2.3 Carbon-Based Molecules

VOCABULARY

- monomer
- polymer
- carbohydrate
- lipid
- fatty acid
- protein
- amino acid
- nucleic acid

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

MAIN IDEAS

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

Connect to Your World

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

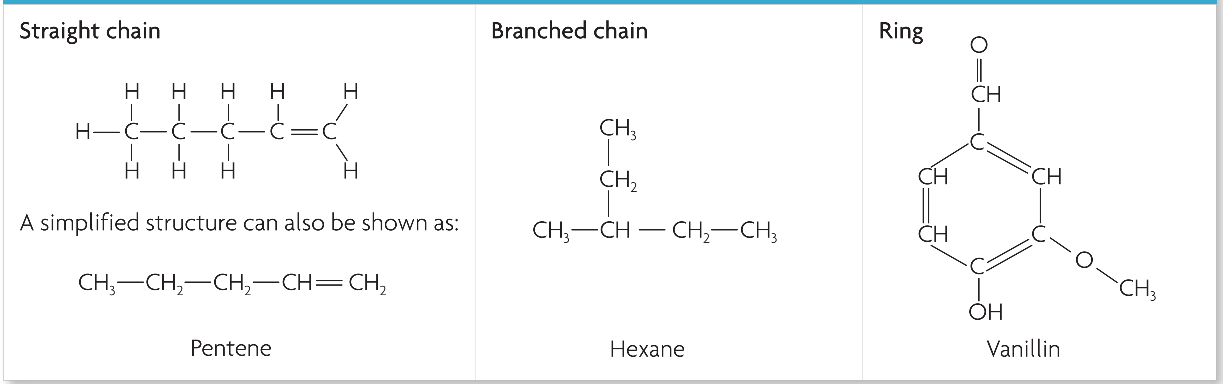
MAIN IDEA

Carbon atoms have unique bonding properties.

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

As **FIGURE 3.1** shows, carbon-based molecules have three fundamental structures—straight chains, branched chains, and rings. All three types of molecules are the result of carbon's ability to form four covalent bonds. Carbon chains can bond with carbon rings to form very large, very complex molecules. These large molecules can be made of many small molecules that are bonded together. In a sense, the way these molecules form is similar to the way in which individual links of metal come together to make a bicycle chain.

FIGURE 3.1 CARBON CHAINS AND RINGS

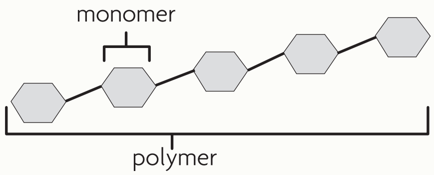


In many carbon-based molecules, small molecules are subunits of an entire molecule, like links in a chain. Each subunit in the complete molecule is called a **monomer.** When monomers are linked, they form molecules called polymers. A **polymer** is a large molecule, or macromolecule, made of many monomers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

VISUAL VOCAB

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

mono- = one
poly- = many



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

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

MAIN IDEA

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

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

READING TOOLBOX

TAKING NOTES

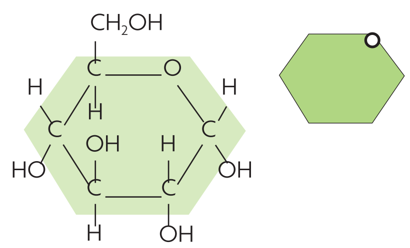
Use a content frame to help you understand monomers and polymers in carbon-based molecules.

Monomer	Polymer	Example	Function

Carbohydrates

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

The most basic carbohydrates are simple sugars, or monosaccharides (MAHN-uh-SAK-uh-RYDZ). Many simple sugars have either five or six carbon atoms. Fruits contain a six-carbon sugar called fructose. Glucose, one of the sugars made by plant cells during photosynthesis, is another six-carbon sugar. Simple sugars can be bonded to make larger carbohydrates. For example, two sugars bonded together make the disaccharide you know as table sugar, shown in **FIGURE 3.2.** Many glucose molecules can be linked to make polysaccharides (PAHL-ee-SAK-uh-RYDZ), which are polymers of monosaccharides.



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

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

FIGURE 3.2 Household sugar (sucrose) is a disaccharide, or two-sugar molecule, of glucose (inset) and fructose.

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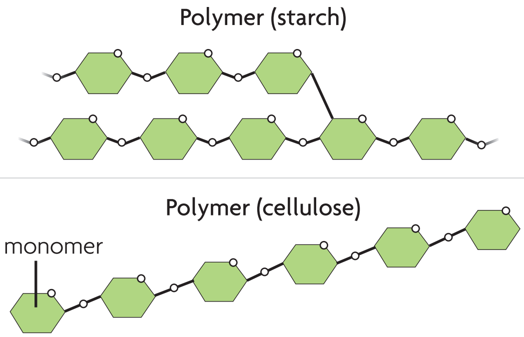
Macromolecules of Life

FIGURE 3.3 CARBOHYDRATE STRUCTURE



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

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

CONNECT TO

CELL STRUCTURE

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

Cellulose is somewhat different from starch and glycogen. Its straight, rigid structure, shown in **FIGURE 3.3**, makes the cellulose molecule a major building block in plant cell structure. Cellulose makes up the cell wall that is the tough outer covering of plant cells. You have eaten cellulose in the stringy fibers of vegetables such as celery, so you know that it is tough to chew and break up.

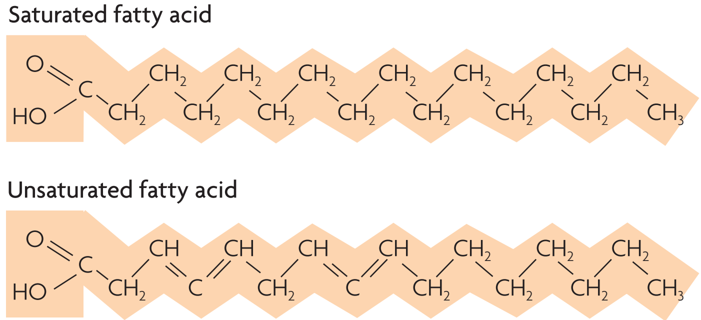
Lipids

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

Fats and oils are two familiar types of lipids. They store large amounts of chemical energy in organisms. Animal fats are found in foods such as meat and butter. You know plant fats as oils, such as olive oil and peanut oil. The structures of fats and oils are similar. They both consist of a molecule called glycerol (GLIHS-uh-RAWL) bonded to molecules called fatty acids. **Fatty acids** are chains of carbon atoms bonded to hydrogen atoms. Two different types of fatty acids are shown in **FIGURE 3.4.**

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

FIGURE 3.4 Fatty acids can be either saturated or unsaturated.



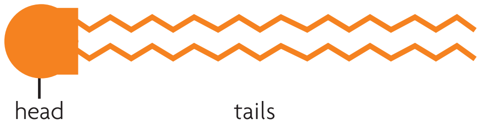
Saturated fats contain fatty acids in which all carbon–carbon bonds are single bonds.

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

All cell membranes are made mostly of another type of lipid, called a phospholipid (FAHS-foh-LIHP-ihd). A phospholipid consists of glycerol, two fatty acids, and a phosphate group (PO_4^-) that is part of the polar "head" of the molecule. The fatty acids are the nonpolar "tails" of a phospholipid. Compare the structure of a phospholipid to the structure of a triglyceride in **FIGURE 3.5.**

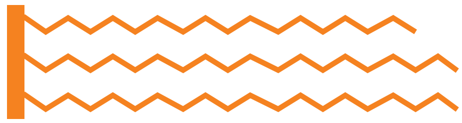
FIGURE 3.5 LIPID STRUCTURE

Phospholipid



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

Triglyceride



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

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

Proteins

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

Look at **FIGURE 3.6** to see the amino acid serine. All amino acids have similar structures. As **FIGURE 3.7** shows, each amino acid monomer has a carbon atom that is bonded to four other parts. Three of these parts are the same in every amino acid: a hydrogen atom, an amino group (NH_2), and a carboxyl group (COOH). Amino acids differ only in their side group, or the R-group.

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

FIGURE 3.6 Serine is one of 20 amino acids that make up proteins in organisms.

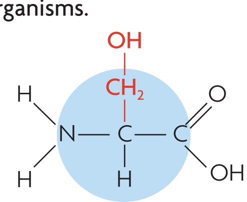
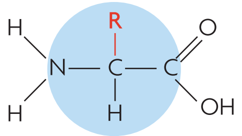
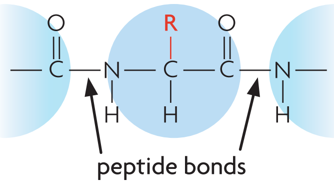


FIGURE 3.7 AMINO ACID AND PROTEIN STRUCTURE

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

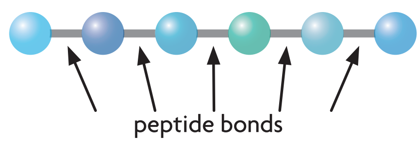


Monomer (amino acid)



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

Polymer (protein)



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

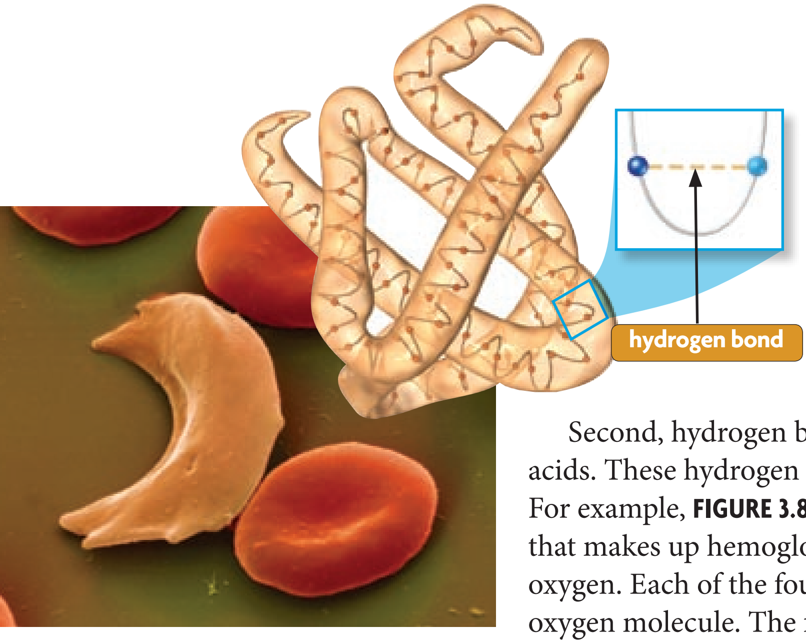


FIGURE 3.8 Hemoglobin in red blood cells transports oxygen. The structure of hemoglobin depends on hydrogen bonds between specific amino acids. Just one amino acid change causes red blood cells to have the curved shape characteristic of sickle cell anemia. (colored SEM; magnification 3500×)

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

Second, hydrogen bonds can form between the side groups of some amino acids. These hydrogen bonds cause the protein to fold into a specific shape. For example, **FIGURE 3.8** shows the structure of one of the four polypeptides that makes up hemoglobin, the protein in your red blood cells that transports oxygen. Each of the four polypeptides contains an iron atom that bonds to an oxygen molecule. The four polypeptides are folded in a way that puts the four oxygen-carrying sites together in a pocketlike structure inside the molecule. If a protein has incorrect amino acids, the structure may change in a way that prevents the protein from working properly. Just one wrong amino acid of the 574 amino acids in hemoglobin causes the disorder sickle cell anemia.

Nucleic Acids

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

Nucleic acids work together to make proteins. DNA stores the information for putting amino acids together to make proteins, and RNA helps to build proteins. DNA is the basis of genes and heredity, but cannot do anything by itself. Instead, the structure of DNA—the order of nucleotides—provides the code for the proper assembly of proteins. Many different kinds of RNA molecules assist in assembling proteins based on the DNA code. RNA may even catalyze reactions. You will learn more about nucleic acids and how they build proteins in the Genetics unit.

Apply What is the relationship between proteins and nucleic acids?

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2.3 Formative Assessment

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REVIEWING ▶ MAIN IDEAS

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

CRITICAL THINKING

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

CONNECT TO BIOCHEMISTRY

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