Properties of Carbon

Organic chemistry refers to the chemistry of carbon-based molecules, because living organisms are responsible for the production of nearly all naturally occurring carbon compounds. It was once believed that carbon-based compounds were only able to be produced in living things. Now, organic chemists know how to synthesize many different types of carbon-based compounds to make foods, materials, medicines, and much more.

Predict Why do you think carbon has an entire branch of chemistry devoted to its study?

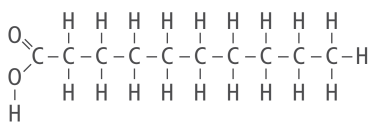
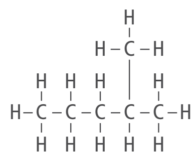
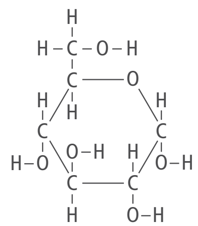
Despite the great number of carbon-based compounds that exist, those that compose all living things can be divided into four main groups: carbohydrates, lipids, proteins, and nucleic acids. Because of their relatively large size, these organic compounds are called macromolecules. Their structures and functions may differ in many ways, but they all share a common feature—they contain carbon.

Structure of Carbon-Based Molecules

Carbon atoms are the basis of most molecules that make up organisms and are involved in most processes that support life. The atomic structure of carbon gives it unique bonding properties. These properties allow it to form covalent bonds, or bonds that share pairs of electrons. Carbon has four available electrons to share with atoms of other elements to form covalent bonds. In organic molecules, carbon is most commonly bonded to the elements hydrogen, oxygen, nitrogen, and phosphorus.

Collaborate With a partner, compare the shapes of the molecules in Figure 2. What is similar? What differs?

FIGURE 2: Carbon-based molecules can have many different structures, including straight chains, branched chains, and rings.

Straight Chain	Branched Chain	Ring
		
CAPRIC ACID	**ISOHEXANE**	**GLUCOSE**
A fatty acid found in plant oils such as coconut oil and palm kernel oil, as well as in the milk of some mammals. This fatty acid has been shown to have antibacterial and anti-inflammatory properties.	A clear liquid used to make gasoline and glues, and as a solvent for extracting oils.	A simple sugar that is an important energy source for living organisms.

Analyze According to Figure 2, how many chemical bonds does carbon form? How is the number of bonds carbon can make related to its ability to form molecules with many different shapes?

In addition to forming single bonds, carbon atoms can also form double, or even triple, bonds. In structural formulas, double bonds are represented with two bars, and triple bonds are represented with three bars. As you can see in Figure 3, the carbon atom in carbon dioxide forms a double bond with each oxygen atom. In acetylene, each carbon forms one triple and one single bond. Both are carbon-based gases, but they have different chemical properties. For example, they have different densities, and carbon dioxide is odorless, while acetylene has a slight odor similar to garlic.

Predict Which do you think is the strongest type of covalent bond? A single, double, or triple bond? Explain your answer.

FIGURE 3: Carbon can form single, double, or triple bonds.

Carbon Dioxide (CO_2)	Acetylene (C_2H_2)
O=C=O	H–C≡C–H
A colorless, odorless gas that is naturally present in air (about 0.03 percent) and is used by plants in photosynthesis.	A colorless gas that burns with a bright flame and is used in welding. In its pure form, it has a sweet, garlic-like odor.

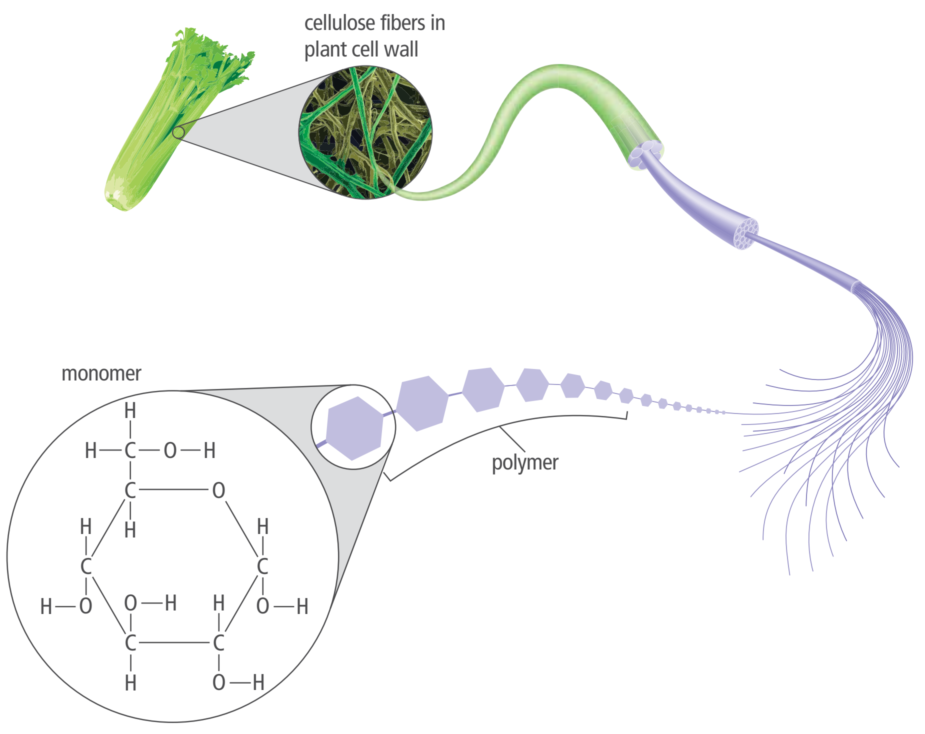
Monomers and Polymers

Looking back at Figure 2, you may note three characteristics of carbon atoms. One is that carbon can bond with itself or other atoms. The second is that the unique bonding in carbon molecules enables them to form a ring or a long-chain structure of repeating subunits. A polymer is a large molecule made of subunits called monomers. The monomers in a polymer may be the same, as they are in the cellulose molecule in Figure 4, or they may be different, as they are in proteins. The third characteristic of carbon atoms is they often bind to hydrogen atoms. In fact, many carbon compounds contain only carbon and hydrogen and are a class of compounds called hydrocarbons. The covalent bonds in hydrocarbons store a great amount of energy.

Monomer
mono - one
Polymer
poly - many

Language Arts Connection One polymer you may have heard of before is silk. Silk fibers, made by spiders and some worms, are very strong and durable. Now, researchers are trying to produce even stronger silk by feeding silkworms carbon-based materials such as carbon nanotubes. Scientists are hoping to use the enhanced silk for medical implants and wearable electronics. With a partner, research carbon-enhanced silk and discuss the ways this material might influence human society.

FIGURE 4: Cellulose is a polymer made of smaller subunits called glucose monomers.



Engineering

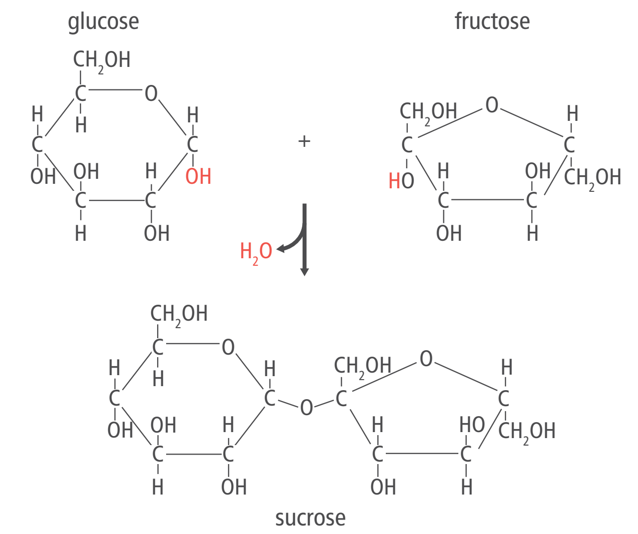
Making Polymers

Polymers may form through the process of dehydration synthesis. This process involves chemical reactions in which a molecule of water (H_2O) is released as one monomer bonds to another. One monomer provides a hydrogen ion (H^+) and the other provides a hydroxyl group (OH^-). Some polymers can be broken down in a reverse reaction, called hydrolysis. The bonds between the monomers are broken by the addition of water molecules.

In the human body, enzymes called hydrolases use hydrolysis to break apart polymers. In industry, dehydration synthesis can be used to make a wide variety of polymers, such as those in nylon and polyester fabrics.

Explain What might be some of the economic and environmental tradeoffs of producing clothes from human-made polymers, such as nylon and polyester, versus natural polymers, such as cotton?

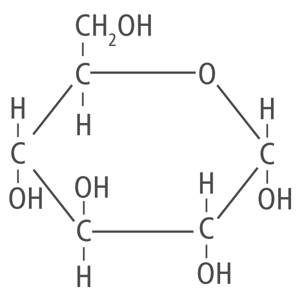
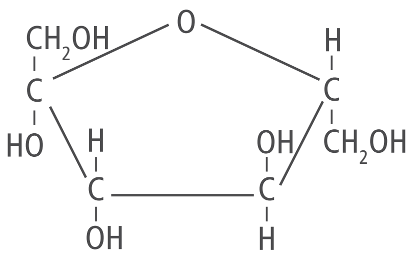
FIGURE 5: Glucose and fructose undergo dehydration to form sucrose, commonly known as table sugar.



Isomers

The ~~molecular structures you've seen so far look flat, but molecules are actually three-dimensional (3D).~~ The 3D placement of atoms and chemical bonds within organic molecules is central to understanding their chemistry. Molecules that share the same chemical formula but differ in the placement, or structure, of their atoms and/or chemical bonds are known as isomers. Because the atoms are connected in different ways, isomers have different physical and chemical properties. For example, glucose and fructose are energy sources for cell processes. However, fructose is not as easily metabolized as glucose. Isomers allow for greater variety of organic compounds with different properties.

FIGURE 6: The isomers glucose and fructose both have the chemical formula $C_6H_{12}O_6$.

Glucose	Fructose
	

Explain Compare and contrast the different types of carbon structures in terms of their structures, chemical formulas, and functions.