3.1 Carbon

Learning objectives

By the end of this section, you will be able to:

- *Describe how carbon is critical to life*
- *Understand why something is organic vs. inorganic*
- *Describe the role of functional groups in biological molecules*
- *List the four categories of macromolecules and their main characteristics*
- *Be able to define and explain all bolded terms*

Cells contain many complex molecules called macromolecules. Carbohydrates, lipids, proteins, and nucleic acids are all examples of large molecules necessary for life. There has been some discussion on what constitutes a macromolecule. For example, carbohydrates, proteins, and nucleic acid are all significantly larger in molecular size when compared to lipids. Some suggest because of this they should not be called a macromolecule. On the other hand, lipids are made up of many atoms and are significantly larger than, for example, a molecule of water. Whether lipids are classified as a macromolecule or not, one fact holds true, lipids are important cell components that perform a wide array of functions allowing living organisms to maintain homeostasis.

Carbohydrates, lipids, proteins, and nucleic acids are all organic molecules. **Organic molecules** generally refer to those molecules that have carbon as the principal element, bonded to hydrogen and other carbon atoms. Some carbon-containing compounds are *not* classified as organic, such as CO and CO_2. Molecules that do not contain carbon and hydrogen, such as water, are classified as inorganic.

Carbon atoms are the fundamental components for all carbohydrates, lipids, proteins, and nucleic acids. Because carbon does not have a full valence electron shell, it is incredibly reactive. Carbon has an atomic number of 6 and is in group six on the periodic table. Therefore, elemental carbon has 6 protons and 6 electrons. Carbon atoms can form up to four covalent bonds with other atoms to satisfy the octet rule. The methane molecule provides an excellent example. In methane, the carbon atom forms four separate covalent bonds with four different hydrogen atoms (Figure 3.2). The valence shells for both hydrogen and carbon are now satisfied, thus creating a relatively stable molecule.

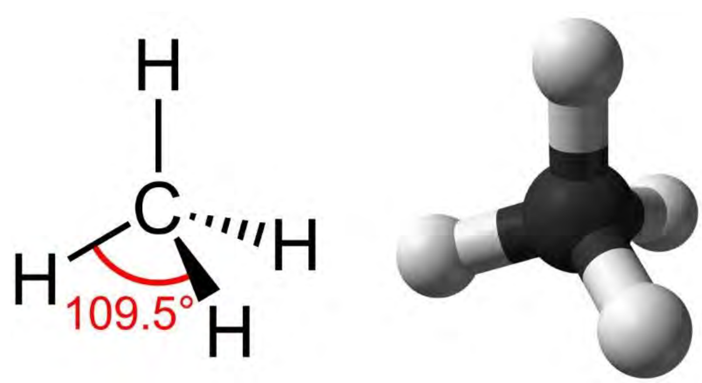


Figure 3.2 Methane has a tetrahedral geometry, with each of the four hydrogen atoms spaced 109.5° apart. (credit: Clark et al./ Biology 2E OpenStax)

Hydrocarbons

Hydrocarbons are organic molecules consisting entirely of carbon and hydrogen, such as methane described above. We often use hydrocarbons in our daily lives. Fuels like the propane in a gas grill, or the butane in a lighter, are classified as hydrocarbons. The atoms in hydrocarbons form many covalent bonds which store large amounts of energy. This energy is released when these molecules burn (oxidize). For this reason, hydrocarbon molecules make excellent fuel sources.

Hydrocarbons form the backbones of large macromolecules and may be linear chains, carbon rings, or a combination of both. Furthermore, carbon-carbon bonds may be single, double, or triple bonds, with each type of bond affecting the molecule's three-dimensional shape in a specific way (Figure 3.3). The three-dimensional shape or conformation of a molecule is critical to determining its function.

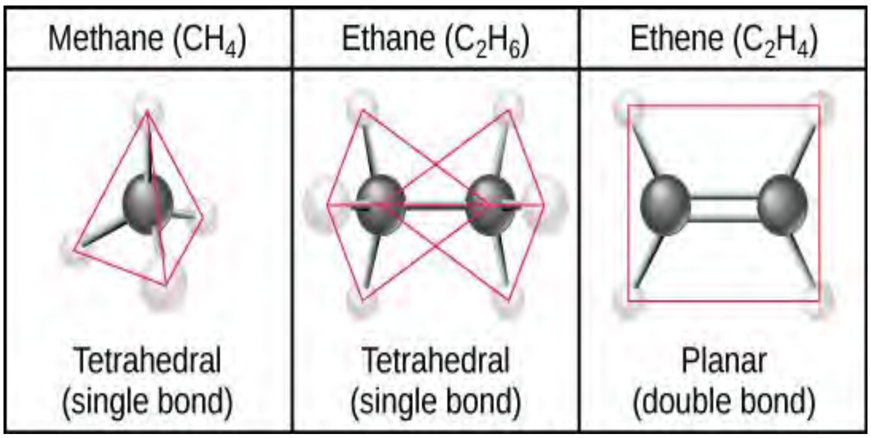


Figure 3.3 When carbon forms single bonds with other atoms, the shape is tetrahedral. When two carbon atoms form a double bond, the shape is planar, or flat. Single bonds, like those in ethane, can rotate. Double bonds, like those in ethene, cannot rotate. (credit: Clark et al./ Biology 2E OpenStax)

Isomers

The bonds that hold a molecule together help dictate its three-dimensional shape. Isomers are molecules that have the same chemical formula but differ from one another in the arrangement of their atoms and or chemical bonds. Structural isomers like butane and isobutane (Figure 3.4) differ in the placement of their covalent bonds. Both molecules have four carbons and ten hydrogen atoms (C_4H_{10}), but they differ from one another in the arrangement of their atoms. Structural differences lead to differences in chemical properties which will cause the isomers to function differently. For example, butane is used as a fuel source for lighters and torches, whereas isobutane is used as a coolant in refrigeration units and a propellant in spray cans.

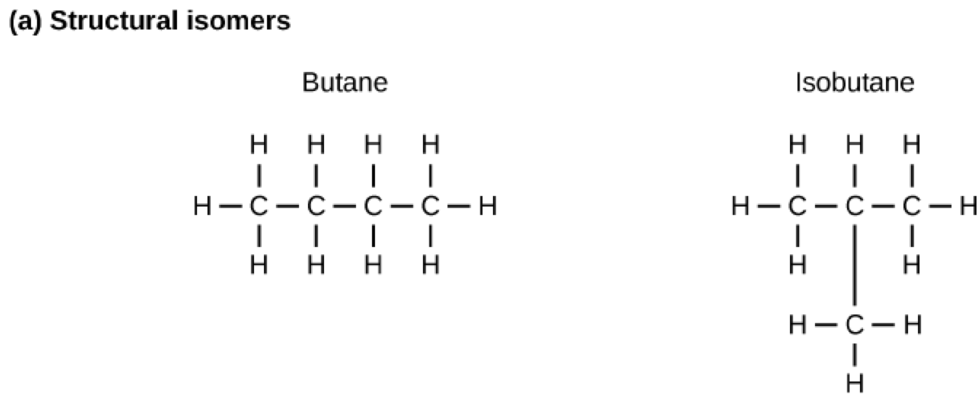


Figure 3.4 a. Structural butane and isobutane isomers have a different covalent arrangement of atoms. (credit: Modified by Elizabeth O'Grady original work of Clark et al./ Biology 2E OpenStax)

Functional Groups

Functional groups are groups of atoms that are found within macromolecules and confer specific chemical properties to those molecules. The functional groups in a macromolecule are usually attached to the carbon backbone at one or several different places along its chain and or ring structure. Carbohydrates, lipids, proteins, and nucleic acids each have their own characteristic set of functional groups that contributes significantly to its differing chemical properties and its function in living organisms. For example, proteins are unique from other biologically important molecules in that their building blocks, amino acids, have both a carboxyl and amino functional group. Nucleic acids in comparison are made of building blocks called nucleotides, that always contain a phosphate functional group.

Figure 3.5 shows some of the important functional groups in biological macromolecules. They include hydroxyl, methyl, carbonyl, carboxyl, amino, phosphate, and sulfhydryl groups. We usually classify functional groups as **hydrophobic** or **hydrophilic** depending on their charge or polarity. An example of a hydrophobic group is the nonpolar methyl molecule, which is hugely prevalent in lipids. The carboxyl group is hydrophilic and found in amino acids, the building blocks of proteins.

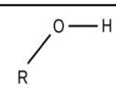
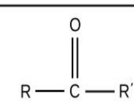
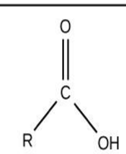
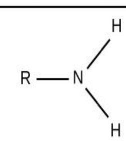
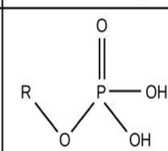
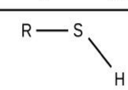
Functional Group	Structure	Properties
Hydroxyl		Polar
Methyl	$R - CH_3$	Nonpolar
Carbonyl		Polar
Carboxyl		Charged, ionizes to release H^+. Since carboxyl groups can release H^+ ions into solution, they are considered acidic.
Amino		Charged, accepts H^+ to form NH_3^+. Since amino groups can remove H^+ from solution, they are considered basic.
Phosphate		Charged, ionizes to release H^+. Since phosphate groups can release H^+ ions into solution, they are considered acidic.
Sulfhydryl		Polar

Figure 3.5 These functional groups are in many different biological molecules. (credit: Clark et al./ Biology 2E OpenStax)