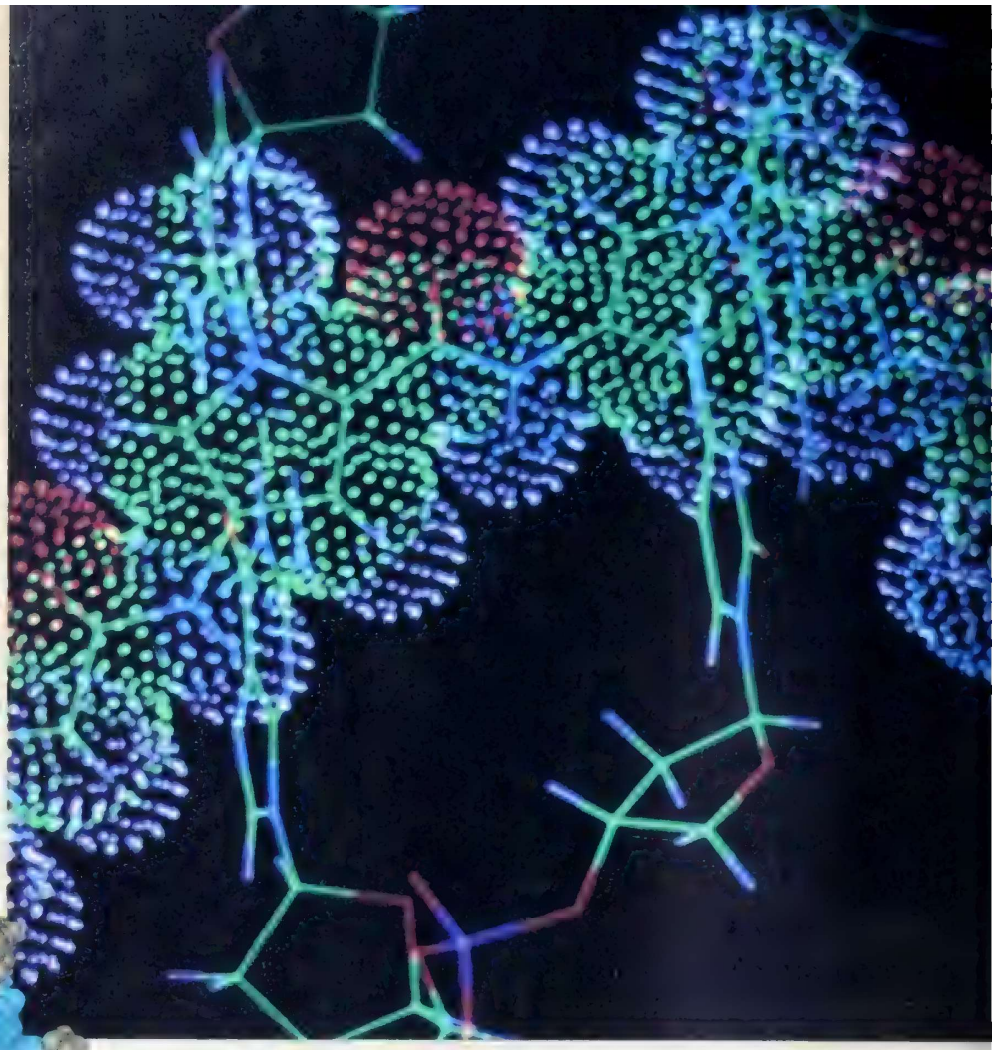
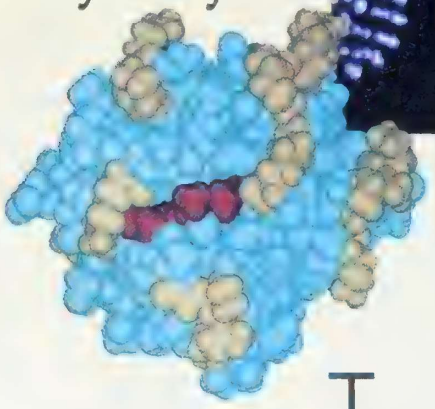
CHAPTER 4

The Chemical Basis of Life





A variety of important chemical substances are combined in specific ways to produce protein molecules, which are among the basic compounds of life.

There are no special elements found in living things. In fact, the molecules that make up a living cell do not, in and of themselves, have the property of life. Yet there can be no doubt that certain elements organized into a variety of molecules do indeed account for life. How, you might ask, is this possible? In a way, we will spend the rest of this book searching for an answer, an answer that will remain incomplete in the end. For life itself is not completely understood. But we can begin. And one way to start is by understanding life not as the property of one particular molecule but as something made possible by a large group of molecules. In this chapter you will learn about the molecules that give life to you and to all other organisms on Earth.

CHAPTER OUTLINE

4–1 Water
- Mixtures
- Solutions
- Suspensions

4–2 Chemical Compounds in Living Things
- Inorganic Compounds
- Organic Compounds
- Polymerization

4–3 Compounds of Life
- Carbohydrates
- Lipids
- Proteins
- Enzymes
- Nucleic Acids

4–1 Water

Section Objectives

- List some important properties of water.
- Describe the nature of mixtures, solutions, and suspensions.
- Define acids, bases, neutralization, and pH scale.

Someone once said that if there is magic on this planet, then it is to be found in water. Water? To most of us, water is so ordinary that it is of little interest and certainly does not seem magical. Yet how wrong we are!

Water is one of the few naturally occurring compounds that is liquid at the temperatures found on much of the Earth's surface. Unlike most other materials, water expands slightly as it makes the phase change from liquid to solid. This explains why ice floats at the surfaces of lakes and rivers rather than sinking to the bottom—a situation that might be disastrous for fish and plant life, to say nothing of the sport of skating!

Water is a most unusual molecule, with physical and chemical properties found in no other material. Water covers more than 75 percent of the Earth's surface and is the most abundant compound in nearly all living organisms.

The most important property of the water molecule is that due to an uneven distribution of electrons, it is slightly



Figure 4–1 *The importance of water to all living things cannot be denied—whether it's as a vital body fluid or as home to penguins in Antarctica. The Earth and its inhabitants cannot survive without water. Every attempt must be made to preserve this resource necessary to life.*

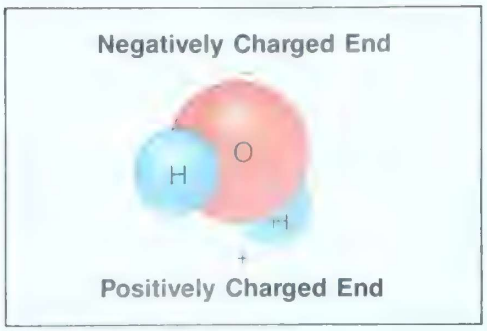


Figure 4–2 *The polarity of a water molecule explains why water is able to dissolve thousands of substances —whether they be ionically or covalently bonded. Which end of a water molecule is positive? Negative?*

charged on each end. See Figure 4–2. In this way, each water molecule is like a little magnet, with one pole near the nucleus of the oxygen atom and the other pole near the nuclei of the two hydrogen atoms. This polarity produces a strong attraction between individual water molecules and between water molecules and other charged molecules.

Mixtures

The slight charges of water molecules make them especially good at forming **mixtures**. A mixture is a substance composed of two or more elements or compounds that are mixed together but not chemically combined. Salt and pepper stirred together constitute a mixture. So do sugar and sand. Unlike chemical compounds, the substances that make up mixtures can be added in varying amounts and are not linked by chemical bonds.

Earth's atmosphere is a mixture of gases; soil is a mixture of individual solid particles; and living things are in part com-

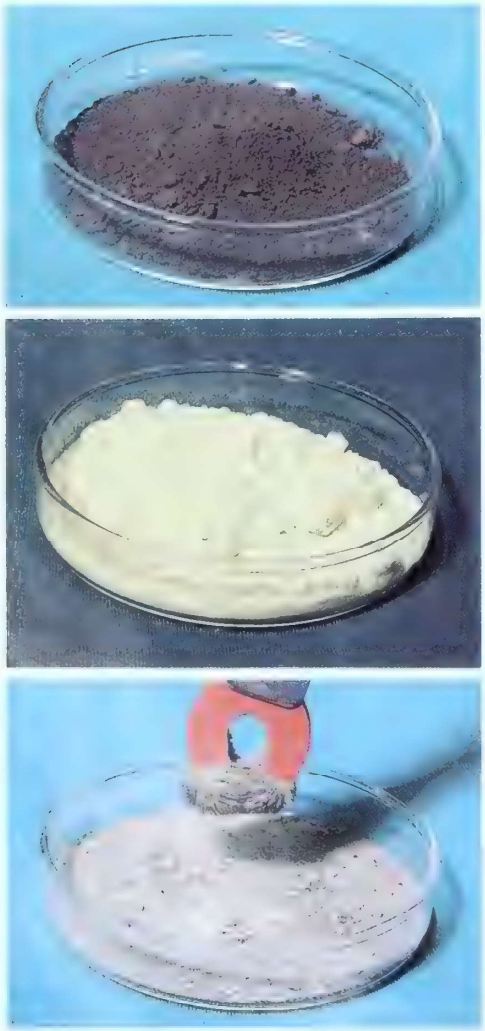


Figure 4–3 *By combining powdered iron (top) with powdered sulfur (center), an iron-sulfur mixture is formed. But because the substances making up this mixture are not linked by chemical bonds, they can be separated easily by a magnet (bottom). The gold miner can separate heavy pieces of gold from rock, sand, and dirt by shaking the mixture in a pan of water and letting the gold settle to the bottom (right).*



posed of mixtures involving water. The mixtures that are made with water can be of two important types: solutions and suspensions.

Solutions

If a cube of sugar is placed in a glass of warm water, the movement of the water molecules gradually breaks off single molecules from the sugar cube. These sugar molecules then become dispersed in the water and the sugar dissolves. See Figure 4-4. Before long, the sugar cube has completely disappeared and the sugar molecules are uniformly spread throughout the water, forming a **solution**. The sweet taste of the solution tells us that the sugar is still there. The sugar has undergone a physical but not a chemical change in forming a solution with water.

You have probably made solutions of water and many other materials, such as sugar, salt, tea, and cocoa. In these solutions, water is the **solvent**, or substance that does the dissolving. The substance that is dissolved—salt or tea, for example—is the **solute**. All solutions consist of a solvent and a solute. Without exaggeration, water is the greatest solvent in the world. This distinction is due largely to the charges at either end of the water molecule, which attract water molecules to other molecules whether they are positively or negatively charged.

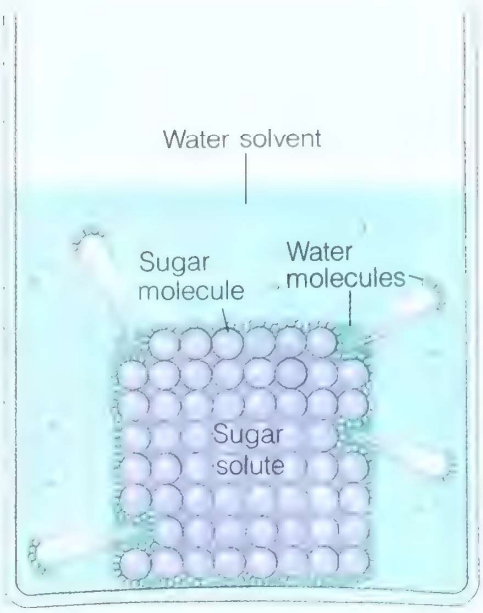


Figure 4–4 *The solution process first involves the separation of solute particles from the surface of the solid solute. Then the solute molecules enter the solution. Finally, the solute molecules are attracted to the solvent molecules.*

ACIDS When ionically bonded compounds dissolve in water, they often dissociate, or break apart, into individual ions. Common table salt (sodium chloride) is a good example.

$$\underset{\text{sodium chloride}}{NaCl} \rightarrow \underset{\text{sodium ion}}{Na^+} + \underset{\text{chloride ion}}{Cl^-}$$

The dissociation of sodium chloride produces the positive sodium ion (Na^+) and the negative chloride ion (Cl^-). Many other compounds follow this general pattern when they dissolve in water. One group of compounds, however, deserves special attention. Consider the following dissociation reaction:

$$\underset{\text{hydrochloric acid}}{HCl} \rightarrow \underset{\text{hydrogen ion}}{H^+} + \underset{\text{chloride ion}}{Cl^-}$$

At first glance this compound dissociates in the same way that salt does. Just like salt, it produces a chloride ion (Cl^-). But the hydrogen ion (H^+) that is produced is very different from the sodium ion (Na^+). The H^+ is the most chemically reactive ion known. It is a single proton, lacking any electrons. This absence of electrons enables the hydrogen ion to attack the chemical bonds in a wide variety of molecules.

Compounds that release hydrogen ions into solution are known as **acids**, and we know HCl as hydrochloric acid. Can you name some other examples of acids?

Figure 4–5 *Hydrochloric acid, HCl, is a strong acid present in the stomach that aids in the process of digestion. Here you see a fiber optic endoscopic image of the stomach lining.*



BASES **Bases** are compounds that release hydroxide ions (OH^-) into solution. Sodium hydroxide is an example of a base.

$$\underset{\text{sodium hydroxide}}{NaOH} \rightarrow \underset{\text{sodium ion}}{Na^+} + \underset{\text{hydroxide ion}}{OH^-}$$

Strong acids and bases are highly reactive chemical compounds. They can attack and break a variety of chemical bonds, thus making them potentially dangerous to living tissue.

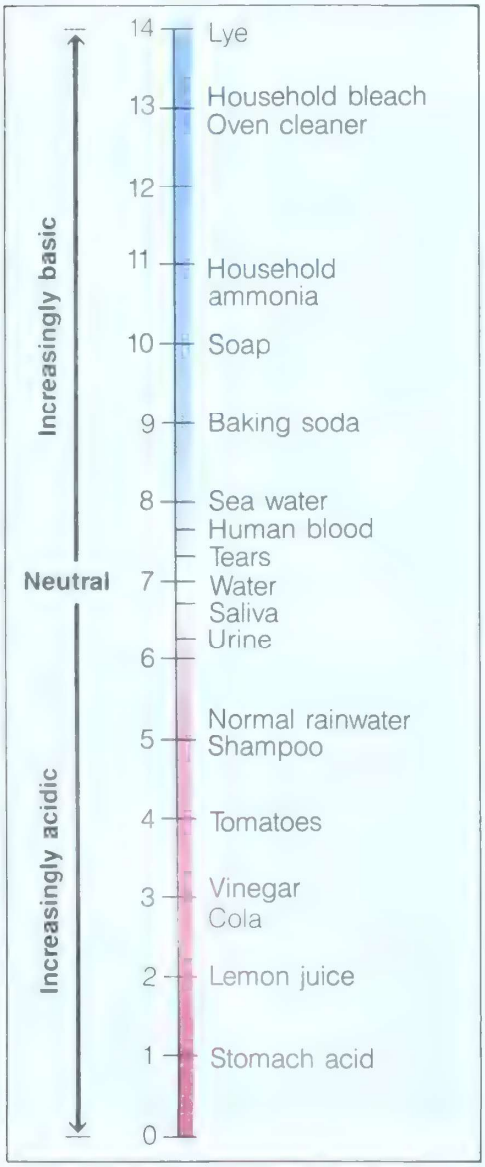
NEUTRALIZATION AND pH Mixing a strong acid and a strong base results in a reaction in which hydrogen ions and hydroxide ions react to form water. This type of reaction is called a **neutralization reaction**. Can you guess the reason for this name?

$$\underset{\text{hydrogen ion}}{H^+} + \underset{\text{hydroxide ion}}{OH^-} \rightarrow \underset{\text{water}}{H_2O}$$

If the quantities of acid and base being mixed are in perfect balance, the neutralized solution that results is neither acid nor base. The concentrations of hydrogen ions and hydroxide ions are equal. The relative concentrations of hydrogen ions and hydroxide ions in a solution is an important indicator of the properties of the solution. A measurement system known as the **pH scale** indicates the relative concentrations of these two ions. See Figure 4-6.

The pH scale ranges from 0 to 14. Pure water, in which the concentrations of H^+ and OH^- ions are equal, has a pH value of 7.0. Acids have pH values of less than 7. Strong acids, such as those that help digest food in the stomach, have pH values of 1 to 3. Bases have pH values greater than 7. Strong bases, like ammonia or lye, have high pH values, ranging from 11 to 13. The pH values within most cells range from 6.5 to 7.5. These near-neutral values are maintained by dissolved compounds that help prevent sharp, sudden swings of pH, which might cause damaging chemical changes within living tissues.

Figure 4-6 On the pH scale, 7 is neutral, acids are between 0 and 7, and bases are between 7 and 14. A difference of 1 between consecutive numbers on the scale is actually a difference of 10 times the relative strengths of the acids or bases. What cleaner is more basic? What body fluid is most acidic?



Suspensions

Some materials do not break into individual molecules when placed in water but still form pieces so small that they will not settle to the bottom of a container. The movement of water molecules keeps these small particles suspended. Such mixtures of water and nondissolved material are known as **suspensions**.

In living things, both solutions and suspensions are very important. A perfect example is the blood that circulates through your body. Blood, as you might have guessed, is mostly water. In that water are many dissolved compounds, including salt. So blood is a solution. But blood is also a suspen-



Figure 4–7 *Mixtures of water and nondissolved material are called suspensions. Oil and water (left) is a common suspension. Perhaps less familiar to you is the suspension circulating through your body—blood! Blood contains clotting structures, living cells, and other particles, all suspended in a solution of water and other dissolved compounds (right).*

sion. It contains tiny structures that aid in clotting, as well as living cells and other suspended particles. See Figure 4–7. These components do not dissolve in blood. Instead, they form a suspension that circulates through the body—an extremely vital suspension made possible by the most important molecule found in living things: water.

4–1 SECTION REVIEW

1. What are some important properties of water? What property accounts for its being the best solvent?
2. What is a mixture? What are two important types of mixtures? How do these two types differ?
3. What is a solution? A solvent? A solute?
4. Describe two important differences between acids and bases.
5. What is a neutralization reaction? Give an example.
6. Hydrogen fluoride (HF) is dissolved in pure water. Predict whether the pH of the solution will be greater than or less than 7.0.

Section Objectives

- Identify the four most abundant elements in living things.
- Compare inorganic compounds and organic compounds.
- Describe the properties that make carbon unique.
- Explain the importance of polymerization.

4–2 Chemical Compounds in Living Things

Although the Earth's crust contains 90 naturally occurring chemical elements, only 11 of these elements are common in living organisms. Another 20 are found in trace amounts. Just four elements—carbon, nitrogen, oxygen, and hydrogen—make up 96.3 percent of the total weight of the human body. **In varying combinations, the elements carbon, hydrogen, oxygen, and nitrogen make up practically all the chemical compounds in living things.** To make the study of these and all other chemical compounds easier, scientists have divided them into two groups: **organic compounds**, which contain carbon, and **inorganic compounds**, which do not.

Inorganic Compounds

Inorganic compounds are primarily those compounds that do not contain carbon. One exception to this definition is carbon dioxide, which although it does contain carbon is an inorganic compound. The natural world is dominated by such compounds. Water is inorganic, as are the minerals that make up most of the sand, soil, and stone of the Earth's landmasses.

Living things contain a great many inorganic compounds, ranging from water to carbon dioxide to calcium phosphate, a mineral from which bones are formed. The group of compounds known as salts that help to balance the pH of the blood are largely inorganic.

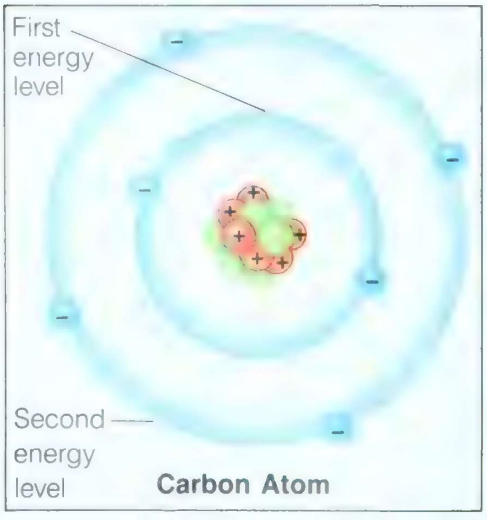
Organic Compounds

Organic compounds are carbon-containing compounds. A special branch of chemistry called organic chemistry deals with the chemistry of carbon and its more than 2 million compounds. Why is carbon so special?

Carbon is a unique element because of its remarkable ability to form covalent bonds that are strong and stable. You will recall that covalent bonds involve the sharing of electrons. Carbon has 6 electrons, 2 in the first energy level and 4 in the second. So only 4 of the 8 positions in its outermost energy level are filled. This means that carbon can form four single covalent bonds. The simplest compound that can be formed from carbon is methane, CH_4. Carbon can also form covalent bonds with oxygen, nitrogen, phosphorus, and sulfur atoms. The ability to bond easily and form compounds with these common elements would be enough to make carbon an interesting element. But there's more!

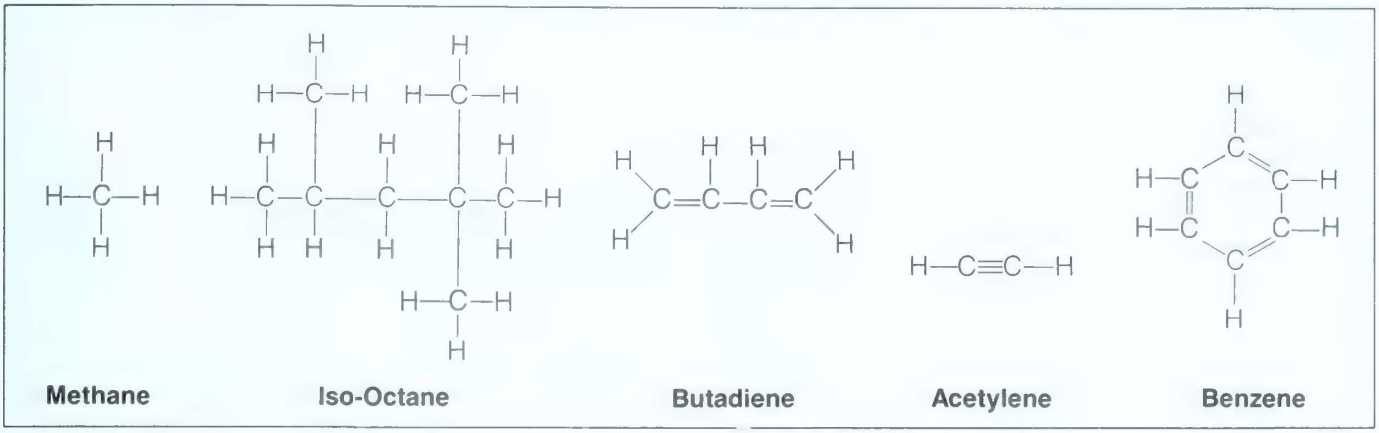
Carbon can form chains of almost unlimited length by bonding to other carbon atoms. The bonds between carbon atoms in these straight chains can be single, double, or triple

Figure 4–8 A carbon atom contains 6 protons, 6 neutrons, and 6 electrons. What is the arrangement of these 6 electrons?



covalent bonds—or combinations of these bonds. No other element can equal carbon in this respect. These chains can be closed on themselves to form rings. The ring structures may include single or double bonds, or a mixture of both. This gives even more variety to the kinds of molecules that carbon can form. See Figure 4-9.

Figure 4–9 *Because of its remarkable ability to form a variety of covalent bonds, carbon is an unparalleled element. Here you see some of the different types and arrangements of carbon bonds.*

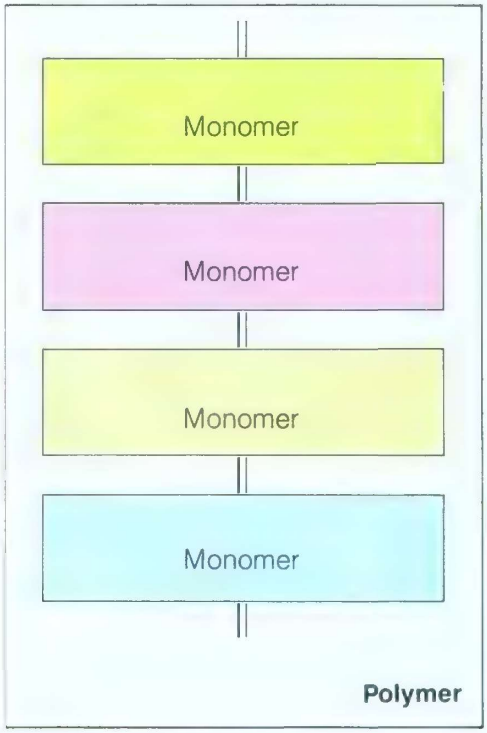


Polymerization

Many carbon-based compounds are formed by a chemical process known as **polymerization**, in which large compounds are constructed by joining together smaller compounds. The smaller compounds, or **monomers**, are joined together by chemical bonds to form **polymers**. Many polymers are so large that they are called **macromolecules**. As used here, the prefix *macro-* means giant.

Polymerization provides a way to form complex molecules by joining monomers together. The chemical diversity that polymerization allows living things is similar to the diversity that our alphabet allows us. Although there are only 26 letters in the alphabet, our ability to join them together (polymerize them) to form words gives us an almost infinite variety of possible words (molecules).

Figure 4–10 *A polymer is made up of a series of monomers.*



4-2 SECTION REVIEW

1. What is an inorganic compound? An organic compound?
2. Is the chemical composition of the human body similar to the composition of the Earth's crust? Explain your answer.
3. What special properties of carbon make it such an important compound in living things?
4. Describe the process of polymerization.

Section Objectives

- Identify the four groups of organic compounds found in living things.
- Describe the structure and function of each group of compounds of life.
- Explain how enzymes work and why they are important to living things.

4–3 Compounds of Life

The number of possible organic compounds is almost limitless. Fortunately, however, it is possible to classify many important organic compounds found in living things into four groups. **The four groups of organic compounds found in living things are carbohydrates, lipids, proteins, and nucleic acids.** By knowing the characteristics of just these groups, you will know a great deal about the chemistry of living things.

Carbohydrates

Although you may not realize it, you are probably quite familiar with the group of organic compounds known as **carbohydrates**. Carbohydrates, you see, are the molecules that we often call sugars. Carbohydrates contain carbon, hydrogen, and oxygen atoms in an approximate ratio of 1:2:1 (C:H:O). The simplest carbohydrates are called **monosaccharides**, meaning single sugars. Examples of monosaccharides include glucose, galactose, and fructose. Glucose is the sugar green plants produce during the food-making process. Galactose is found in milk. And fructose, the sweetest of these simple sugars, is found in fruits. The formula for all three of these simple sugars is $C_6H_{12}O_6$. What makes them different from one another is the arrangement of the individual atoms. See Figure 4–11.

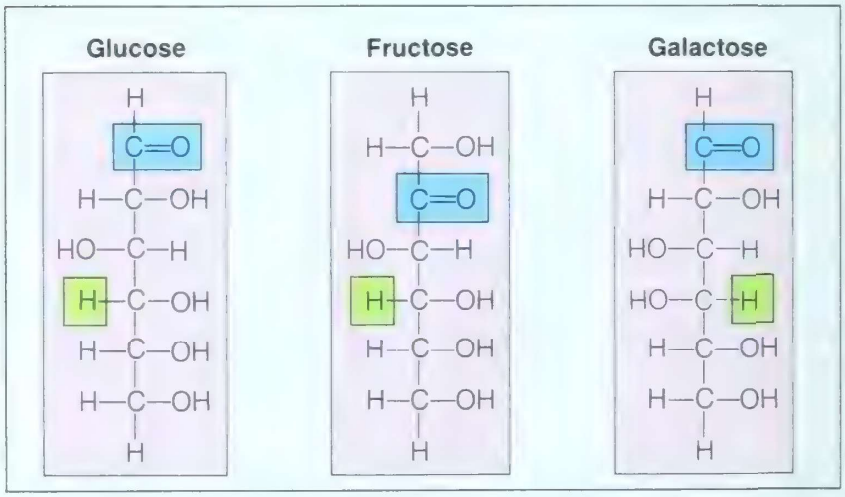


Figure 4–11 *Glucose, fructose, and galactose are single sugars, or monosaccharides. Sugars form a group of organic compounds known as carbohydrates. The formula for all three of these single sugars is $C_6H_{12}O_6$. What makes them different from one another?*

Sugars are important to living things because they contain a great deal of energy. This energy is stored in the chemical bonds that make up the carbohydrate molecules. When the chemical bonds are broken, the energy is released. Nearly all organisms use glucose as one of their basic energy sources. In Chapter 6, you will learn how the energy from sugar molecules is used by living things.

DEHYDRATION SYNTHESIS Complex carbohydrates are made by a process of polymerization in which two or more

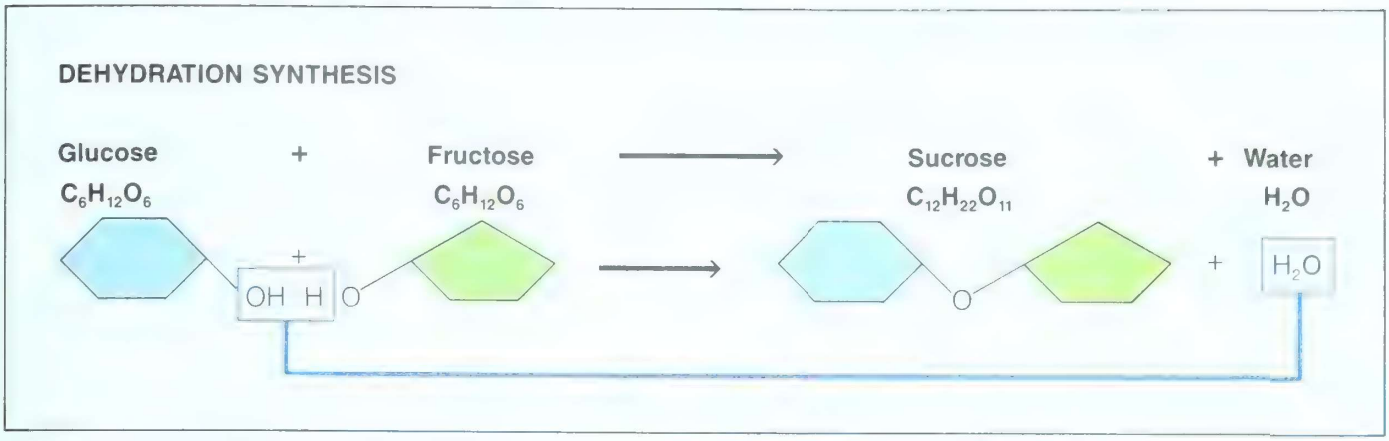


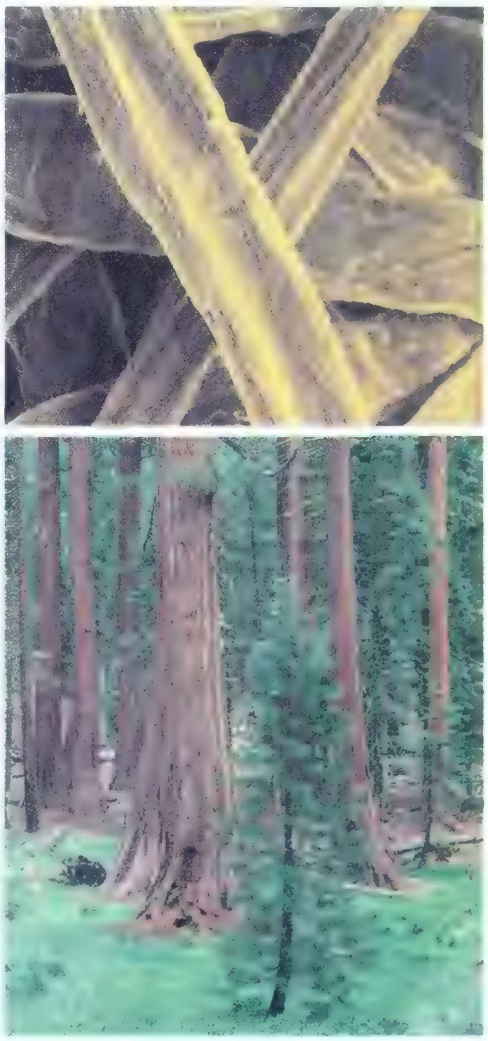
Figure 4–12 *The dehydration synthesis of a molecule of glucose and a molecule of fructose produces a molecule of sucrose and a molecule of water. What type of sugar is sucrose?*

monosaccharides are combined to form larger molecules. The chemical bond that links two simple sugars is formed between the -OH groups present in each molecule. As you can see from Figure 4–12, one OH from one molecule combines with the H of the OH from the other molecule. When the bond is complete, a molecule of water is removed from the two monosaccharides. Because of the loss of water, the joining of two sugars is known as **dehydration synthesis**. Dehydration means loss of water, and synthesis means putting together.

The compound formed from the joining of two single sugars in dehydration synthesis is called a **disaccharide**, or double sugar. Ordinary table sugar, or sucrose ($C_{12}H_{22}O_{11}$), is a disaccharide. Other disaccharides include maltose (malt sugar) and lactose (milk sugar).

POLYSACCHARIDES Very large molecules can be formed by joining together many monosaccharide units. Such compounds are known as **polysaccharides**. Polysaccharides are the form in which living things store excess sugar. One important polysaccharide is starch. Plants store excess sugar in the form of starch, which is present in potatoes and bread. Starch is a very large molecule formed by joining together hundreds of glucose molecules. Animals store their excess sugar in the form of glycogen in the liver and muscles. Glycogen is an even larger molecule consisting of hundreds or even thousands of glucose molecules. Glycogen is sometimes called animal starch. Do you see why? Because they are polymers of single sugars, both starch and glycogen help store energy in living things. Another polysaccharide is cellulose, which is found only in plants. Cellulose helps to support a plant by giving it strength and rigidity. Cellulose is the major component of wood. As such, it is often used as a building material or a printing material. The page upon which these words are printed is made principally of cellulose.

Figure 4–13 *Cellulose fibers (top) are extremely strong and thus able to support the enormous mass of these giant sequoia trees (bottom).*



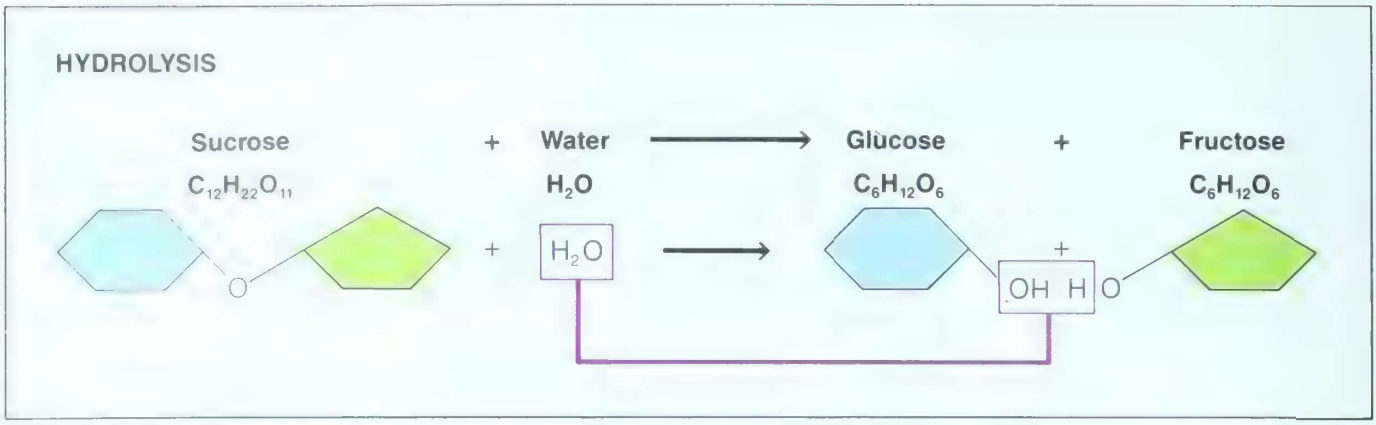


Figure 4–14 The hydrolysis of a molecule of sucrose produces a molecule of glucose and a molecule of fructose.

HYDROLYSIS When polysaccharides are split apart to again form monosaccharides, the dehydration synthesis reaction is reversed. This reverse reaction is known as **hydrolysis**. Hydrolysis, which means water splitting, is an appropriate name because a molecule of water is consumed by the chemical reaction that splits the bond between adjacent monosaccharides. Figure 4–14 illustrates the hydrolysis reaction.

Lipids

Lipids are organic compounds that are waxy or oily. Lipids have three major roles in living organisms. Like carbohydrates, lipids can be used to store energy. Lipids are used to form biological membranes. And certain lipids are used as chemical messengers. The common names by which we know lipids are fats, oils, and waxes. Generally, fats and waxes are solid at room temperature, whereas oils are liquid.

Many important lipids are formed from combinations of fatty acids and glycerol. Fatty acids are long chains of hydrogen and carbon atoms that have a carboxyl group attached at one

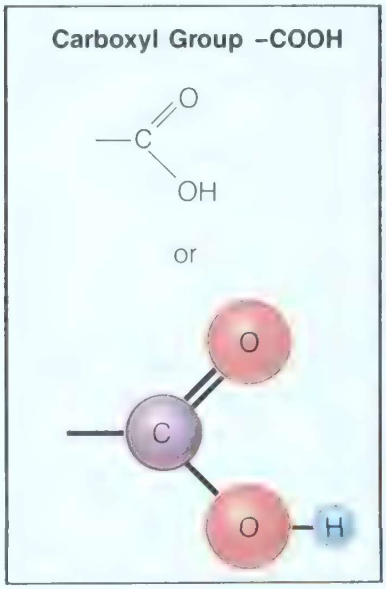




Figure 4–15 Lipids are organic compounds that are most familiar as fats, oils, and waxes (right). Many lipids are formed from fatty acids and glycerol. All fatty acids contain long chains of carbon and hydrogen atoms to which a carboxyl group is attached. A carboxyl group consists of 1 carbon atom, 1 hydrogen atom, and 2 oxygen atoms (left).

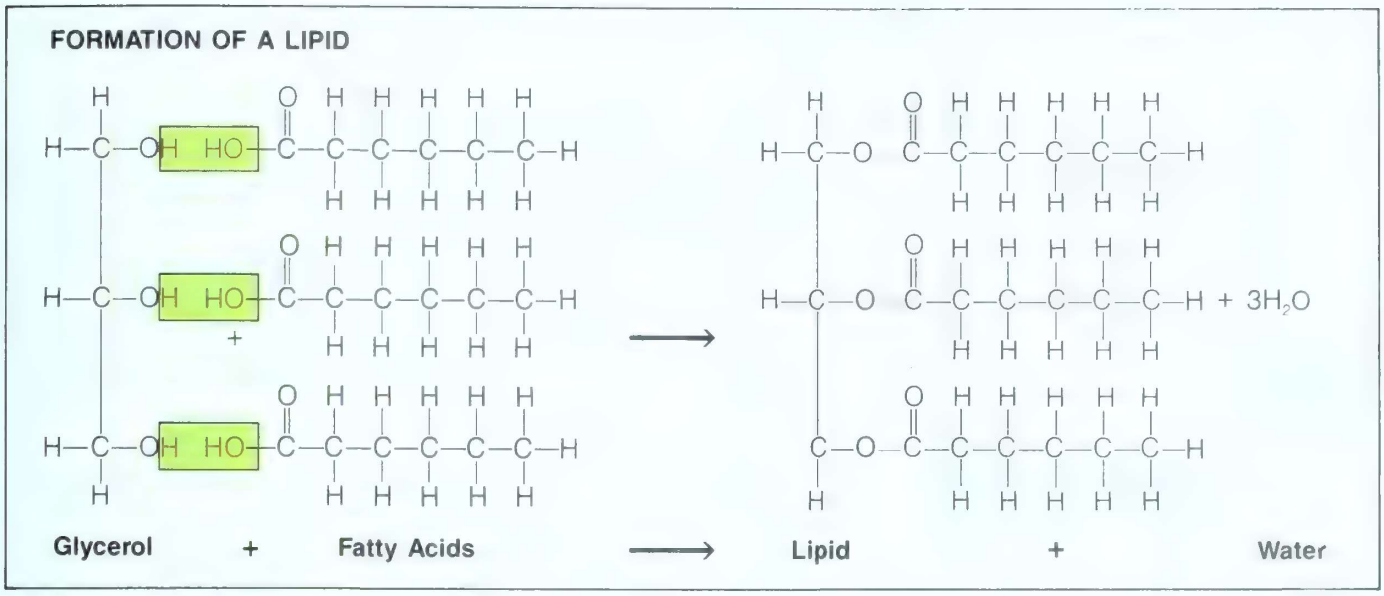


Figure 4–16 *The formation of a lipid involves the combination of three fatty-acid molecules with one glycerol molecule. What type of chemical reaction is taking place here?*

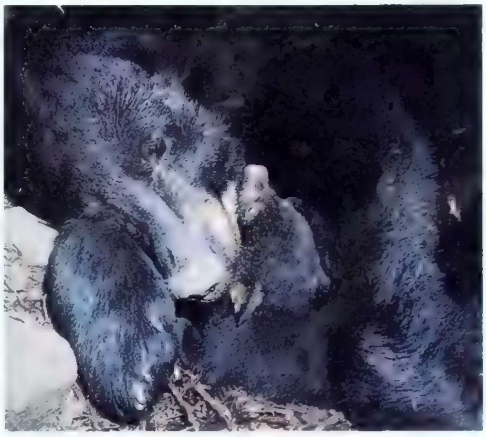
end. A carboxyl group is a chemical group consisting of one carbon atom, one hydrogen atom, and two oxygen atoms (–COOH). See Figure 4–15. Glycerol, which is an organic alcohol, contains three carbon atoms, each of which is attached to a hydroxyl (–OH) group. Many lipids are formed by the attachment of two or three fatty acids to glycerol. Figure 4–16 shows how fatty acids combine with glycerol to form a lipid. Can you recognize the chemical reaction that is responsible for the formation of the lipid?

SATURATED AND UNSATURATED LIPIDS If every carbon atom in a fatty acid chain is joined to another carbon atom by a single bond, the fatty acid is said to be saturated because it contains the maximum number of hydrogen atoms. If a pair of carbon atoms is joined by a double bond, the fatty acid is said to be unsaturated. Because of the double bond, it does not contain the maximum number of hydrogen atoms. If a fatty acid contains several double bonds, it is said to be polyunsaturated. Figure 4–18 on page 74 shows an example of each of these types of fatty acids.

Lipids made from saturated fatty acids are called saturated fats. Such fats are commonly found in meats and most dairy products. Lipids made from polyunsaturated fatty acids are called polyunsaturated fats. If that term seems familiar, it should. Polyunsaturated fats tend to be liquid at room temperature and are used in many cooking oils, such as sesame, peanut, and corn oil. Including polyunsaturated fats in the diet may help to prevent heart disease, a connection we will explore more completely in Chapter 41.

Both plants and animals use lipids as a means of storing energy. Because lipids contain far fewer oxygen atoms than carbohydrates do, they have less mass per unit of chemical energy than carbohydrates. In other words, when lipids are

Figure 4–17 *Animals use lipids as a means of storing energy. When black bears retreat to their dens in late autumn, they lie down and often cease to move, eat, drink, and eliminate wastes for about 5 months. Burning up nearly 4000 calories per day, a bear's metabolism operates at 50 to 80 percent its normal rate. The energy the bear needs comes primarily from its stored lipids.*



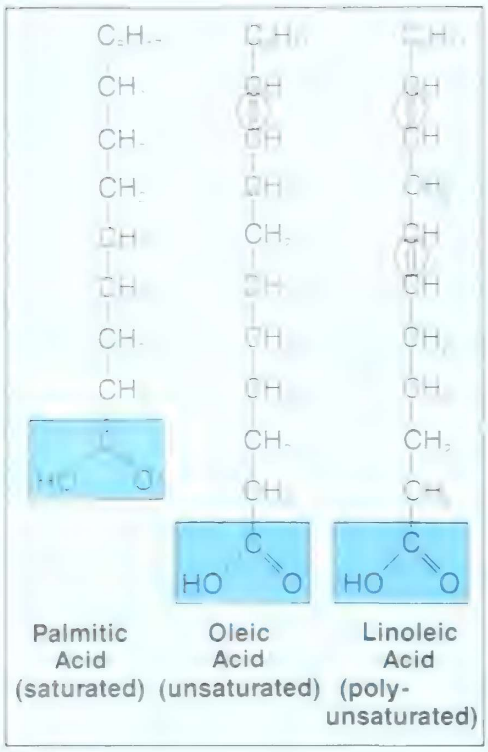
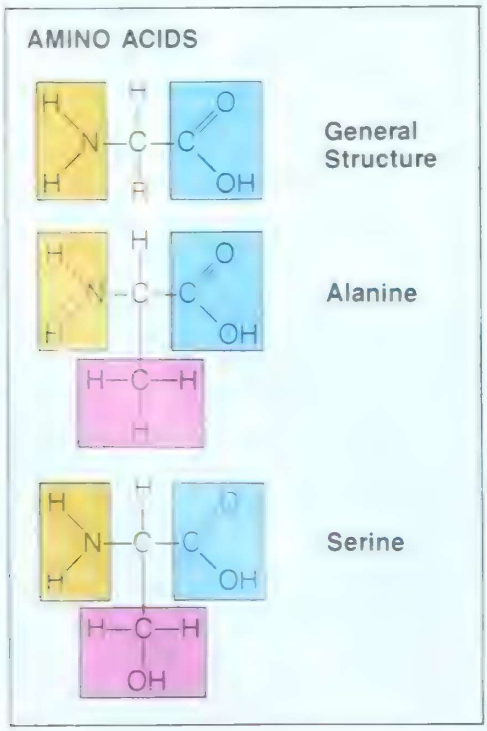


Figure 4–18 *Palmitic acid is a saturated fatty acid. Why do we say that oleic acid is unsaturated? Why is linoleic acid polyunsaturated?*

Figure 4–19 *All amino acids have an amino group ($-NH_2$) on one end and a carboxyl group (–COOH) on the other. They differ in a region of the molecule known as an R group.*



broken down, they produce more energy gram for gram than carbohydrates do.

STEROLS AND PHOSPHOLIPIDS Two other kinds of lipids are particularly important in living organisms. They are sterols and phospholipids. One of the most common sterols is a molecule called **cholesterol**. Cholesterol is an important part of many cells, but excessive cholesterol in the diet is a risk factor in heart disease. Sterol lipids play a number of important roles in building cells and carrying messages from one part of the body to another. We will learn more about sterols later in this textbook.

Phospholipids are molecules consisting of parts that dissolve well in water and parts that do not dissolve well in water. The portions of a phospholipid molecule that do not dissolve in water are oily. What happens to a molecule made of two very different parts? When phospholipid molecules are mixed with water, they may form small balloonlike structures known as liposomes. Each liposome is formed from a double layer, or bilayer, of lipid molecules. A liposome forms spontaneously, or without any outside help. It forms merely by the attraction of the oily parts of the lipid molecules for each other and by the attraction of the other parts of the lipid molecules for the surrounding water. The ability to form bilayers spontaneously is an important property of lipids that enables them to play a key role in forming cell membranes.

Proteins

Proteins are organic compounds that contain nitrogen in addition to carbon, hydrogen, and oxygen. Proteins are polymers of **amino acids**. An amino acid has an amino group ($-NH_2$) on one end and a carboxyl group (–COOH) on the other. These groups can form covalent bonds with each other. As a result of these bonds, very long chains of amino acids can be put together. All amino acids have a similar chemical structure, but they differ in a region of the molecule known as an R group. See Figure 4–19. There are more than 20 different amino acids, each of which contains a different R group.

PEPTIDES The covalent bond that joins two amino acids is known as a **peptide bond**. A molecule of water is lost when a peptide bond is formed between two amino acids. This reaction is another example of dehydration synthesis. A dipeptide is two amino acids joined by a peptide bond. A tripeptide contains three amino acids. And, as you might expect, a polypeptide is a long chain of amino acids.

PROTEIN STRUCTURE A complete protein contains one or more polypeptide chains and may contain a few other chemical groups that are important to its proper function. Proteins

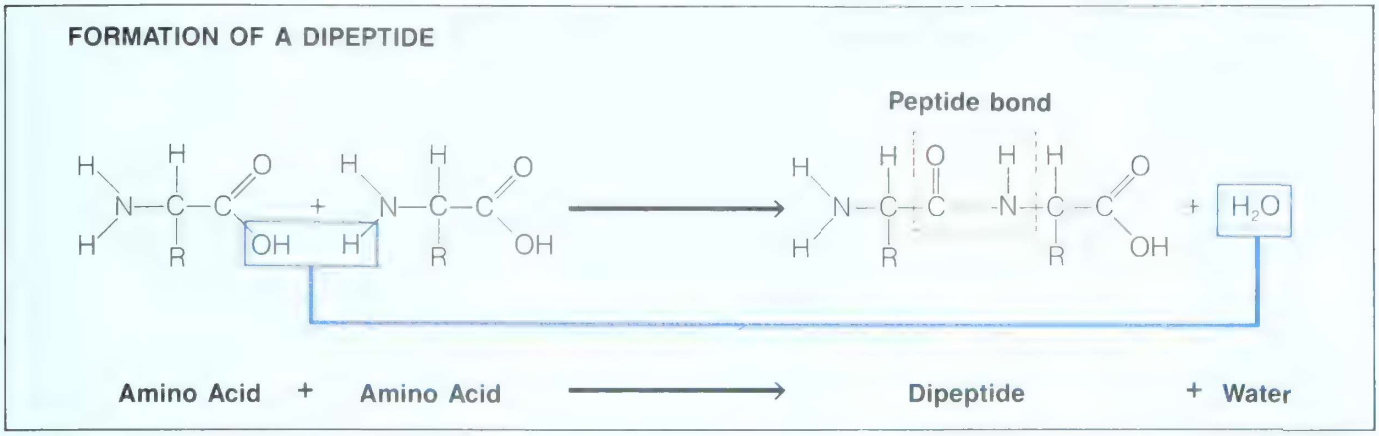


Figure 4-20 *Peptide bonds—which result in the formation of dipeptides, tripeptides, and polypeptides—form during the dehydration synthesis of amino acids.*

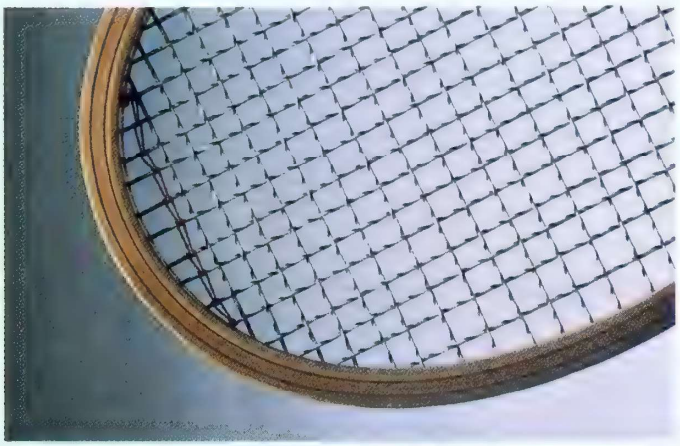
have numerous roles: They help to carry out chemical reactions; they pump small molecules in and out of cells; and they are even responsible for the ability of cells to move. The functions of proteins are at the very center of life itself.

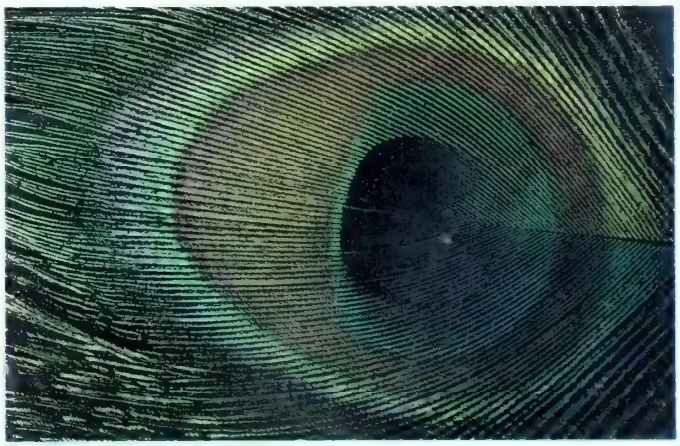
Enzymes

Chemical reactions make life possible. Hundreds of chemical reactions are involved in a process as simple as digesting a chocolate bar. If these chemical reactions proceeded too slowly, not only would the chocolate bar remain in the stomach for a long time, but the ordinary activities of life would come to a halt as well. Since this is not the case, some substances in the body must be responsible for speeding up the process.

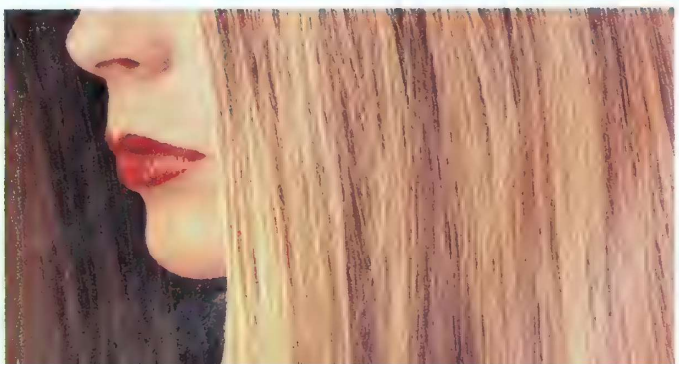
A substance that speeds up the rate of a chemical reaction is called a **catalyst**. Catalysts are not changed by the reactions

Figure 4–21 *Proteins are found in a variety of substances. These photographs show some of the more common proteins: collagen used in tennis racket strings (top, left), keratin in a peacock feather (top, right), silk from a spider's web (bottom, left), and human hair (bottom, right).*









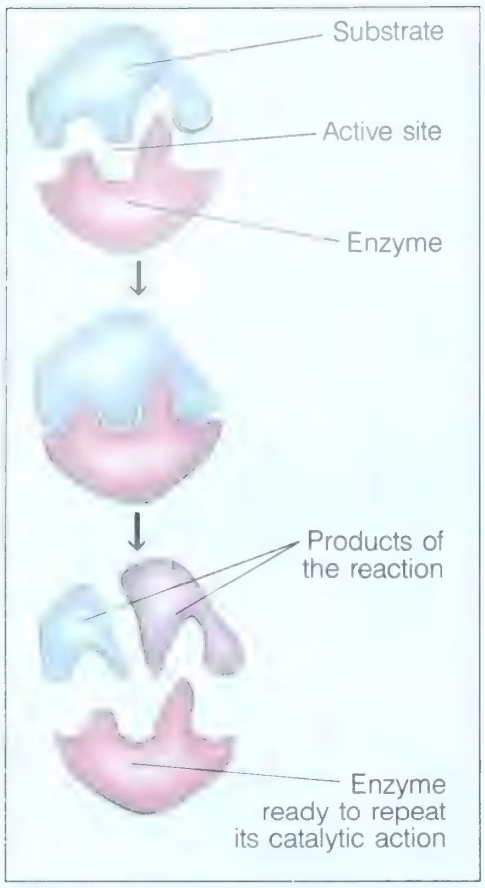
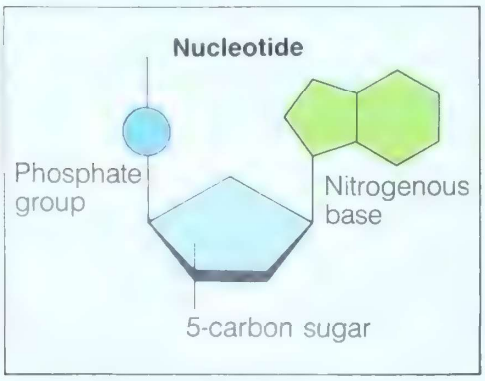


Figure 4–22 *In the lock-and-key hypothesis of enzyme action, an enzyme and its substrate bind at a region known as the active site in a manner similar to the way in which two pieces of a jigsaw puzzle fit together. What is the role of an enzyme?*

Figure 4-23 *Nucleic acids are polymers of nucleotides, which are molecules built up from three basic parts: a special 5-carbon sugar, a phosphate group, and a nitrogenous base.*



they promote, and therefore they are not used up during the reaction. Catalysts work by lowering the "start-up" energy of a reaction. Chemists often seek catalysts that will speed up reactions important to industry. Living organisms have gone the industrial chemist one better—they contain their own special catalysts, which are known as **enzymes**.

With a few exceptions, enzymes are proteins. Understanding their function is an important part of the study of proteins. Simple cells may have as many as 2000 different enzymes, each one catalyzing a different reaction. An enzyme may accelerate a reaction by a factor of 10^{10}—that is, making it happen 10,000,000,000 times faster! Thus a reaction that might take as long as 1500 years without an enzyme can be completed in just 5 seconds!

Enzymes speed up a reaction by binding to the reactants, which, as you may recall, are the substances that enter into a chemical reaction. The reactants that are affected by an enzyme are known as **substrates**. Substrates bind to enzymes at a region known as the **active site**.

The way in which a chemical reaction is catalyzed varies from one enzyme to another. An enzyme can catalyze a reaction by holding two substrates in positions in which they can react with each other. Or an enzyme can catalyze a reaction by twisting a substrate molecule slightly so that a chemical bond is weakened and broken.

Enzymes are very specific. A particular enzyme can catalyze only one particular chemical reaction involving specific substrates. Scientists theorize that this has something to do with the shape of the enzyme's active site. In fact, the fit between an enzyme's active site and its substrate is often compared to that of a lock and key.

Enzymes are important in regulating chemical pathways, synthesizing materials needed by cells, releasing energy, and transferring information. You will discover that enzymes are involved in digestion, respiration, reproduction, vision, movement, thought, and even in the making of other enzymes.

Nucleic Acids

Nucleic acids are large complex organic molecules composed of carbon, oxygen, hydrogen, nitrogen, and phosphorus atoms. Nucleic acids are polymers of individual monomers known as **nucleotides**. Nucleotides are molecules built up from three basic parts: a special 5-carbon sugar, a phosphate group, and a molecule generally known as a nitrogenous base. See Figure 4–23. Individual nucleotides can be linked together by covalent bonds to form a polynucleotide. There are two basic kinds of nucleic acids: **ribonucleic acid (RNA)**, which contains the sugar ribose, and **deoxyribonucleic acid (DNA)**, which contains the sugar deoxyribose. Despite their name, nucleic acids are not strongly acidic.

Nucleic acids store and transmit the genetic information that is responsible for life itself. How they do this, and how that information is decoded and transferred, is a fascinating story that we will leave for Chapter 7.

4-3 SECTION REVIEW

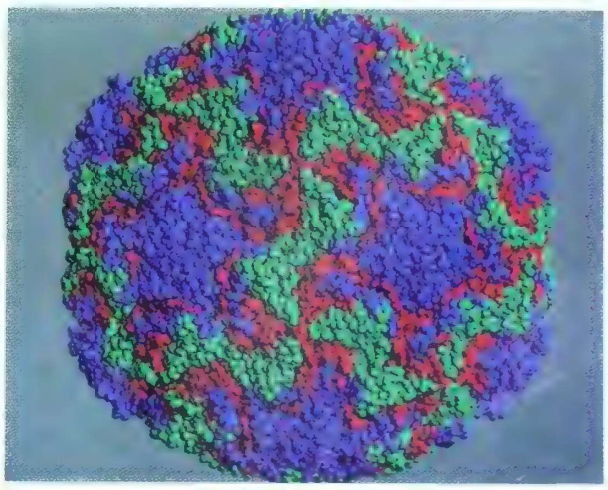
1. What are the four groups of organic compounds found in living things? Give an example of each.
2. Distinguish between monosaccharides, disaccharides, and polysaccharides.
3. What are lipids? How are they important to living things?
4. Describe the structure of a protein.
5. What is an enzyme? What is its function in living things?
6. Describe the structure and function of nucleic acids. What are two important nucleic acids?

SCIENCE, TECHNOLOGY, AND SOCIETY BREAKTHROUGH

The Structure of Proteins

Although proteins are among the largest of all macromolecules, it is sometimes possible to determine their detailed structure, including the position of every atom. This is done with the aid of a technique called X-ray crystallography.

The first, and often the trickiest, step in the procedure is to grow small crystals of a protein—often no larger than a grain of salt (0.1 mm). These protein crystals are then placed in a finely tuned beam of X-rays. As the X-rays pass through the crystal, they are scattered in a pattern that is recorded on film and then analyzed by computers. These X-ray scattering patterns contain enough information to allow scientists to build a complete model of the protein. The accompanying photograph, showing the arrangement of proteins on the surface of a common cold virus, was obtained by this technique. X-ray crystallography is a powerful scientific tool that enables us to visualize protein structure and understand the biological activities of complex molecules.



LABORATORY INVESTIGATION

TESTING ENZYME ACTIVITY

PROBLEM

How does pH influence the activity of the enzyme catalase?

MATERIALS *(per group)*

5 125-mL flasks	0.1 M hydrochloric acid
graduated cylinder	3% hydrogen peroxide
petri dish	liver puree (catalase)
3 medicine droppers	small piece of raw beef liver
stirring rod	glass-marking pencil
hydrion (pH) papers	safety goggles
0.1 M sodium hydroxide	

PROCEDURE

1. Prepare an appropriate data table on a separate sheet of paper.
2. Put on safety goggles. Put a small piece of raw liver in an open petri dish. Using a medicine dropper, put a drop of hydrogen peroxide on the liver. **CAUTION:** *Hydrogen peroxide can be irritating to skin and eyes. If you spill any on yourself or your clothes, wash it off immediately.* Observe what happens. Liver contains the enzyme catalase, which breaks down hydrogen peroxide formed in cells. When hydrogen peroxide is broken down by catalase, bubbles of oxygen gas are released.
3. Using the glass-marking pencil, number the flasks from 1 through 5. With a clean medicine dropper, put 10 drops of water in flask 1. Using a graduated cylinder, measure out 5 mL of hydrochloric acid and add it to the water in the flask. **CAUTION:** *When diluting an acid, always pour the acid into the water.* Rinse the dropper and the cylinder.
4. Prepare the following solutions for the remaining flasks. Use procedures similar to those used in step 3. Flask 2: 10 drops of hydrochloric acid added to 5 mL of water. Flask 3: 5.5 mL of water only. Flask 4: 10 drops of sodium hydroxide added to 5 mL of water. Flask 5: 5 mL of sodium hydroxide added to 10 drops of water.
5. Using the stirring rod, put a drop of the solution from flask 1 on a piece of hydrion paper to measure the solution's pH. Record the results in the data table. Repeat the procedure for the solutions in flasks 2, 3, 4, and 5.
6. Using the clean graduated cylinder, add 5 mL of hydrogen peroxide to each flask. Look for bubbles. Identify the amount of activity in each flask by assigning it a number from 0 to 3, when 0 means no bubbles, 1 means few bubbles, and 3 means many bubbles.
7. Rinse out the five flasks thoroughly. Repeat steps 3 through 5.
8. Using a clean medicine dropper, add 5 drops of liver puree to each solution and mix well by swirling the flask.
9. Using the clean graduated cylinder, add 5 mL of hydrogen peroxide to each flask. Identify the amount of activity in each flask from 0 to 3, as you did in step 6.

OBSERVATIONS

1. What happened when hydrogen peroxide was added to each flask without liver puree?
2. What happened when hydrogen peroxide was added to each flask with liver puree?
3. In which flask(s) was the bubble activity greatest? What was the pH of the solution(s)?

ANALYSIS AND CONCLUSIONS

1. What is the purpose of the flasks without liver puree?
2. At what pH does catalase function best? How do you know?
3. If a strong acid has a pH of 1, a strong base, 14, and water, 7, does catalase work best in an acid, base, or neutral environment? Explain.
4. What conclusions can you draw about the pH in body cells?
5. Predict ways in which pH affects the chemical reactions in living cells.

STUDENT STUDY GUIDE

SUMMARIZING THE CONCEPTS

The key concepts in each section of this chapter are listed below to help you review the chapter content. Make sure you understand each concept and its relationship to other concepts and to the theme of this chapter.

4–1 Water

- Water is the most abundant compound in the majority of living organisms.
- A mixture is a substance composed of two or more compounds mixed together but not chemically combined.
- A solution consists of a solvent and solute.
- Compounds that release hydrogen ions (H^+) in solution are acids. Those that release hydroxide ions (OH^-) are bases.

4–2 Chemical Compounds in Living Things

- The four most abundant elements in living things are carbon, hydrogen, oxygen, and nitrogen.
- Inorganic compounds are primarily those that do not contain carbon. Organic compounds contain carbon.
- Polymerization is the process in which polymers are made by joining monomers.

4–3 Compounds of Life

- The four groups of organic compounds found in living things are carbohydrates, lipids, proteins, and nucleic acids.
- The polymerization of two monosaccharides to form a disaccharide occurs as a result of dehydration synthesis. Hydrolysis is the reverse reaction.
- Lipids are important sources of energy and compounds of biological membranes.
- Proteins are polymers of amino acids.
- Enzymes are, with a few exceptions, proteins. Enzymes are catalysts.
- Nucleic acids are polymers of nucleotides.

REVIEWING KEY TERMS

Vocabulary terms are important to your understanding of biology. The key terms listed below are those you should be especially familiar with. Review these terms and their meanings. Then use each term in a complete sentence. If you are not sure of a term's meaning, return to the appropriate section and review its definition.

4–1 Water

mixture
solution
solvent
solute
acid
base
neutralization reaction
pH scale
suspension

4–2 Chemical Compounds in Living Things

organic compound
inorganic compound
polymerization
monomer
polymer
macromolecule

4–3 Compounds of Life

carbohydrate
monosaccharide
dehydration synthesis
disaccharide
polysaccharide
hydrolysis
lipid
cholesterol
protein
amino acid
peptide bond
catalyst
enzyme
substrate
active site
nucleic acid
nucleotide
ribonucleic acid (RNA)
deoxyribonucleic acid (DNA)

CHAPTER REVIEW

CONTENT REVIEW

Multiple Choice

Choose the letter of the answer that best completes each statement.

1. The most abundant compound in most living things is
   a. carbon dioxide.
   b. water.
   c. sodium chloride.
   d. hydrochloric acid.
2. A strong acid has a pH of
   a. 14.
   b. 7.
   c. 5.
   d. 2.
3. Which group of elements combine to form practically all the chemical compounds in living things?
   a. carbon, hydrogen, oxygen, nitrogen
   b. carbon, hydrogen, phosphorus, nitrogen
   c. carbon, sodium, chlorine, oxygen
   d. sulfur, phosphorus, carbon, oxygen
4. Proteins are polymers of
   a. fatty acids.
   b. amino acids.
   c. sterols.
   d. nucleic acids.
5. The region on an enzyme to which a substrate binds is called the
   a. catalyst.
   b. activated complex.
   c. active site.
   d. carboxyl group.
6. The function of nucleic acids is related to
   a. energy release.
   b. enzyme formation.
   c. transmission of genetic information.
   d. catalyzing chemical reactions.
7. When phospholipid molecules are mixed with water, they form small balloonlike structures called
   a. liposomes.
   b. vacuoles.
   c. lysosomes.
   d. dipeptides.
8. The polysaccharide found only in plants is
   a. glucose.
   b. glycogen.
   c. cholesterol.
   d. cellulose.

True or False

Determine whether each statement is true or false. If it is true, write "true." If it is false, change the underlined word or words to make the statement true.

1. A mixture of oil and vinegar is an example of a <u>solution</u>.
2. Compounds that release hydrogen ions into solution are known as <u>bases</u>.
3. Compounds that contain carbon are called <u>organic</u> compounds.
4. The simplest carbohydrates are called <u>disaccharides</u>.
5. A common sterol whose excessive intake is related to heart disease is <u>cholesterol</u>.
6. Individual monomers of nucleic acids are known as <u>nucleotides</u>.
7. Including <u>saturated</u> fats in the diet may help to prevent heart disease.
8. Polysaccharides are split apart to form monosaccharides in a reaction called <u>hydrolysis</u>.

Word Relationships

In each of the following sets of terms, three of the terms are related. One term does not belong. Determine the characteristic common to three of the terms and then identify the term that does not belong.

1. solution, suspension, solute, solvent
2. monosaccharide, starch, glycogen, cellulose
3. fats, oils, waxes, proteins
4. substrate, enzyme, active site, nucleic acid

CONCEPT MASTERY

Use your understanding of the concepts developed in the chapter to answer each of the following in a brief paragraph.

1. Explain how the polarity of water molecules makes water the best solvent.
2. Compare solutions and suspensions.
3. Describe the properties of carbon that make carbon compounds so numerous.
4. Explain why the formation of a lipid molecule is a dehydration synthesis reaction. Use a diagram to help explain your answer.
5. Distinguish between a saturated, unsaturated, and polyunsaturated fatty acid.
6. Explain the importance of enzymes to living things. Be sure to include the following terms in your answer: catalyst, substrate, active site, "start-up energy," lock and key.

CRITICAL AND CREATIVE THINKING

Discuss each of the following in a brief paragraph.

1. **Applying concepts** One of the digestive juices in the human stomach is hydrochloric acid (HCl). Sometimes an excess of the acid causes stomach discomfort. In such a case, a person might take an antacid such as magnesium hydroxide ($Mg(OH)_2$). Explain why this substance works to relieve the discomfort. What reaction is taking place?
2. **Identifying patterns** Explain why the name carbohydrate is an indication of the chemical composition of any sugar.
3. **Relating facts** Give two reasons why dehydration synthesis and hydrolysis are opposite chemical reactions.
4. **Applying concepts** Relate the structure of a phospholipid to the property that makes it so important in forming cell membranes.
5. **Developing a model** Materials generally dissolve more quickly in a solvent if its temperature is increased. Why do you think this is so?
6. **Identifying relationships** Describe the role that polymerization plays in the formation of carbohydrates, proteins, and nucleic acids.
7. **Applying concepts** The chemical process by which a saturated fat is converted to an unsaturated fat is called dehydrogenation. Explain why this is an appropriate name.
8. **Relating concepts** Despite their name, many amino acids actually raise the pH of a solution in which they are dissolved. How could this be true?
9. **Using the writing process** At the yearly convention of chemical compounds, a great debate is raging. The organic compounds, represented by the carbohydrates, claim they are the most important compounds in living things. The inorganic compounds, championed by water molecules, claim that life could not exist without them. Write a 5-minute speech in which you take the side of the organic or the inorganic compounds. Or, as an alternative, you may file a minority report in which you argue both sides are incorrect.
10. **Using the writing process** Write a short story entitled, "The Day Ice Stopped Floating."