvent (42)	base (44)
mixture (42)	suspension (42)	buffer (44)

2.3 Carbon Compounds

Carbon can bond with many elements, including hydrogen, oxygen, phosphorus, sulfur, and nitrogen to form the molecules of life.

Living things use carbohydrates as their main source of energy. Plants, some animals, and other organisms also use carbohydrates for structural purposes.

Lipids can be used to store energy. Some lipids are important parts of biological membranes and waterproof coverings.

Nucleic acids store and transmit hereditary, or genetic, information.

Some proteins control the rate of reactions and regulate cell processes. Some proteins build tissues such as bone and muscle. Others transport materials or help to fight disease.

monomer (46)	nucleic acid (48)
polymer (46)	nucleotide (48)
carbohydrate (46)	protein (48)
monosaccharide (46)	amino acid (48)
lipid (47)	

2.4 Chemical Reactions and Enzymes

Chemical reactions always involve changes in the chemical bonds that join atoms in compounds.

Chemical reactions that release energy often occur spontaneously. Chemical reactions that absorb energy will not occur without a source of energy.

Enzymes speed up chemical reactions that take place in cells.

Temperature, pH, and regulatory molecules can affect the activity of enzymes.

chemical reaction (50)	catalyst (52)
reactant (50)	enzyme (52)
product (50)	substrate (52)
activation energy (51)	

Think Visually Create a table in which you compare the structures and functions of the following macromolecules: carbohydrates, lipids, proteins, and nucleic acids.

2 Assessment

2.1 The Nature of Matter

Understand Key Concepts

- The positively charged particle in an atom is called the
 - neutron.
 - ion.
 - proton.
 - electron.
- Two or more different atoms are combined in definite proportions in any
 - symbol.
 - isotope.
 - element.
 - compound.
- A covalent bond is formed by the
 - transfer of electrons.
 - sharing of electrons.
 - gaining of electrons.
 - losing of electrons.
- Explain the relationship among atoms, elements, and compounds.
- What is a radioactive isotope? Describe two scientific uses of radioactive isotopes.
- Describe how the atoms in a compound are held together.
- Distinguish among single, double, and triple covalent bonds.

Think Critically

- Use Models** Make a diagram like the one in **Figure 2-4** to show how chlorine and hydrogen form from the compound hydrogen chloride, HCl.
- Calculate** A nanometer (nm) is one billionth of a meter ($1 \text{ nm} = 10^{-9} \text{ m}$). If 100 million atoms make a row 1 cm in length, what is the diameter of one atom in nanometers? **MATH**

2.2 Properties of Water

Understand Key Concepts

- When you shake sugar and sand together in a test tube, you cause them to form a
 - compound.
 - mixture.
 - solution.
 - suspension.

- A compound that produces hydrogen ions in solution is a(n)
 - salt.
 - acid.
 - base.
 - polymer.
- Compared to most other substances, a great deal of heat is needed to raise the temperature of water by a given amount. This is because water
 - is an acid.
 - readily forms solutions.
 - has a high heat capacity.
 - acts as a buffer.
- Explain the properties of cohesion and adhesion. Give an example of each property.
- What is the relationship among solutions, solutes, and solvents?
- How are acids and bases different? How do their pH values differ?

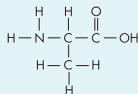
Think Critically

- Propose a Solution** Silica is a hard, glassy material that does not dissolve in water. Suppose sodium chloride is accidentally mixed with silica. Describe a way to remove the sodium chloride.
- Predict** As part of the digestive process, the human stomach produces hydrochloric acid, HCl. Sometimes excess acid causes discomfort. In such a case, a person might take an antacid such as magnesium hydroxide, $\text{Mg}(\text{OH})_2$. Explain how this substance can reduce the amount of acid in the stomach.

2.3 Carbon Compounds

Understand Key Concepts

- What does the following formula represent?



- a sugar
 - a starch
 - an amino acid
 - a fatty acid
- Proteins are polymers formed from
 - lipids.
 - carbohydrates.
 - amino acids.
 - nucleic acids.

20. Explain the relationship between monomers and polymers, using polysaccharides as an example.
21. Identify three major roles of proteins.
22. Describe the parts of a nucleotide.

Think Critically

23. **Design an Experiment** Suggest one or two simple experiments to determine whether a solid white substance is a lipid or a carbohydrate. What evidence would you need to support each hypothesis?
24. **Infer** Explain what the name “carbohydrate” might indicate about the chemical composition of sugars.

2.4 Chemical Reactions and Enzymes

Understand Key Concepts

25. An enzyme speeds up a reaction by
 - a. lowering the activation energy.
 - b. raising the activation energy.
 - c. releasing energy.
 - d. absorbing energy.
26. In a chemical reaction, a reactant binds to an enzyme at a region known as the
 - a. catalyst.
 - b. product.
 - c. substrate.
 - d. active site.
27. Describe the two types of energy changes that can occur in a chemical reaction.
28. What relationship exists between an enzyme and a catalyst?
29. Describe some factors that may influence enzyme activity.

Think Critically

30. **Infer** Why is it important that energy-releasing reactions take place in living organisms?
31. **Predict** Changing the temperature or pH can change an enzyme’s shape. Describe how changing the temperature or pH might affect the function of an enzyme.
32. **Use Analogies** Explain why a lock and key are used to describe the way an enzyme works. Describe any ways in which the analogy is not perfect.



solve the CHAPTER MYSTERY

THE GHOSTLY FISH

The oxygen-binding abilities of hemoglobin enable the blood of most fish to carry nearly 50 times the oxygen it would without the protein. The ghostly white appearance of the antarctic ice fish results from its clear blood—blood without hemoglobin. Ice fish, however, are able to survive without hemoglobin because of the properties of water at low temperatures.

Oxygen from the air dissolves in seawater, providing the oxygen that fish need to survive. Fish absorb dissolved oxygen directly through their gills, where it passes into their bloodstream. The solubility of oxygen is much greater at low temperatures. Therefore, the icy cold antarctic waters are particularly rich in oxygen.

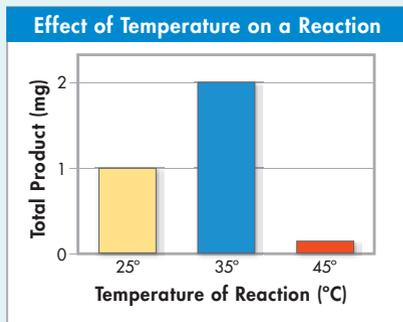
The large, well-developed gills and scaleless skin of ice fishes allow them to absorb oxygen efficiently from the water. Compared to red-blooded fishes, ice fishes have a higher blood volume, thinner blood, and larger hearts. So, their blood can carry more dissolved oxygen and the large hearts can pump the thinner blood through the body faster. These and other physical features, combined with the chemistry of oxygen in water at low temperatures, enable ice fish to survive where many other organisms cannot.

1. **Relate Cause and Effect** Ice fish produce anti-freeze proteins to keep their blood from freezing; their body temperature stays below 0°C. How does low body temperature affect the blood’s ability to carry dissolved oxygen?
2. **Infer** People living at high altitudes generally have more hemoglobin in their blood than people living at sea level. Why do you think this is so?
3. **Predict** If the antarctic oceans were to warm up, how might this affect ice fish?
4. **Connect to the Big idea** The chemical reactions in all living things slow down at low temperatures. Since some of the most important reactions in our body require oxygen, how would low temperatures affect the ice fish’s need for oxygen?

Connecting Concepts

Use Science Graphics

The following graph shows the total amount of product from a chemical reaction performed at three different temperatures. The same enzyme was involved in each case. Use the graph to answer questions 33–35.



33. **Interpret Graphs** At which temperature was the greatest amount of product formed?

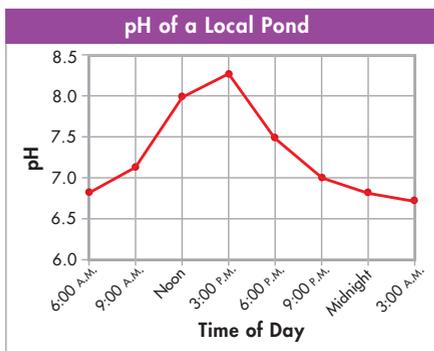
34. **Draw Conclusions** Describe the results of each reaction. How can you explain these results?
35. **Predict** A student performs the same chemical reaction at 30°C. Approximately how much product can she expect to obtain?

Write About Science

36. **Explanation** Write a paragraph that includes the following: (a) a description of the four major classes of organic compounds found in living things, and (b) a description of how these organic compounds are used by the human body.
37. **Assess the Big Idea** What properties of carbon allow it to play such a major role in the chemistry of living things?

Analyzing Data

A student measured the pH of water from a small pond at several intervals throughout the day. Use the graph to answer questions 38 and 39.



38. **Interpret Graphs** At what time of day is the pond most acidic?
- between noon and 6:00 P.M.
 - at noon
 - between midnight and 6:00 A.M.
 - at 6:00 P.M.
39. **Form a Hypothesis** Which of the following is the most reasonable hypothesis based on the results obtained?
- Pond water maintains constant pH throughout the day.
 - pH rises with increasing daylight and falls with decreasing daylight.
 - Living things cannot survive in this pond because enzymes will be destroyed.
 - pH is higher at night than during the day.

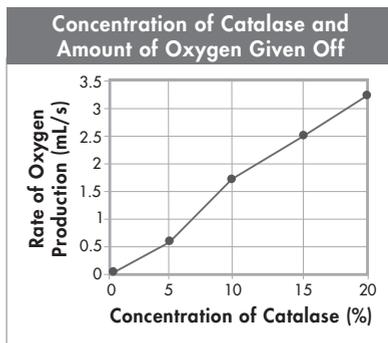
Standardized Test Prep

Multiple Choice

- The elements or compounds that enter into a chemical reaction are called
 - products.
 - catalysts.
 - active sites.
 - reactants.
- Chemical bonds that involve the total transfer of electrons from one atom or group of atoms to another are called
 - covalent bonds.
 - ionic bonds.
 - hydrogen bonds.
 - van der Waals bonds.
- Which of the following is NOT an organic molecule found in living organisms?
 - protein
 - nucleic acid
 - sodium chloride
 - lipid
- Which combination of particle and charge is correct?
 - proton: positively charged
 - electron: positively charged
 - neutron: negatively charged
 - electron: no charge
- In which of the following ways do isotopes of the same element differ?
 - in number of neutrons only
 - in number of protons only
 - in numbers of neutrons and protons
 - in number of neutrons and in mass
- Which of the following molecules is made up of glycerol and fatty acids?
 - sugars
 - starches
 - lipids
 - nucleic acids
- Nucleotides consist of a phosphate group, a nitrogenous base, and a
 - fatty acid.
 - lipid.
 - 5-carbon sugar.
 - 6-carbon sugar.

Questions 8–9

The enzyme catalase speeds up the chemical reaction that changes hydrogen peroxide into oxygen and water. The amount of oxygen given off is an indication of the rate of the reaction.



- Based on the graph, what can you conclude about the relationship between enzyme concentration and reaction rate?
 - Reaction rate decreases with increasing enzyme concentration.
 - Reaction rate increases with decreasing enzyme concentration.
 - Reaction rate increases with increasing enzyme concentration.
 - The variables are indirectly proportional.
- Which concentration of catalase will produce the fastest reaction rate?
 - 5%
 - 10%
 - 15%
 - 20%

Open-Ended Response

- List some of the properties of water that make it such a unique substance.

If You Have Trouble With . . .

Question	1	2	3	4	5	6	7	8	9	10
See Lesson	2.4	2.1	2.3	2.1	2.1	2.3	2.3	2.4	2.4	2.2

Unit Project

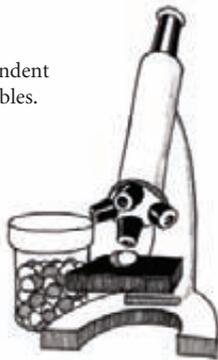
Design the Experiment

Did you ever wonder how a medication goes from the lab to your local drug store shelf? A lot of research and experimentation by scientists goes into testing a new medication to make sure it is safe and effective. Imagine you are a scientist working for a pharmaceutical company. Your current project is to test a new medication for heartburn. Heartburn is a painful condition in which acid inside the stomach backs up into the esophagus—the connection between your throat and stomach. This new medication helps neutralize stomach acid to prevent irritation.

Your Task Design *three* possible experiments to test the safety and effectiveness of the new heartburn medication. Before you begin, think about how you will know if the medication actually neutralizes stomach acid. Once you've written your procedures, you will propose the experiments to your company's Executive Board for Research and Development.

For each experiment,

- identify clear independent and dependent variables.
- identify a control.
- form a hypothesis—predict the results you'd expect to find if the medication worked.
- write a specific procedure that tests your hypothesis.



Reflection Questions

1. Score your experimental designs using the rubric below. What score did you give yourself?
2. What did you do well in this project?
3. What about your designs needs improvement?
4. Are there any ethical dilemmas related to your experiments? Explain.

Assessment Rubric

Score	Scientific Content	Quality of Experiments
4	Correctly and extensively applies knowledge and understanding of unit concepts (i.e., pH scale) to experimental designs and predictions.	Experimental designs are clever and effectively test the hypotheses. Experimental conditions are carefully controlled and variables are correctly identified.
3	Applies relevant knowledge and understanding of unit concepts (i.e., pH scale) to experimental designs and predictions.	Experimental designs are logical and test the hypotheses. Experimental conditions are controlled and variables are correctly identified.
2	Applies relevant knowledge and understanding of unit concepts (i.e., pH scale) incompletely to experimental designs and predictions.	Experimental designs need some revisions—some parts are unclear or do not fully test the hypotheses. Variables and controls need corrections.
1	Does not correctly apply knowledge and understanding of unit concepts (i.e., pH scale) to experimental designs and predictions.	Experimental designs are unclear and do not test the hypotheses. Variables and controls listed are incorrect or absent.