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.

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.

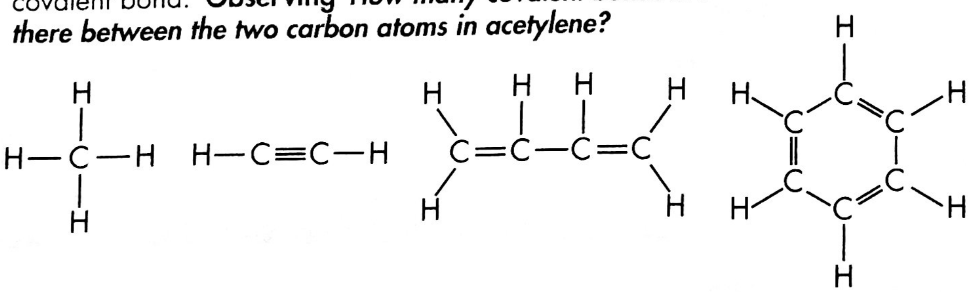
The Chemistry of Carbon

What elements does carbon bond with to make up life's molecules?

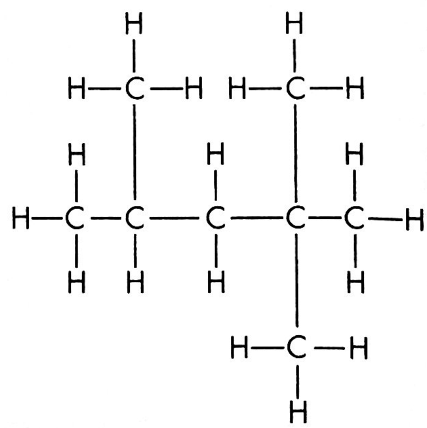
Why is carbon so interesting that a whole branch of chemistry should be set aside just to study carbon compounds? There are two reasons for this. First, carbon atoms have four valence electrons, allowing them to form strong covalent bonds with many other elements. **Carbon can bond with many elements,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

Macromolecules

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

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.

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."

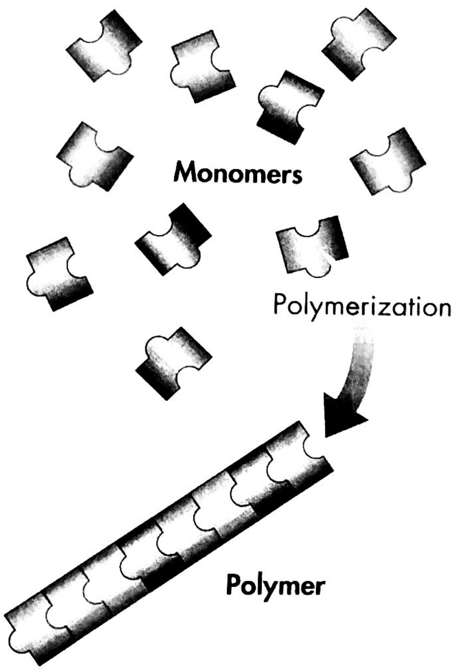


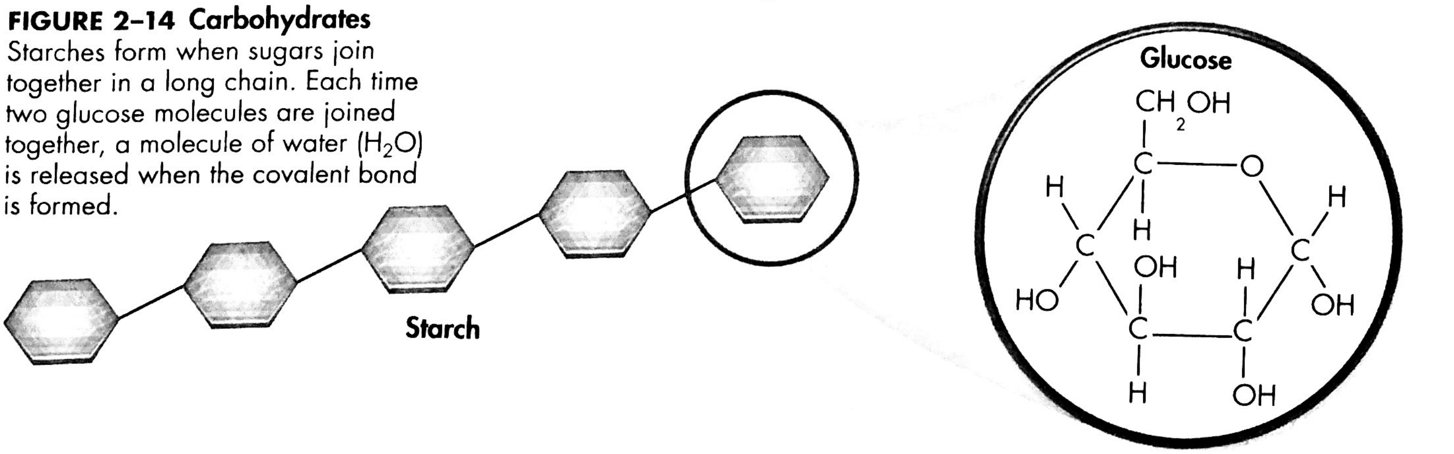
FIGURE 2–13 Polymerization When monomers join together, they form polymers. **Using Analogies** ***How are monomers similar to links in a chain?***

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.



▶ ***Complex Carbohydrates*** The large macromolecules formed from monosaccharides are known as polysaccharides. Many animals store excess sugar in a polysaccharide called glycogen, which is sometimes called "animal starch." When the level of glucose in your blood runs low, glycogen is broken down into glucose, which is then released into the blood. The glycogen stored in your muscles supplies the energy for muscle contraction and, thus, for movement.

Plants use a slightly different polysaccharide, called starch, to store excess sugar. Plants also make another important polysaccharide called cellulose. Tough, flexible cellulose fibers give plants much of their strength and rigidity. Cellulose is the major component of both wood and paper, so you are actually looking at cellulose as you read these words!

Lipids Lipids are a large and varied group of biological molecules that are generally not soluble in water. **Lipids** are made mostly from carbon and hydrogen atoms. The common categories of lipids are fats, oils, and waxes. **Lipids can be used to store energy. Some lipids are important parts of biological membranes and waterproof coverings.** Steroids synthesized by the body are lipids as well. Many steroids, such as hormones, serve as chemical messengers.

Many lipids are formed when a glycerol molecule combines with compounds called fatty acids, as shown in **Figure 2–15.** If each carbon atom in a lipid's fatty acid chains is joined to another carbon atom by a single bond, the lipid is said to be saturated. The term *saturated* is used because the fatty acids contain the maximum possible number of hydrogen atoms.

If there is at least one carbon-carbon double bond in a fatty acid, the fatty acid is said to be unsaturated. Lipids whose fatty acids contain more than one double bond are said to be polyunsaturated. If the terms *saturated* and *polyunsaturated* seem familiar, you have probably seen them on food package labels. Lipids that contain unsaturated fatty acids, such as olive oil, tend to be liquid at room temperature. Other cooking oils, such as corn oil, sesame oil, canola oil, and peanut oil, contain polyunsaturated lipids.

In Your Notebook *Compare and contrast saturated and unsaturated fats.*

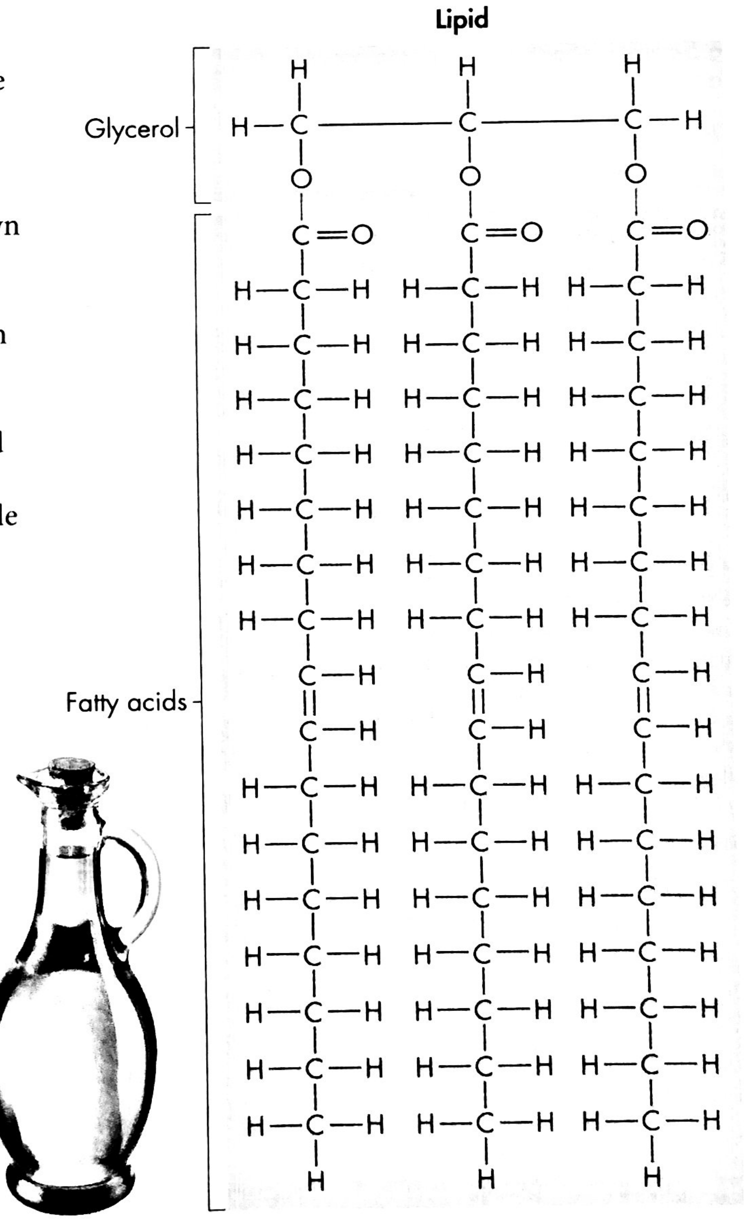


FIGURE 2–15 Lipids Lipid molecules are made up of glycerol and fatty acids. Liquid lipids, such as olive oil, contain mainly unsaturated fatty acids.

Analyzing Data

Comparing Fatty Acids

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

1. Interpret Data Which of the four fatty acids is saturated? Which are unsaturated?

2. 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

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

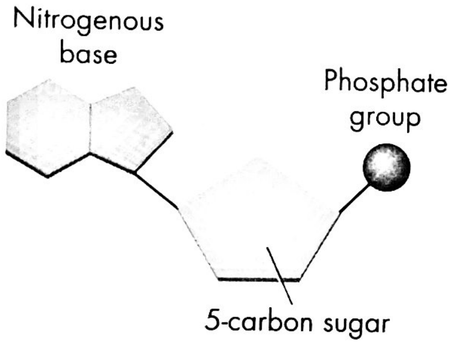


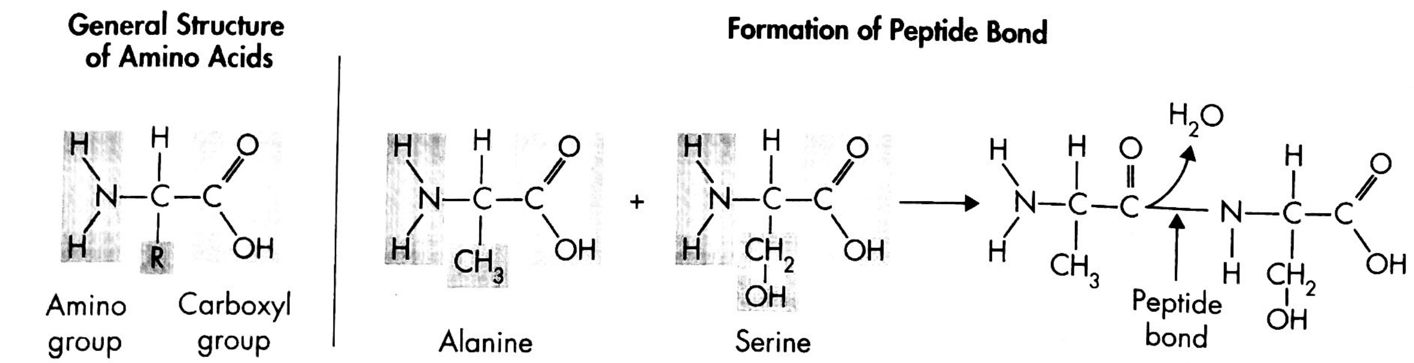
FIGURE 2–16 Nucleic Acids The monomers that make up a nucleic acid are nucleotides. Each nucleotide has a 5-carbon sugar, a phosphate group, and a nitrogenous base.

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.**

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.



▸ *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.

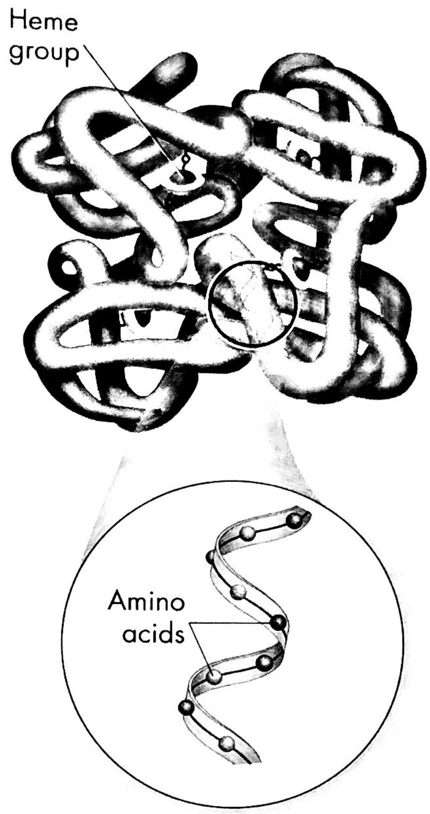


FIGURE 2–18 Protein Structure
The protein hemoglobin consists of four subunits. The iron-containing heme group in the center of each subunit gives hemoglobin its red color. An oxygen molecule binds tightly to each heme molecule. **Interpret Visuals** ***How many levels of organization does hemoglobin have?***

2.3 Assessment

Review Key Concepts

1. 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?

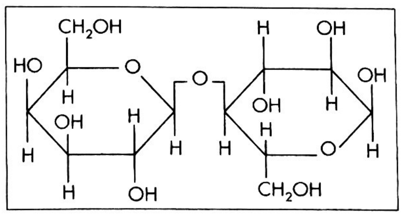
2. a. Review Name four groups of organic compounds found in living things.

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

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



a. Observe What atoms constitute the compound above?

b. Classify What class of macromolecule does the compound belong to?