CHAPTER 4
CARBON AND MOLECULAR DIVERSITY

OUTLINE

I. The Importance of Carbon
   A. Organic chemistry is the study of carbon compounds
   B. Carbon atoms are the most versatile building blocks of molecules
   C. Variation in carbon skeletons contributes to the diversity of organic molecules

II. Functional Groups
   A. Functional groups also contribute to the molecular diversity of life

OBJECTIVES

After reading this chapter and attending lecture, the student should be able to:

1. Summarize the philosophies of *vitalism* and *mechanism*, and explain how they influenced the development of organic chemistry, as well as mainstream biological thought.
2. Explain how carbon's electron configuration determines the kinds and number of bonds carbon will form.
3. Describe how carbon skeletons may vary, and explain how this variation contributes to the diversity and complexity of organic molecules.
4. Distinguish among the three types of isomers: structural, geometric and enantiomers.
5. Recognize the major functional groups, and describe the chemical properties of organic molecules in which they occur.

KEY TERMS

organic chemistry	enantiomer	aldehyde	amine
hydrocarbon	functional group	ketone	sulfhydryl group
isomer	hydroxyl group	carboxyl group	thiol
structural isomer	alcohol	carboxylic acid	phosphate group
geometric isomer	carbonyl group	amino group	

LECTURE NOTES

Aside from water, most biologically important molecules are carbon-based (*organic*).

The structural and functional diversity of organic molecules emerges from the ability of carbon to form large, complex and diverse molecules by bonding to itself and to other elements such as H, O, N, S, and P.

I. The Importance of Carbon

A. Organic chemistry is the study of carbon compounds

Organic chemistry = The branch of chemistry that specializes in the study of carbon compounds.

Organic molecules = Molecules that contain carbon

Vitalism = Belief in a life force outside the jurisdiction of chemical/physical laws.

- Early 19th century organic chemistry was built on a foundation of vitalism because organic chemists could not artificially synthesize organic compounds. It was believed that only living organisms could produce organic compounds.

Mechanism = Belief that all natural phenomena are governed by physical and chemical laws.

- Pioneers of organic chemistry began to synthesize organic compounds from inorganic molecules. This helped shift mainstream biological thought from vitalism to mechanism.
- For example, Friedrich Wohler synthesized urea in 1828; Hermann Kolbe synthesized acetic acid.
- Stanley Miller (1953) demonstrated the possibility that organic compounds could have been produced under the chemical conditions of primordial Earth.

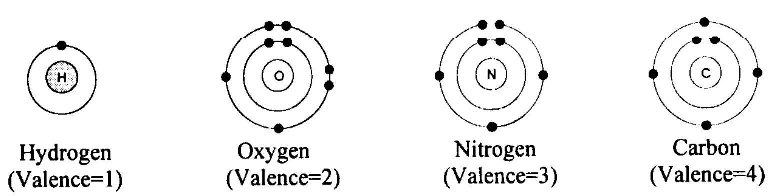
B. Carbon atoms are the most versatile building blocks of molecules

The carbon atom:

- Usually has an atomic number of 6; therefore, it has 4 valence electrons.
- Usually completes its outer energy shell by sharing valence electrons in four covalent bonds. (Not likely to form ionic bonds.)

Emergent properties, such as the kinds and number of bonds carbon will form, are determined by their *tetravalent* electron configuration.

- It makes large, complex molecules possible. The carbon atom is a central point from which the molecule branches off into four directions.
- It gives carbon covalent compatibility with many different elements. The four major atomic components of organic molecules are as follows:



- It determines an organic molecule's three-dimensional shape, which may affect molecular function. For example, when carbon forms four single covalent bonds, the four valence orbitals hybridize into teardrop-shaped orbitals that angle from the carbon atoms toward the corners of an imaginary tetrahedron.

> Students have problems visualizing shapes of organic molecules in three dimensions. Specific examples can be enhanced by an overhead transparency of ball-and-stick or space-filling models. A large three-dimensional molecular model that can be held up in front of class works best (see Campbell, Figure 4.2)

C. Variation in carbon skeletons contributes to the diversity of organic molecules

Covalent bonds link carbon atoms together in long chains that form the skeletal framework for organic molecules. These carbon skeletons may vary in:

- Length
- Shape (straight chain, branched, ring)
- Number and location of double bonds
- Other elements covalently bonded to available sites

This variation in carbon skeletons contributes to the complexity and diversity of organic molecules (see Campbell, Figure 4.4).

Hydrocarbons = Molecules containing only carbon and hydrogen

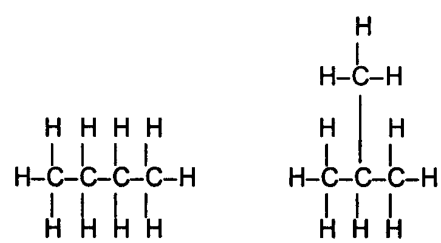
- Are major components of fossil fuels produced from the organic remains of organisms living millions of years ago, though they are not prevalent in living organisms.
- Have a diversity of carbon skeletons which produce molecules of various lengths and shapes.
- As in hydrocarbons, a carbon skeleton is the framework for the large diverse organic molecules found in living organisms. Also, some biologically important molecules may have regions consisting of hydrocarbon chains (e.g. fats).
- Hydrocarbon chains are hydrophobic because the C–C and C–H bonds are nonpolar.

1. Isomers

Isomers = Compounds with the same molecular formula but with different structures and hence different properties. Isomers are a source of variation among organic molecules.

There are three types of isomers (see Campbell, Figure 4.6):

Structural isomers = Isomers that differ in the covalent arrangement of their atoms.



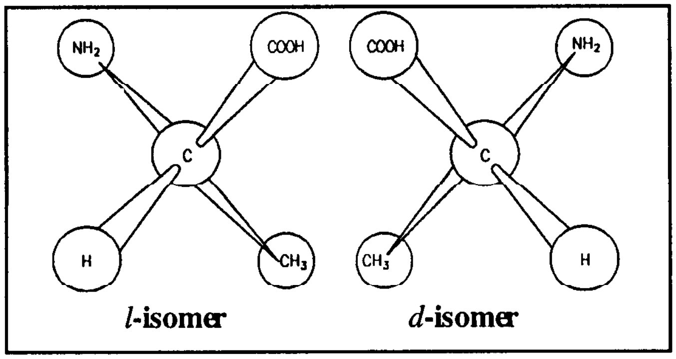
- Number of possible isomers increases as the carbon skeleton size increases.
- May also differ in the location of double bonds.

Geometric isomers = Isomers which share the same covalent partnerships, but differ in their spatial arrangements.

- Result from the fact that double bonds will not allow the atoms they join to rotate freely about the axis of the bonds.
- Subtle differences between isomers affects their biological activity.

Enantiomers = Isomers that are mirror images of each other.

- Can occur when four different atoms or groups of atoms are bonded to the same carbon (*asymmetric carbon*).
- There are two different spatial arrangements of the four groups around the asymmetric carbon. These arrangements are mirror images.
- Usually one form is biologically active and its mirror image is not.



It is often helpful to point at the pharmacological significance of enantiomers, e.g., Campbell, Figure 4.7.

II. Functional Groups

A. Functional groups also contribute to the molecular diversity of life

Small characteristic groups of atoms (functional groups) are frequently bonded to the carbon skeleton of organic molecules. These functional groups:

- Have specific chemical and physical properties.
- Are the regions of organic molecules which are commonly chemically reactive.
- Behave consistently from one organic molecule to another.
- Depending upon their number and arrangement, determine unique chemical properties of organic molecules in which they occur.

As with hydrocarbons, diverse organic molecules found in living organisms have carbon skeletons. In fact, these molecules can be viewed as hydrocarbon derivatives with functional groups in place of H, bonded to carbon at various sites along the molecule.

1. The hydroxyl group

Hydroxyl group = A functional group that consists of a hydrogen atom bonded to an oxygen atom, which in turn is bonded to carbon (–OH).

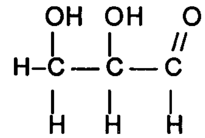
- Is a *polar* group; the bond between the oxygen and hydrogen is a polar covalent bond.
- Makes the molecule to which it is attached *water soluble*. Polar water molecules are attracted to the polar hydroxyl group which can form hydrogen bonds.
- Organic compounds with hydroxyl groups are called *alcohols*.

2. The carbonyl group

Carbonyl group = Functional group that consists of a carbon atom double-bonded to oxygen (–CO).

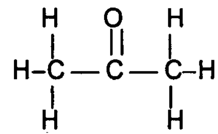
- Is a *polar* group. The oxygen can be involved in hydrogen bonding, and molecules with his functional group are *water soluble*.
- Is a functional group found in sugars.

- If the carbonyl is at the end off the carbon skeleton, the compound is an *aldehyde*.



Glyceraldehyde

- If the carbonyl is at the end of the carbon skeleton, the compound is a *ketone*.

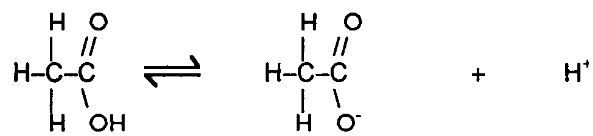


Acetone

3. **The carboxyl group**

Carboxyl group = Functional group that consists of a carbon atom which is both double-bonded to an oxygen and single-bonded to the oxygen of a hydroxyl group (–COOH).

- Is a polar group and water soluble. The covalent bond between oxygen and hydrogen is so polar, that the hydrogen reversibly dissociates as H^+. This polarity results from the combined effect of the two electronegative oxygen atoms bonded to the same carbon.



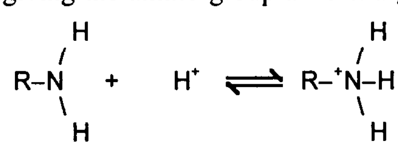
Acetic acid Acetate ion Hydrogen ion

- Since it donates protons, this group has acidic properties. Compounds with this functional group are called *carboxylic acids*.

4. **The amino group**

Amino group = Functional group that consists of a nitrogen atom bonded to two hydrogens and to the carbon skeleton ($-NH_2$).

- Is a polar group and soluble in water.
- Acts as a weak base. The unshared pair of electrons on the nitrogen can accept a proton, giving the amino group a +1 charge.



Amine Ammonium ion

- Organic compounds with this function group are called *amines*.

5. **The Sulfhydryl group**

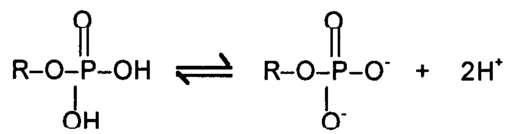
Sulfhydryl group = Functional group which consists of an atom of sulfur bonded to an atom of hydrogen (–SH).

- Help stabilize the structure of proteins. (Disulfide bridges will be discussed with tertiary structure of proteins in Chapter 5, Structure and Function of Macromolecules.)
- Organic compounds with this functional group are called *thiols.*

6. **The phosphate group**

Phosphate group = Functional group which is the dissociated form of phosphoric acid (H_3PO_4).

- Loss of two protons by dissociation leaves the phosphate group with a negative charge.



- Has acid properties since it loses protons.
- Polar group and soluble in water.
- Organic phosphates are important in cellular energy storage and transfer. (ATP is discussed with energy for cellular work in Chapter 6: Introduction to Metabolism.)

In lecture, you may also choose to include the methyl group ($-CH_3$) as an example of a nonpolar hydrophobic functional group. This is helpful later in the course in explaining how nonpolar amino acids contribute to the tertiary structure of proteins including integral membrane proteins.

To impress upon students how important functional groups are in determining chemical behavior of organic molecules, use the following demonstration: show a comparison of estradiol and testosterone and ask students to find the differences in functional groups. Ask one male and female student to stand up or show pictures of sexual dimorphism in other vertebrates. Point out that differences between males and females are due to slight variation in functional groups attached to sex hormones.

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