Section 6.4

SB1b. Explain how enzymes function as catalysts. SB1c. Identify the function of the four major macromolecules (i.e., carbohydrates, proteins, lipids, nucleic acids). Also covers: SCSh2a–b, SCSh3a–b, d, SCSh5a, c, SCSh8a, f, SCSh9a, d). SB2a

# The Building Blocks of Life

### Objectives

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

### Review Vocabulary

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

### New Vocabulary

macromolecule
polymer
carbohydrate
lipid
protein
amino acid
nucleic acid
nucleotide

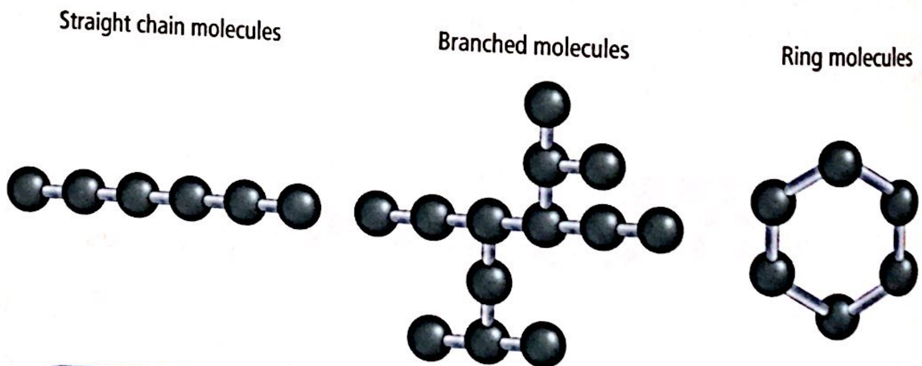
**MAIN Idea** **Organisms are made up of carbon-based molecules.**

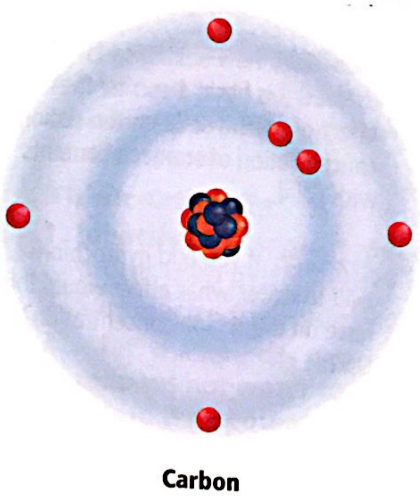
**Real-World Reading Link** Many people spend hours at a time with a model train set, connecting the cars first in one configuration, then another. Children enjoy toy trains because they can link long lines of cars together and make patterns by joining cars of similar color or function. Similarly, in biology, there are large molecules made of many smaller units joined together.

## Organic Chemistry

The element carbon is a component of almost all biological molecules. For this reason, life on Earth often is considered carbon-based. Because carbon is an essential element, scientists have devoted an entire branch of chemistry, called organic chemistry, to the study of organic compounds—those compounds containing carbon.

As shown in **Figure 6.25,** carbon has four electrons in its outermost energy level. Recall that the second energy level can hold eight electrons, so one carbon atom can form four covalent bonds with other atoms. These covalent bonds enable the carbon atoms to bond to each other, which results in a variety of important organic compounds. These compounds can be in the shape of straight chains, branched chains, and rings, such as those illustrated in **Figure 6.25.** Together, carbon compounds lead to the diversity of life on Earth.



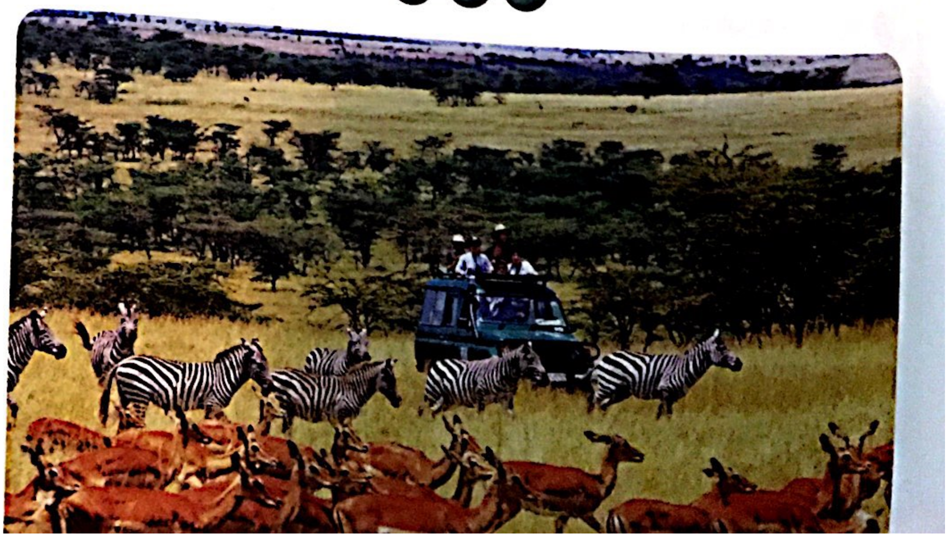



**Figure 6.25** The amazing diversity of life is based on the variety of carbon compounds. The half-filled outer energy level of carbon allows for the formation of straight chain, branched, and ring molecules.

## Macromolecules

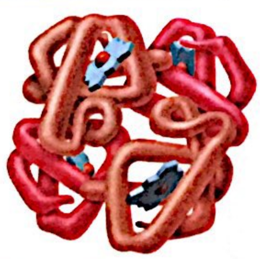
Carbon atoms can be joined to form carbon molecules. Similarly, most cells store small carbon compounds that serve as building blocks for large molecules. **Macromolecules** are large molecules that are formed by joining smaller organic molecules together. These large molecules are also called polymers. **Polymers** are molecules made from repeating units of identical or nearly identical compounds called monomers that are linked together by a series of covalent bonds. As shown in **Table 6.1**, biological macromolecules are organized into four major categories: carbohydrates, lipids, proteins, and nucleic acids.

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

**VOCABULARY**
**WORD ORIGIN**
**Polymer**
***poly–*** prefix; from Greek, meaning *many*.
***–meros*** from Greek, meaning *part*.

**Table 6.1** **Biological Macromolecules**

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

| Group | Example | Function |
|---|---|---|
| Carbohydrates |  | • Store energy<br>• Provide structural support |
| Lipids |  | • Store energy<br>• Provide barriers |
| Proteins | <br>**Hemoglobin** | • Transport substances<br>• Speed reactions<br>• Provide structural support<br>• Make hormones |
| Nucleic acids | <br>DNA stores genetic information in the cell's nucleus. | • Store and communicate genetic information |

*Study Tip*

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

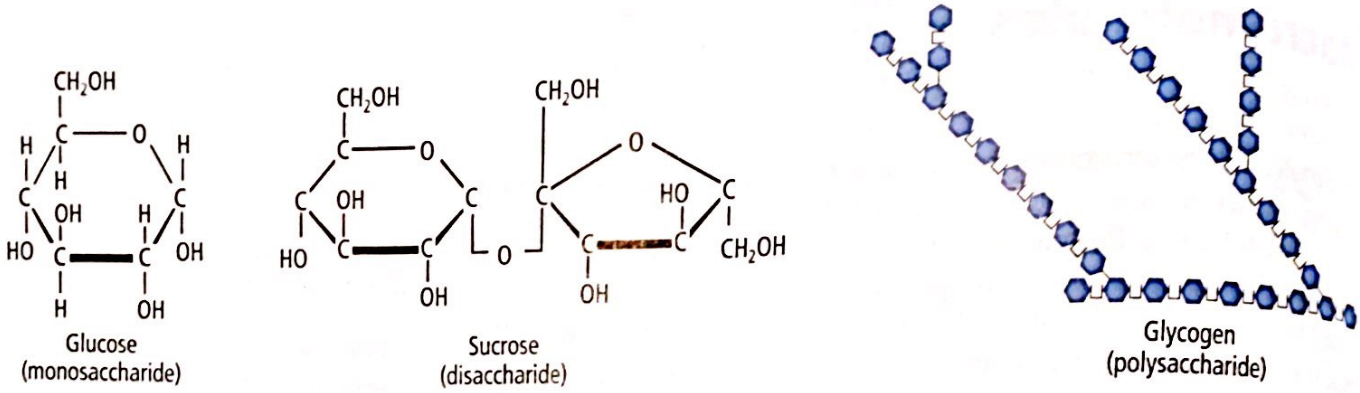


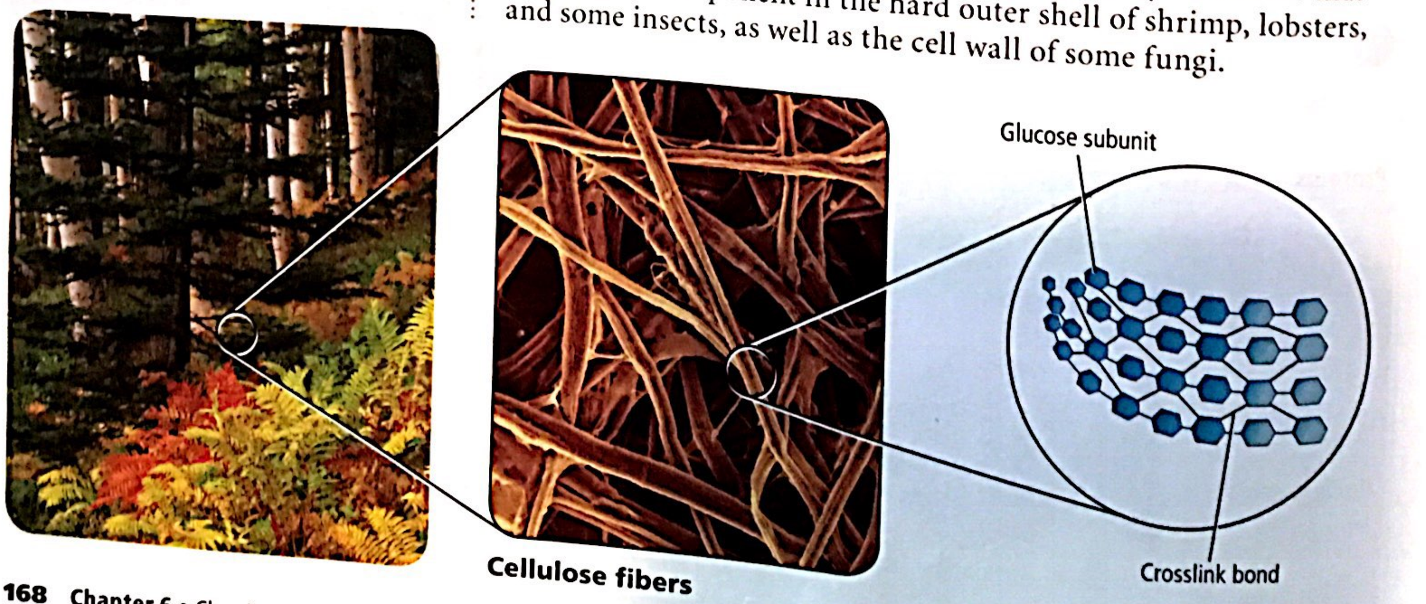

**Figure 6.26** Glucose is a monosaccharide. Sucrose is a disaccharide composed of glucose and fructose monosaccharides. Glycogen is a branched polysaccharide made from glucose monomers.

**Carbohydrates** Compounds composed of carbon, hydrogen, and oxygen in a ratio of one oxygen and two hydrogen atoms for each carbon atom are called **carbohydrates.** A general formula for carbohydrates is written as $(CH_2O)_n$. Here the subscript $n$ indicates the number of $CH_2O$ units in a chain. Biologically important carbohydrates that have values of $n$ ranging from three to seven are called simple sugars, or monosaccharides (mah nuh SA kuh rid). The monosaccharide glucose, shown in **Figure 6.26,** plays a central role as an energy source for organisms.

Monosaccharides can be linked to form larger molecules. Two monosaccharides joined together form a disaccharide (di SA kuh rid). Like glucose, disaccharides serve as energy sources. Sucrose, also shown in **Figure 6.26,** which is table sugar, and lactose, which is a component of milk, are both disaccharides. Longer carbohydrate molecules are called polysaccharides. One important polysaccharide is glycogen, which is shown in **Figure 6.26.** Glycogen is an energy storage form of glucose that is found in the liver and skeletal muscle. When the body needs energy between meals or during physical activity, glycogen is broken down into glucose.

In addition to their roles as energy sources, carbohydrates have other important functions in biology. In plants, a carbohydrate called cellulose provides structural support in cell walls. As shown in **Figure 6.27,** cellulose is made of chains of glucose linked together into tough fibers that are well-suited for their structural role. Chitin (KI tun) is a nitrogen-containing polysaccharide that is the main component in the hard outer shell of shrimp, lobsters, and some insects, as well as the cell wall of some fungi.

**Figure 6.27** The cellulose in plant cells provides the structural support for trees to stand in a forest.



**Lipids** Another important group of biological macromolecules is the lipid group. **Lipids** are molecules made mostly of carbon and hydrogen that make up the fats, oils, and waxes. Lipids are composed of fatty acids, glycerol, and other components. The primary function of lipids is to store energy. A lipid called a triglyceride (tri GLIH suh rid) is a fat if it is solid at room temperature and an oil if it is liquid at room temperature. In addition, triglycerides are stored in the fat cells of your body. Plant leaves are coated with lipids called waxes to prevent water loss, and the honeycomb in a beehive is made of beeswax.

**Saturated and unsaturated fats** Organisms need lipids in order to function properly. The basic structure of a lipid includes fatty acid tails as shown in **Figure 6.28.** Each tail is a chain of carbon atoms bonded to hydrogen and other carbon atoms by single or double bonds. Lipids that have tail chains with only single bonds between the carbon atoms are called saturated fats because no more hydrogens can bond to the tail. Lipids that have at least one double bond between carbon atoms in the tail chain can accommodate at least one more hydrogen and are called unsaturated fats. Fats with more than one double bond in the tail are called polyunsaturated fats.

**Phospholipids** A special lipid shown in **Figure 6.28,** called a phospholipid, is responsible for the structure and function of the cell membrane. Lipids are hydrophobic, which means they do not dissolve in water. This characteristic is important because it allows lipids to serve as barriers in biological membranes.

**Steroids** Another important category of lipids is the steroid group. Steroids include substances such as cholesterol and hormones. Despite its reputation as a "bad" lipid, cholesterol provides the starting point for other necessary lipids such as vitamin D and the hormones estrogen and testosterone.

## DATA ANALYSIS LAB 6.2

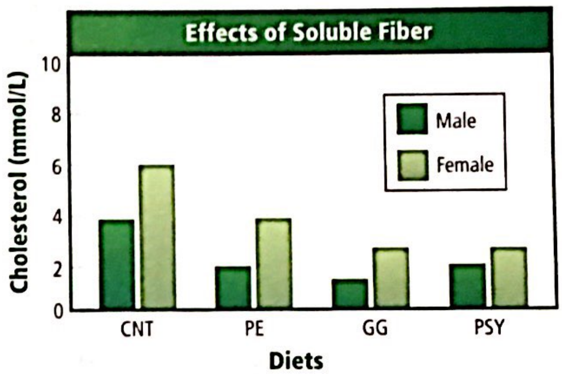
**Based on Real Data***

### Interpret the Data

**Does soluble fiber affect cholesterol levels?** High amounts of a steroid called cholesterol in the blood are associated with the development of heart disease. Researchers study the effects of soluble fiber in the diet on cholesterol.

**Data and Observations**

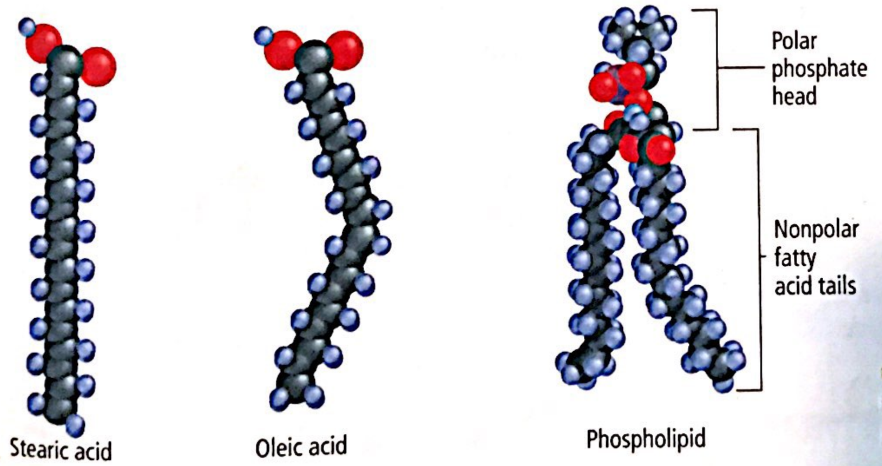
This experiment evaluated the effects of three soluble fibers on cholesterol levels in the blood: pectin (PE), guar gum (GG), and psyllium (PSY). Cellulose was the control (CNT).



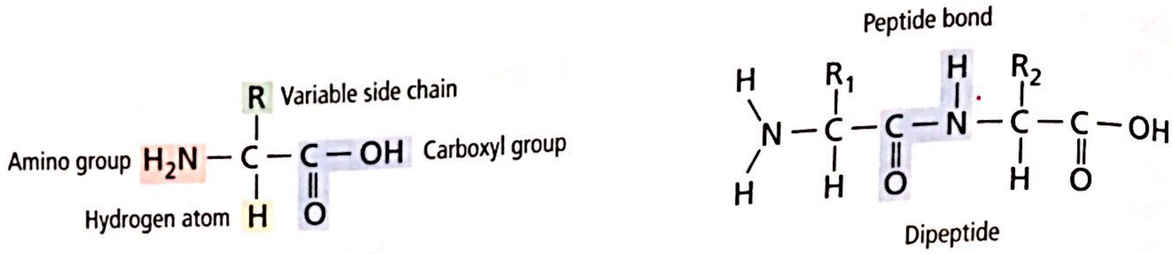

**Think Critically**

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

*Data obtained from: Shen, et al. 1998. Dietary soluble fiber lowers plasma LDL cholesterol concentrations by altering lipoprotein metabaolism in female Guinea pigs. *Journal of Nutrition* 128: 1434-1441.




■ **Figure 6.28** Stearic acid has no double bonds between carbon atoms; oleic acid has one double bond. Phospholipids have a polar head and two nonpolar tails.




**■ Figure 6.29**
**Left:** The general structure of an amino acid has four groups around a central carbon.
**Right:** The peptide bond in a protein happens as a result of a chemical reaction.
**Interpret** ***What other molecule is a product when a peptide bond forms?***

**Concepts In Motion**
**Interactive Figure** To see an animation of peptide bond, visit biologygmh.com.

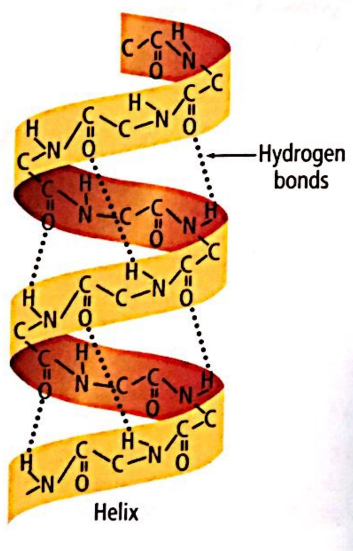
**Proteins** Another primary building block of living things is protein. A **protein** is a compound made of small carbon compounds called amino acids. **Amino acids** are small compounds that are made of carbon, nitrogen, oxygen, hydrogen, and sometimes sulfur. All amino acids share the same general structure.

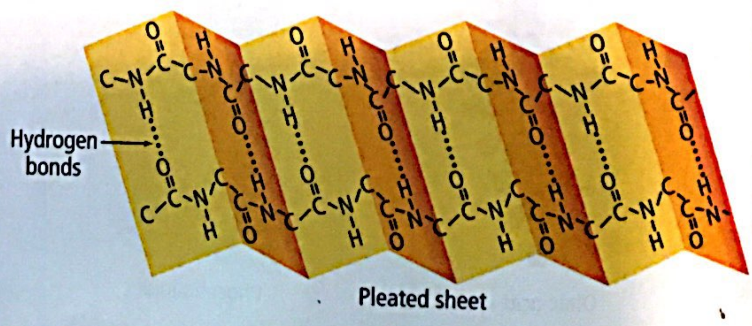
**Amino acid structure** Amino acids have a central carbon atom like the one shown in **Figure 6.29.** Recall that carbon can form four covalent bonds. One of those bonds is with hydrogen. The other three bonds are with an amino group ($-NH_2$), a carboxyl group ($-COOH$), and a variable group ($-R$). The variable group makes each amino acid different. There are 20 different variable groups, and proteins are made of different combinations of all 20 different amino acids. Several covalent bonds called peptide bonds join amino acids together to form proteins, which is also shown in **Figure 6.29.** A peptide forms between the amino group of one amino acid and the carboxyl group of another.

**Three-dimensional protein structure** Based on the variable groups contained in the different amino acids, proteins can have up to four levels of structure. The number of amino acids in a chain and the order in which the amino acids are joined define the protein's primary structure. After an amino acid chain is formed, it folds into a unique three-dimensional shape, which is the protein's secondary structure. **Figure 6.30** shows two basic secondary structures—the helix and the pleat. A protein might contain many helices, pleats, and folds. The tertiary structure of many proteins is globular, such as the hemoglobin protein shown in **Table 6.1,** but some proteins form long fibers. Some proteins form a fourth level of structure by combining with other proteins.

**Protein function** Proteins make up about 15 percent of your total body mass and are involved in nearly every function of your body. For example, your muscles, skin, and hair all are made of proteins. Your cells contain about 10,000 different proteins that provide structural support, transport substances inside the cell and between cells, communicate signals within the cell and between cells, speed up chemical reactions, and control cell growth.

**■ Figure 6.30** The shape of a protein depends on the interactions among the amino acids. Hydrogen bonds help the protein hold its shape.



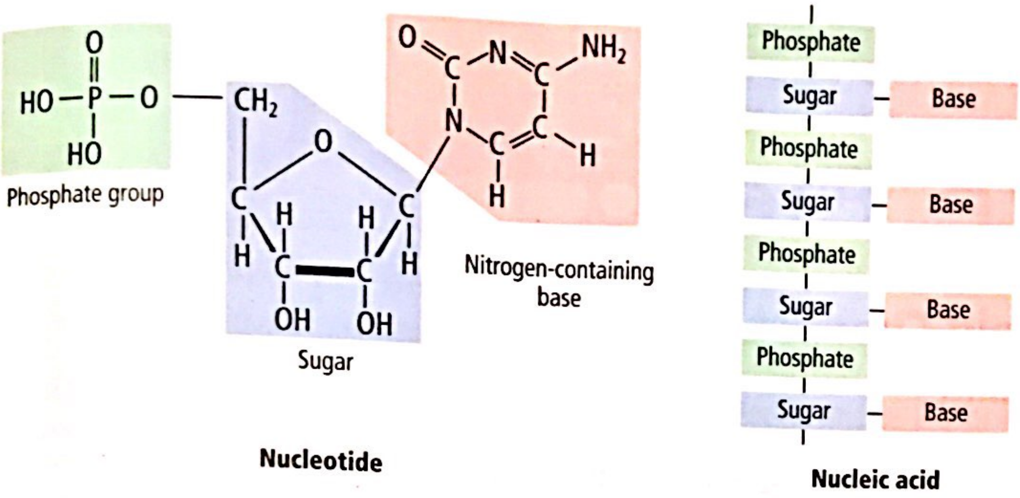



**Figure 6.31**
**Left:** DNA nucleotides contain the sugar deoxyribose. RNA nucleotides contain the sugar ribose.
**Right:** Nucleotides are joined together by bonds between their sugar group and phosphate group.

**Nucleic acids** The fourth group of biological macromolecules are nucleic acids. **Nucleic acids** are complex macromolecules that store and transmit genetic information. Nucleic acids are made of smaller repeating subunits called **nucleotides.** Nucleotides are composed of carbon, nitrogen, oxygen, phosphorus, and hydrogen atoms arranged as shown in **Figure 6.31.** There are six major nucleotides, all of which have three units—a phosphate, a nitrogenous base, and a ribose sugar.

There are two types of nucleic acids found in living organisms: deoxyribonucleic (dee AHK sih rib oh noo klay ihk) acid (DNA) and ribonucleic (rib oh noo KLAY ihk) acid (RNA). In nucleic acids such as DNA and RNA, the sugar of one nucleotide bonds to the phosphate of another nucleotide. The nitrogenous base that sticks out from the chain is available for hydrogen bonding with other bases in other nucleic acids. You will learn more about the structure and function of DNA and RNA in Chapter 12.

A nucleotide with three phosphate groups is adenosine triphosphate (ATP). ATP is a storehouse of chemical energy that can be used by cells in a variety of reactions. It releases energy when the bond between the second and third phosphate group is broken.

# Section 6.4 Assessment

## Section Summary

- Carbon compounds are the basic building blocks of living organisms.
- Biological macromolecules are formed by joining small carbon compounds into polymers.
- There are four types of biological macromolecules.
- Peptide bonds join amino acids in proteins.
- Chains of nucleotides form nucleic acids.

## Understand Main Ideas

1. MAIN Idea **Explain** If an unknown substance found on a meteorite is determined to contain no trace of carbon, can scientists conclude that there is life at the metorite's origin?
2. **List** and compare the four types of biological macromolecules.
3. **Identify** the components of carbohydrates and proteins.
4. **Discuss** the importance of amino acid order to a protein's function.

## Think Scientifically

5. *Summarize* Given the large number of proteins in the body, explain why the shape of an enzyme is important to its function.
6. *Draw* two structures (one straight chain and one ring) of a carbohydrate with the chemical formula $(CH_2O)_6$.