# Structure and Function of Carbon-Based Molecules

The carbon-based macromolecules found in all organisms may be classified in four basic types: carbohydrates, lipids, proteins, and nucleic acids. These molecules, often called biomolecules, have different structures and functions, but all are formed around carbon chains and rings. Some organisms, like most green plants, make high-energy biomolecules through a process called photosynthesis. Other organisms obtain carbon-based molecules by eating food. All living things break down organic molecules and rearrange them to form new molecules necessary for life.

## Carbohydrate Structure and Function

**Analyze** Which of the carbohydrates shown in Figure 7 are monomers, and which are polymers? Explain your answer.

Carbohydrates are composed of carbon, hydrogen, and oxygen. The most basic carbohydrates are simple sugars, or monosaccharides. Many simple sugars have either five or six carbon atoms. Glucose, one of the sugars made by plant cells during photosynthesis, is a six-carbon sugar. Simple sugars bind together to make larger carbohydrates called polysaccharides. A polysaccharide with two sugars joined together, such as sucrose, is called a disaccharide.

**FIGURE 7:** Glucose, sucrose, and cellulose are all carbohydrates.

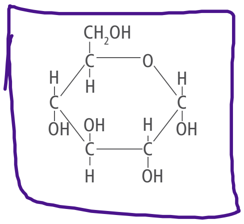
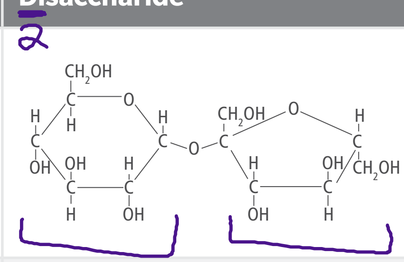
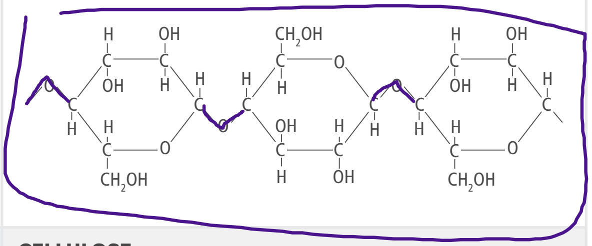
| **Monosaccharide** | **Disaccharide** | **Polysaccharide** |
|---|---|---|
|  |  |  |
| **GLUCOSE** | **SUCROSE** | **CELLULOSE** |
| A simple sugar that is an important energy source in living organisms. | A simple sugar made of a glucose monomer bonded to a fructose monomer. Known as table sugar. | A complex carbohydrate with a straight, rigid structure that makes up the cell wall—a tough, outer layer of plant cells. |

**FIGURE 8:** Carbohydrate-rich Foods

The energy contained in carbohydrate molecules can be released and used for essential cell processes. Carbohydrate-rich foods such as bread, pasta, vegetables, fruit, and sweeteners contain carbohydrate molecules that your body breaks down to release usable energy. Simple carbohydrates like glucose and sucrose can be quickly broken down and absorbed by your body. Complex carbohydrates are made up of longer chains of molecules and are broken down more slowly. Sources of complex carbohydrates include whole grains, potatoes, and vegetables. Complex carbohydrates are often rich in cellulose, or fiber, which is not broken down in your digestive system.

**Predict** Why does it take longer for your body to break down complex carbohydrates than simple carbohydrates? How is this related to their molecular structures?

## Lipid Structure and Function

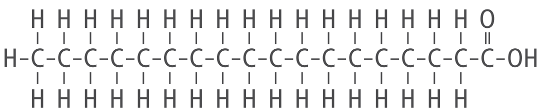
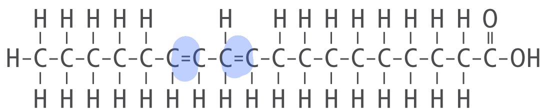
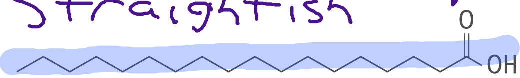
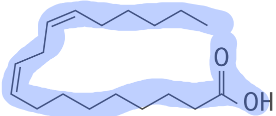
Lipids are similar to carbohydrates in that they contain many of the same elements. Unlike carbohydrates, lipids are nonpolar molecules. Thus, most lipids are insoluble in water because water molecules are polar. This is the origin of the phrase, “oil and water don’t mix, ” because lipids include many natural fats, oils, and waxes. Lipids also include phospholipids and steroids. Some lipids, such as fats and oils, are broken down as a source of usable energy for cells. Phospholipids are important for cell membrane structure. Waxes form protective coatings, and steroids act as chemical messengers.

The simplest lipids are fatty acids. More complex lipids often contain several fatty acids linked together. Fatty acids consist of long chain hydrocarbons containing two oxygen atoms at one end. Fatty acids are distinguished from one another by chain length and by the number of hydrogen atoms connected to each carbon atom. As shown in Figure 9, fatty acids are modeled in two different ways. The line drawings represent the same molecules as those above them, but the individual elements are not labeled. Each kink in the chain represents a carbon atom, including the ends.

**FIGURE 9:** Otters have a gland that secretes oil onto their fur.

**Explain** How does secreting oil onto their fur help otters maintain homeostasis?

**FIGURE 10:** Fatty acids can be saturated or unsaturated.

| Saturated Fatty Acid | Unsaturated Fatty Acid |
|---|---|
|  |  |
| Straightish shape   | NOT straight   |
| Saturated fatty acids are found mostly in foods from animals and some plants. They are usually solid at room temperature. There are no double bonds between the carbon atoms, so this molecule is “saturated” with hydrogen atoms. The saturated fatty acid shown here is stearic acid. | Unsaturated fatty acids are found mostly in oils from plants and are usually liquid at room temperature. There are double bonds between some carbon atoms, so this molecule is not saturated with hydrogen atoms, and it has a bent shape. The unsaturated fatty acid shown here is linoleic acid. |

**Collaborate** With a partner, make a chart to compare and contrast these two sets of molecules: carbohydrates and lipids, and saturated and unsaturated fatty acids. Compare and contrast the elements that make them up, the arrangement of their atoms, and the types of bonds that hold the atoms together.

### Fats and Oils

We often think of fats as something to avoid in our diets. However, fats and lipids serve many important roles in maintaining overall health. Fats contain 2.25 times as much energy per gram as carbohydrates, so fats are a major source of energy. They also play an important role in the absorption of some vitamins and minerals. Fats are needed to build and repair cell membranes and are an essential part of the myelin sheath that surrounds and protects nerves. Fats are also required for processes such as muscle movement, blood clotting, and inflammation.

**FIGURE 11:** Foods Containing Fats and Oils

## Phospholipids

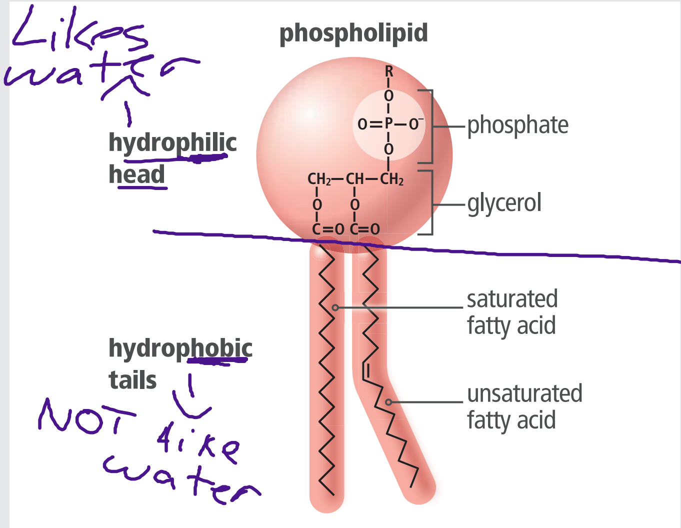
A phospholipid is a lipid that consists of glycerol, two fatty acids, and a phosphate group. The "head" of the phospholipid is made up of the glycerol backbone and the phosphate group. The fatty acids make up the "tails." The polar head of a phospholipid is soluble in water, or hydrophilic, which means "water loving." The nonpolar tails are insoluble in water, or hydrophobic, which means "water fearing." When phospholipids are placed in a watery environment, they arrange themselves in two layers. The hydrophilic phosphate heads face outside, and the hydrophobic tails face the inside, away from the water.

hydro = water

philic = like

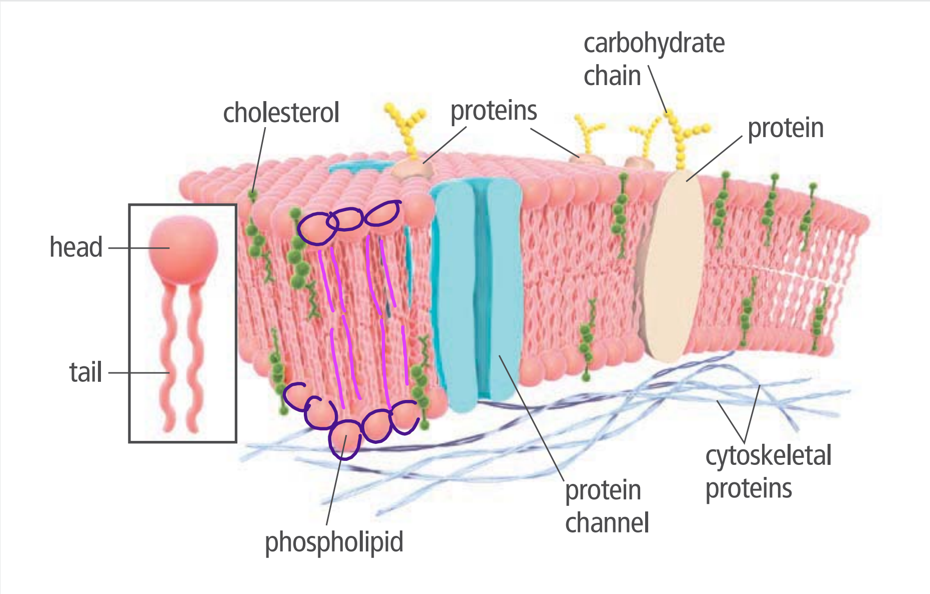
phobic = NOT Like

**FIGURE 12:** A phospholipid is made up of a hydrophilic head and hydrophobic tails. The head contains glycerol and a phosphate group. The fatty acids in the tails may be saturated or unsaturated.




Cell membranes are made up of a double layer of phospholipids. The polar heads face the outside of the membrane, and the nonpolar tails face the inside of the membrane. Since some of the molecules that need to pass through the membrane are polar, the nonpolar tails of the phospholipids would normally repel them. Proteins in the membrane create "passageways" that allow both polar and nonpolar molecules to pass from one side to the other.

**FIGURE 13:** Phospholipids are responsible for the dynamic nature of the cell membrane. The membrane also contains carbohydrates, cholesterol, and proteins.




**Predict** The hydrophobic tails of phospholipids keep water from passing directly through the cell membrane. How might this be beneficial for the maintenance of homeostasis in a cell?

## Waxes

Waxes are distinguished from other lipids by very long carbon chains that are very hydrophobic. They resist water and are solid at a range of temperatures. Waxes form protective coatings for many living things, including plants, animals, fungi, and bacteria. Their properties also make waxes valuable commodities. Many products contain waxes, including makeup and foods.

Worker honey bees make wax out of carbohydrate molecules in honey. Bees consume the honey, and special glands in their abdomens convert the sugars in the honey into wax molecules. The wax then oozes out of the bee through small pores and forms flakes on the outside of the bee's body. Worker bees then chew the wax to make it soft and pliable, and finally incorporate it into the beehive structure. These bees are breaking down carbon-based molecules to make different molecules.

**FIGURE 14:** Waxes form protective coatings on leaves.

**Analyze** Waxes are a main component of the cuticle found on the upper surface of some plant leaves. Why might the leaves of these plants have a waxy cuticle?

## Steroids

So far, the lipids you have examined have a mostly linear structure. Steroids, however, are a class of lipid that has a fused ring structure. All steroids have four linked carbon rings, and several of them have a short tail. Steroids contain both hydrophobic and hydrophilic regions, and they are insoluble in water.

Cholesterol is an example of a lipid with a fused ring structure. Your body needs a certain amount of cholesterol to function properly. Not all of the cholesterol in your body comes from your diet; your cells can make cholesterol from fatty acids. The ability to make cholesterol is important because it is an important part of cell membranes. Cholesterol is also the starting compound for steroid hormone production. 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.

**FIGURE 15:** A nutrition label shows how many milligrams of cholesterol are present in your food. Nutrition labels also show how many grams of carbohydrates, fats, and proteins are present.


**Explain** Excess cholesterol has been linked to heart disease, so the labels on some food products contain wording such as "cholesterol-free." Is it necessary to eat a completely cholesterol-free diet? Explain your answer.

6th

## Protein Structure and Function

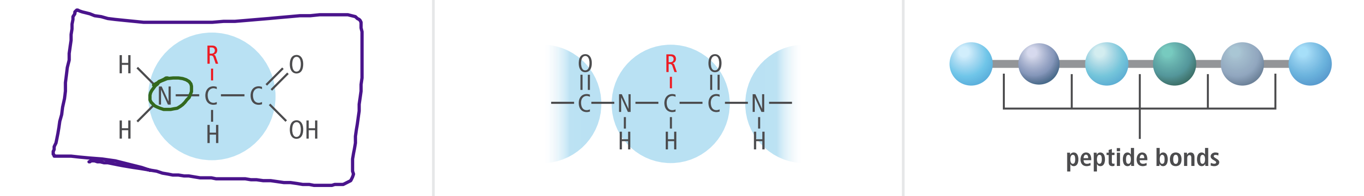
**Analyze** How do the terms polymer and monomer apply to the structure of protein molecules?

Nitrogen

Proteins are often described as the building blocks of life. They play many essential roles in organisms. Many proteins function as enzymes, which help regulate chemical reactions within our bodies. The building blocks for proteins are amino acids. There are a number of different amino acids, but organisms use only 20 to build proteins. Our bodies can make 12 of these standard amino acids. The others come from foods you eat, such as meats, beans, and nuts.

**FIGURE 16:** Proteins are made up of amino acids linked together in a chain called a polypeptide.

4th



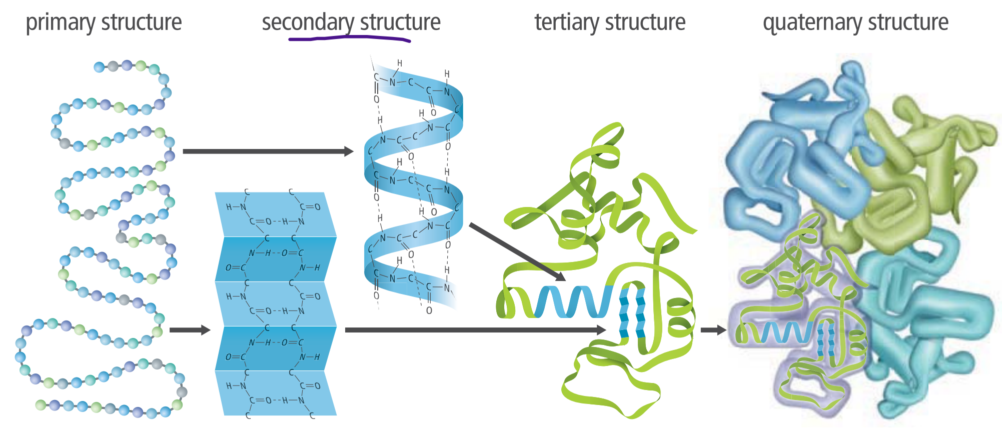

Amino acids have a carbon atom bonded to a hydrogen atom, an amino group ($NH_2$), and a carboxyl group (COOH). Different amino acids have different side groups (R).

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

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

Proteins differ in the number and order of amino acids. The specific sequence of amino acids determines a protein's structure and function. Proteins may have three, and sometimes four, levels of structure: primary, secondary, tertiary, and quaternary.

**FIGURE 17:** There are four possible levels of protein structure.




**Predict** Which would probably have the greatest effect on a protein's function—a change to the primary, secondary, or tertiary structure? Explain your answer.

The primary structure of a protein is the sequence of amino acids in the polypeptide. Hydrogen bonds between amino acids cause the chain to fold into zig-zag-shaped sheets and spirals, which make up the secondary structure. The tertiary structure is the 3D shape of the protein. Many proteins contain multiple polypeptide chains, or subunits, which combine to form the quaternary structure.

Remember that enzymes and other proteins are particularly sensitive to environmental changes. If pH or temperature exceed the normal ranges for a cell, the shape of its proteins may change, and their function may be disrupted. This process, called denaturation, only disrupts secondary, tertiary, and quaternary structures—the sequence of the protein remains unaffected.

# Nucleic Acid Structure and Function

The unique sequence of amino acids in a protein is determined by the sequence of monomers in another biological polymer: nucleic acid. Nucleic acid polymers 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. The sugar and phosphate nucleotides form the backbone of the DNA double helix. The nitrogenous bases form matching pairs held together by hydrogen bonds.

There are two general types of nucleic acids: DNA and RNA. Figure 19 shows the structure of each of these nucleotides and their nitrogenous bases. The names of the nitrogenous base also refer to the nucleotides that contain the bases.

**FIGURE 19:** DNA and RNA are both nucleic acids.

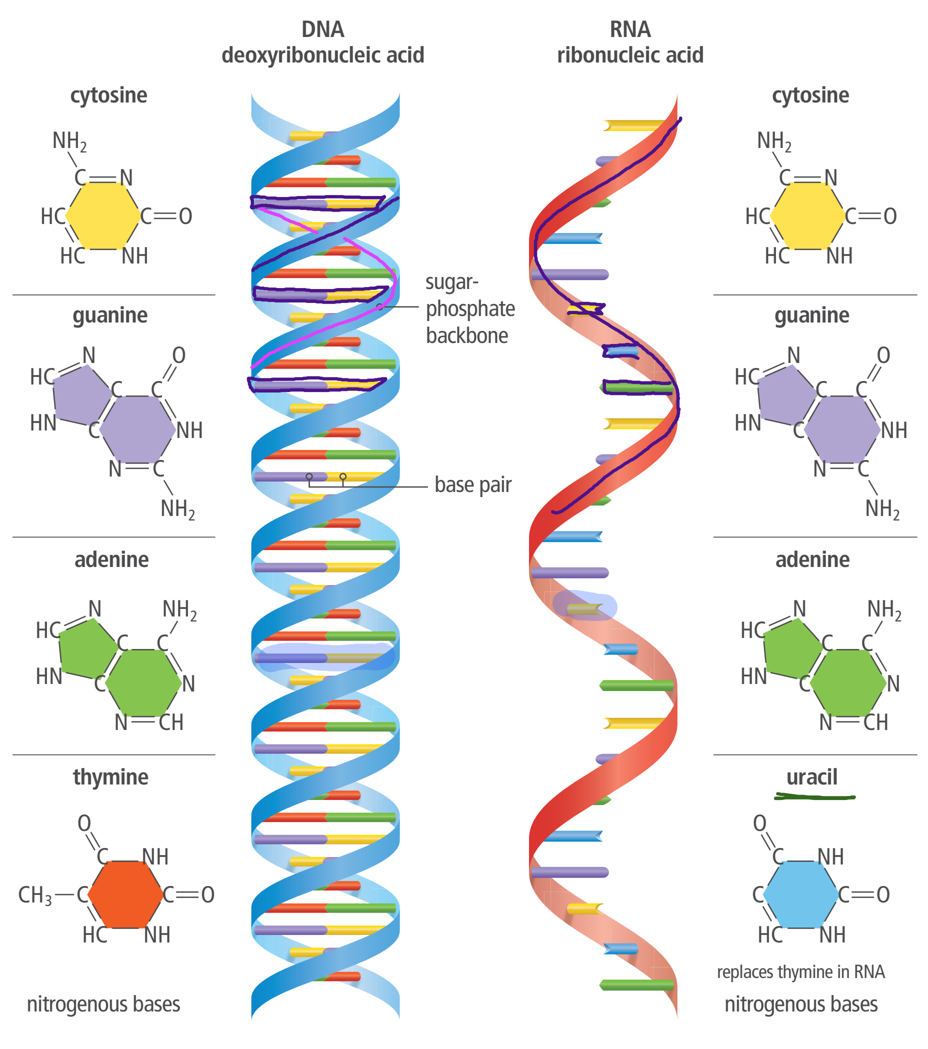
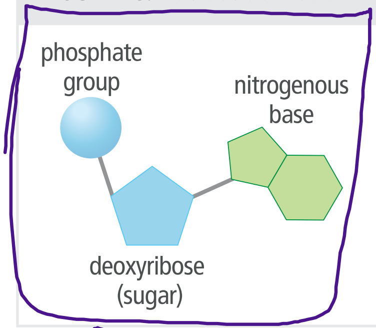



**FIGURE 18:** Nucleotide Model




BASE

**Collaborate** With a partner, compare and contrast RNA and DNA in terms of structure and nitrogenous bases.

**Explore Online**

**Hands-On Lab**

**Modeling Biochemical Compounds** Model a variety of biomolecules to better understand how atoms are arranged in these large molecules.

**Explain** Use evidence you have gathered to support or refute the claim that living things break down and rearrange carbon-based molecules. To organize your thoughts, make a graphic organizer to compare and contrast the four main types of biomolecules in these aspects: elemental makeup, overall structure, and main functions.