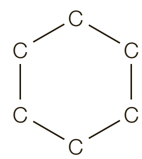
3.1 The Chemistry of Biology

LEARNING OBJECTIVES

- Use appropriate examples to describe functional groups.
- Describe some different ways of representing organic molecules.
- Explain how the molecules of life are polymers.
- Give an example of a metabolic reaction.

CARBON, THE STUFF OF LIFE

The same elements that make up a living body also occur in nonliving things, but their proportions differ. For example, compared to sand or seawater, a human body has a much larger proportion of carbon atoms (Section 2.1). Why? Unlike sand or seawater, a body has a lot of the molecules of life—complex carbohydrates and lipids, proteins, and nucleic acids—which, in turn, consist of a high proportion of carbon atoms. Compounds that consist mainly of carbon and hydrogen are said to be **organic**. The term is a holdover from a time when these molecules were thought to be made only by living things, as opposed to the "inorganic" molecules that formed by nonliving processes. We now know that organic compounds were present on Earth long before organisms were.



A Carbon's versatile bonding behavior allows it to form a variety of structures, including rings.

B Carbon rings form the framework of many sugars, starches, and fats (including those that make up doughnuts).

Figure 3.1 Carbon rings.

A carbon atom is unusual among elements because it can bond stably with many other elements. It also has four vacancies (Section 2.2), so it can form four covalent bonds with other atoms—including other carbon atoms. Many organic molecules have a chain of carbon atoms, and this backbone often forms rings (**Figure 3.1**).

The versatility of carbon atoms means that they can be assembled into a wide variety of organic compounds. A molecule that consists only of carbon and hydrogen atoms is called a **hydrocarbon**, and it is nonpolar. The molecules of life have other elements in addition to carbon and hydrogen. These other elements are often part of **functional groups**: small molecular groups covalently bonded to the carbon backbone (**Table 3.1**).

TABLE 3.1

Some Functional Groups in Biological Molecules

Group	Structure	Character	Formula	Found in:
methyl	H above and below; —C—H	nonpolar	$—CH_3$	fatty acids, some amino acids
hydroxyl	—O—H	polar	—OH	alcohols, sugars
sulfhydryl	—S—H	forms rigid disulfide bonds	—SH	cysteine, many cofactors
amine	—N with two H	very basic	$—NH_2$	nucleotide bases, amino acids
carbonyl	O (double bond) above —C—	polar, reactive	—CO	alcohols, other functional groups
carboxyl	O (double bond) above —C—C—OH	acidic, reactive	—COOH	fatty acids, amino acids
aldehyde	O (double bond) above —C—C—H	polar, reactive	—CHO	simple sugars
acetyl	O (double bond) above —C—CH	polar, acidic	$—COCH_3$	some proteins, coenzymes
amide	O (double bond) above —C—N<	weakly basic, stable, rigid	—CON—	proteins, nucleotide bases
ketone	O (double bond) above —C—C—C—	polar, acidic	—CO—	simple sugars, nucleotide bases
phosphate	O (double bond) above, O^- below; —O—P—O^-	polar, reactive	$—PO_4$	nucleotides, DNA, RNA, phospholipids, proteins

Each functional group imparts a particular chemical property to an organic compound. For example, carboxyl groups (—COOH) make amino acids and fatty acids acidic. A hydroxyl group (—OH) adds polar character, thus increasing solubility in water. Hydroxyl groups turn hydrocarbons into alcohols. A methyl group ($—CH_3$) adds nonpolar character. Methyl groups added to DNA act like an "off" switch for this molecule; acetyl groups act like an "on" switch (we return to this topic in Chapter 10). The chemical behavior of the molecules of life arises mainly from the number, kind, and arrangement of their functional groups.

The structure of biological molecules can be quite complex (**Figure 3.2A**). For clarity, we may omit some features when representing them: some of the bonds in a structural formula, for example, or hydrogen atoms bonded to a carbon backbone. Carbon rings such as the ones that occur in glucose and other sugars are often depicted as polygons (**Figure 3.2B**). If no atom is shown at a corner or at the end of a bond, a carbon is implied there. Ball-and-stick models are used to depict an organic molecule's three-dimensional arrangement of atoms (**Figure 3.2C**); space-filling models are used to show its overall shape (**Figure 3.2D**). Proteins

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and nucleic acids are often represented as ribbon structures, which, as you will see in Section 3.4, show how the backbone of these molecules folds and twists.

METABOLIC REACTIONS

All biological systems are based on the same organic molecules, a similarity that is one of many legacies of life's common origin. However, the details of those molecules differ. Just as atoms bonded in different numbers and arrangements form different molecules, simple organic building blocks bonded in different numbers and arrangements form different versions of the molecules of life. The building blocks—sugars, fatty acids, amino acids, and nucleotides—are **monomers** when used as subunits of larger molecules. A molecule that consists of repeated monomers is a **polymer**.

Cells link monomers to form polymers, and break apart polymers to release monomers. These and any other processes of molecular change are called **reactions.** Cells constantly run reactions as they acquire and use energy to stay alive, grow, reproduce, and so on. Collectively, these reactions are called **metabolism** (Figure 3.3). Metabolism requires **enzymes**, which are organic molecules (usually proteins) that speed up reactions without being changed by them. Enzymes remove monomers from polymers in a common metabolic reaction called **hydrolysis** 1. Hydrolysis requires water (hence the name). The reverse of hydrolysis is a reaction called **condensation**, in which an enzyme joins one monomer to another 2. Water forms during condensation, so the reaction is also called dehydration.

Chapter 5 returns to metabolism. The rest of this chapter introduces the different types of biological molecules and the monomers from which they are built.

condensation Chemical reaction in which a large molecule is assembled from smaller subunits; water also forms.

enzyme Organic molecule that speeds up a reaction without being changed by it.

functional group An atom (other than hydrogen) or a small molecular group bonded to a carbon of an organic compound; imparts a specific chemical property.

hydrocarbon Compound that consists only of carbon and hydrogen atoms.

hydrolysis (hy-DRAWL-uh-sis) Water-requiring chemical reaction that breaks a molecule into smaller subunits.

metabolism All of the enzyme-mediated reactions in a cell.

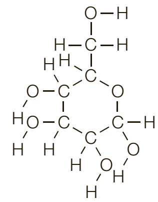
monomer Molecule that is a subunit of a polymer.

organic Describes a molecule that consists mainly of carbon and hydrogen atoms.

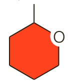
polymer Molecule that consists of repeated monomers.

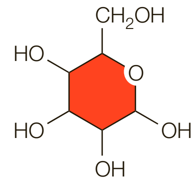
reaction Process of molecular change.

A A structural formula for an organic molecule—even a simple one—can be very complicated. The overall structure is obscured by detail.



B Structural formulas of organic molecules are often simplified by using polygons as symbols for rings, and omitting some bonds and element labels. If no atom is shown at a corner or at the end of a bond, a carbon is implied there.

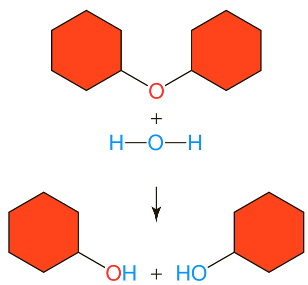




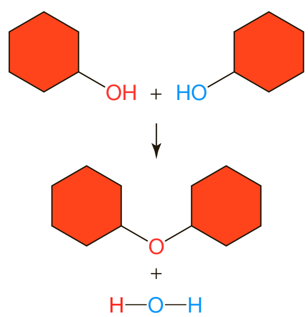
C A ball-and-stick model shows the arrangement of atoms and bonds in three dimensions.

D A space-filling model can be useful to show a molecule's overall shape. Individual atoms are visible in this model. Space-filling models of larger molecules often show only the surface contours.

Figure 3.2 Modeling an organic molecule. All of these models represent the same molecule: glucose.



1 **Hydrolysis.** Cells use this water-requiring reaction to split polymers into monomers. An enzyme attaches a hydroxyl group and a hydrogen atom (both from water) at the site of the split.



2 **Condensation.** Cells use this reaction to build polymers from monomers. An enzyme removes a hydroxyl group from one molecule and a hydrogen atom from another. A covalent bond forms between the two molecules. Water forms, so this reaction is also called dehydration.

Figure 3.3 Examples of metabolic reactions. Common reactions by which cells build and break down organic molecules are shown.