Chapter 4

Carbon and the Molecular Diversity of Life

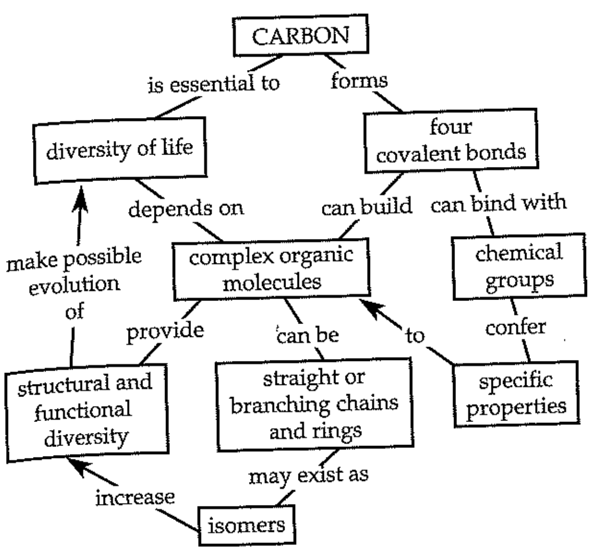
Key Concepts

4.1 **Organic chemistry is the study of carbon compounds**

4.2 **Carbon atoms can form diverse molecules by bonding to four other atoms**

4.3 **A few chemical groups are key to molecular function**

Framework



Chapter Review

4.1 Organic chemistry is the study of carbon compounds

Organic chemistry is the study of carbon-containing compounds. Early chemists could not make the complex molecules found in living organisms. Later these organic compounds were synthesized, supporting the view that the processes of life are governed by physical and chemical laws.

Organic Molecules and the Origin of Life on Earth Stanley Miller's 1953 experiment showed that organic molecules could form under conditions believed to simulate those on early Earth.

INTERACTIVE QUESTION 4.1

How did Miller's classic experiment relate to the origin of life?

4.2 Carbon atoms can form diverse molecules by bonding to four other atoms

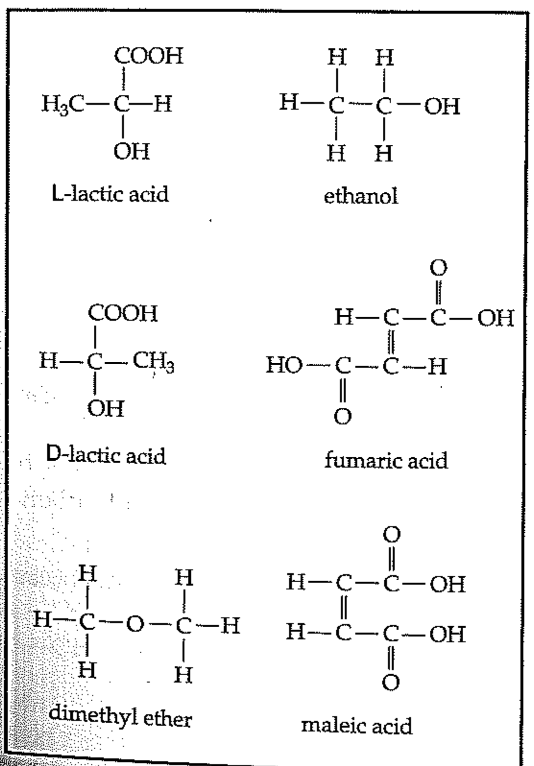
The Formation of Bonds with Carbon How many covalent bonds must carbon (with an atomic number of 6) form to complete its valence shell? Carbon's valence of four is at the center of its ability to form large and complex molecules. When carbon forms four single covalent bonds, its hybrid orbitals create a tetrahedral shape. When two carbons are joined by a double bond, the other atoms bonded to the carbons are in the same plane, forming a flat molecule.

Molecular Diversity Arising from Variation in Carbon Skeletons Carbon skeletons can vary in length, branching, placement of double bonds, and the presence of rings. **Hydrocarbons** consist of only carbon and hydrogen. Hydrocarbon chains are hydrophobic due to their nonpolar C—H bonds, and they release energy when broken down.

Isomers are compounds with the same molecular formula but different structural arrangements and thus different properties. **Structural isomers** differ in the covalent arrangement of atoms and often in the location of double bonds. ***Cis-trans* isomers** (formerly called geometric isomers) have the same sequence of covalently bonded atoms overall but differ in structure due to the inflexibility of double bonds. A *cis* isomer has the same atoms attached to the carbons on the same side of the double bond; a *trans* isomer has these atoms on opposite sides of the double bond. **Enantiomers** are left- and right-handed versions of a molecule and can differ greatly in their biological activity. An *asymmetric carbon* is one that is covalently bonded to four different kinds of atoms or groups of atoms, whose arrangement can result in mirror images.

INTERACTIVE QUESTION 4.2

Define structural isomers, *cis-trans* isomers, and enantiomers, and then identify these types of isomers in the following compounds. Which of the *cis-trans* isomers is the *cis* isomer?



4.3 A few chemical groups are key to molecular function

The Chemical Groups Most Important in the Processes of Life The properties of organic molecules are largely determined by characteristic chemical groups attached to the carbon skeleton. The following six **functional groups** may participate in chemical reactions. Except for the sulfhydryl group, these hydrophilic groups increase the solubility of organic compounds in water. A seventh group, the nonpolar methyl group, alters molecular shape and may serve as a signal on organic molecules.

The **hydroxyl group** consists of an oxygen and hydrogen (—OH). Organic molecules with hydroxyl groups are called alcohols, and their names usually end in *-ol*.

A **carbonyl group** consists of a carbon double-bonded to an oxygen (>CO). If the carbonyl group is at the end of the carbon skeleton, the compound is called an aldehyde. Otherwise, the compound is called a ketone.

A **carboxyl group** consists of a carbon double-bonded to an oxygen and also attached to a hydroxyl group (—COOH). Compounds with a carboxyl group are called carboxylic acids or organic acids because they tend to donate an H^+, becoming a carboxylate ion ($—COO^-$).

An **amino group** consists of a nitrogen atom bonded to two hydrogen atoms ($—NH_2$). Compounds with an amino group, called amines, can act as bases, picking up an H^+ and becoming $—NH_3^+$.

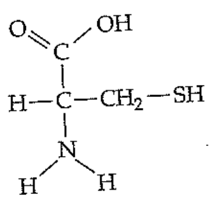
The **sulfhydryl group** consists of a sulfur atom bonded to a hydrogen (—SH). Thiols are compounds containing sulfhydryl groups.

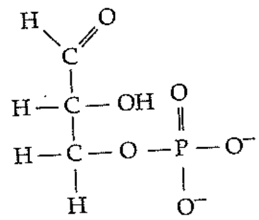
A **phosphate group** is bonded to a carbon skeleton by an oxygen attached to a phosphorus atom that is bonded to three other oxygen atoms ($—OPO_3^{2-}$). This anion contributes negative charge to organic phosphates.

A **methyl group** consists of a carbon bonded to three H atoms ($—CH_3$). Methylated compounds may have their function modified due to the addition of the methyl group.

INTERACTIVE QUESTION 4.3

Practice recognizing the functional groups by circling and naming the groups you see in the following molecules.





ATP: An Important Source of Energy for Cellular Processes **Adenosine triphosphate,** or **ATP,** consists of the organic molecule adenosine to which three phosphate groups are attached. When ATP reacts with water, the third phosphate is split off and energy is released.

The Chemical Elements of Life: A Review Carbon, oxygen, hydrogen, nitrogen, and smaller quantities of sulfur and phosphorus, all capable of forming strong covalent bonds, are combined into the complex organic molecules of living matter.

Word Roots

carb- = coal (*carboxyl group:* a chemical group present in organic acids, consisting of a carbon atom double-bonded to an oxygen atom and also bonded to a hydroxyl group)

enanti- = opposite (*enantiomer:* one of two compounds that are mirror images of each other and that differ in shape due to the presence of an asymmetric carbon)

hydro- = water (*hydrocarbon:* an organic molecule consisting only of carbon and hydrogen)

iso- = equal (*isomer:* one of several organic compounds with the same molecular formula but different structures and therefore different properties)

sulf- = sulfur (*sulfhydryl group:* a chemical group that consists of a sulfur atom bonded to a hydrogen atom)

Structure Your Knowledge

1. Construct a concept map that illustrates your understanding of the characteristics and significance of the three types of isomers. *A suggested map is in the answer section. Comparing and discussing your map with that of a study partner would be most helpful.*
2. Fill in the following table to review the important chemical groups of organic compounds.

Chemical Group	Molecular Formula	Names and Characteristics of Compounds Containing Group
	—OH	
		Aldehyde or ketone; polar group
Carboxyl		
	$—NH_2$	
		Thiols; cross-links stabilize protein
Phosphate		
	$—CH_3$	

Test Your Knowledge

MULTIPLE CHOICE: *Choose the one best answer.*

1. Carbon's valence of four most directly results from its
   a. tetrahedral shape.
   b. four electrons in the valence shell that can form four covalent bonds.
   c. ability to form single, double, and triple bonds.
   d. ability to form chains and rings of carbon atoms.
2. Hydrocarbons are not soluble in water because
   a. they are hydrophilic.
   b. their C—H bonds are nonpolar.
   c. they do not ionize.
   d. they are lighter than water.
3. Which of the following is *not* true of an asymmetric carbon atom?
   a. It is attached to four different atoms or groups.
   b. It results in right- and left-handed versions of a molecule.

c. Its configuration is in the shape of a tetrahedron.

d. It is found in *cis-trans* isomers.

4. Which statement is *not* true about structural isomers?

a. They have the same molecular formula but different chemical properties.

b. Their atoms and bonds are arranged in different sequences.

c. They are a result of restricted movement around a carbon double bond.

d. Their possible numbers increase as carbon skeletons increase in size.

5. The fats stored in your body consist mostly of

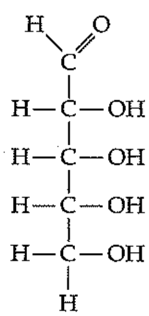
a. methyl groups.

b. alcohols.

c. carboxylic acids.

d. hydrocarbons.

6. The following ribose molecule contains how many asymmetric carbons?



a. 1
b. 2
c. 3
d. 4

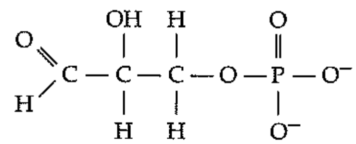
7. The chemical group that can cause an organic molecule to act as a base is

a. —COOH.
b. —OH.
c. —SH.
d. $—NH_2$.

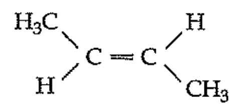
8. The chemical group that confers acidic properties to organic molecules is

a. —COOH.
b. —OH.
c. —SH.
d. $—NH_2$.

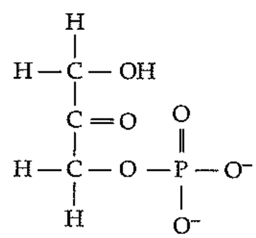
MATCHING: *Match the formulas (a–f) to the terms at the right. Choices may be used more than once, and terms may have more than one correct answer.*



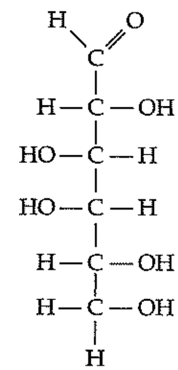
a.



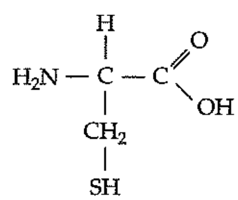
b.



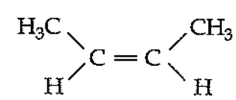
c.



d.



e.



f.

________ 1. structural isomers

________ 2. *cis-trans* isomers

________ 3. can have enantiomers

________ 4. carboxylic acid

________ 5. can make cross-link in protein

________ 6. hydrophilic

________ 7. hydrocarbon

________ 8. amino acid

________ 9. organic phosphate

________ 10. aldehyde

________ 11. amine

________ 12. ketone