BIOLOGY I

Chapter 4: Carbon and the Molecular Diversity of Life

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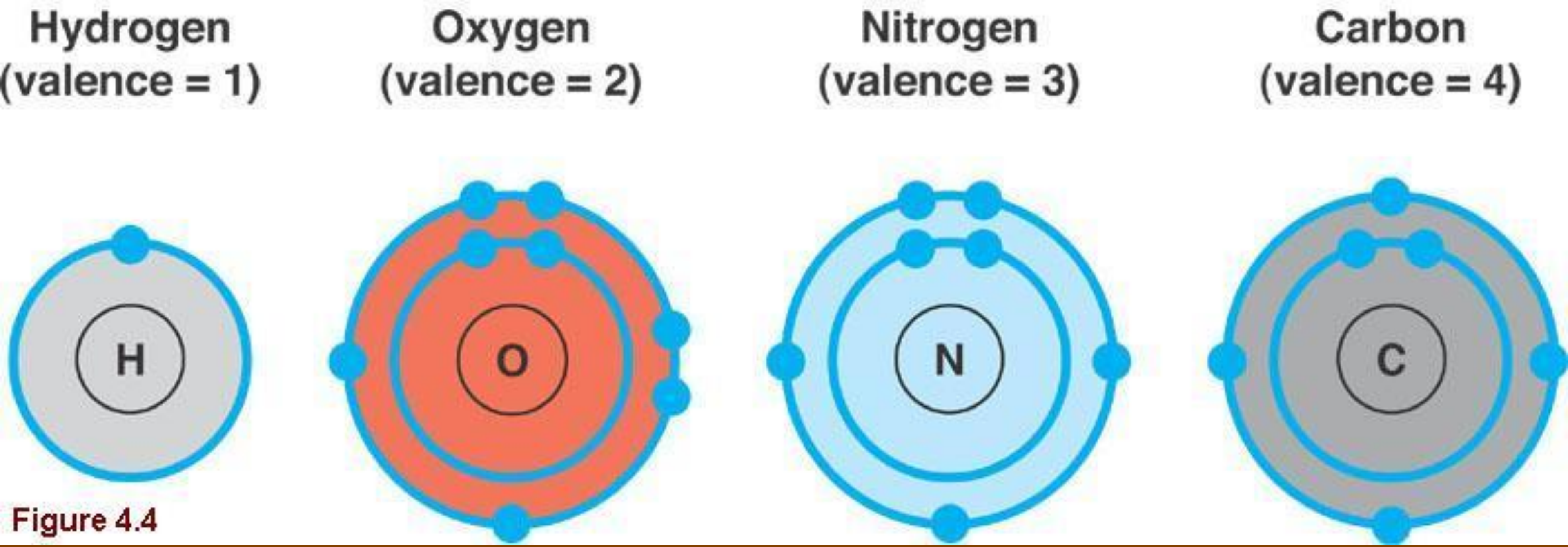
Carbon and the Molecular Diversity of Life

- **Carbon (C)** accounts for the large diversity of biological molecules; it is the backbone of biological organic molecules:
  - **Carbohydrates, lipids, nucleic acids, proteins.**
- Molecules that contain carbon (and at least one hydrogen atom) are called **organic molecules**, or organic compounds. Living organisms are made up of these molecules, which distinguish them from inanimate material.
- * Remember: The ***major elements of life*** are **carbon (C)**, **hydrogen (H)**, **oxygen (O)**, and **nitrogen (N)**; with smaller amounts of **sulfur (S)** and **phosphorus (P)**.

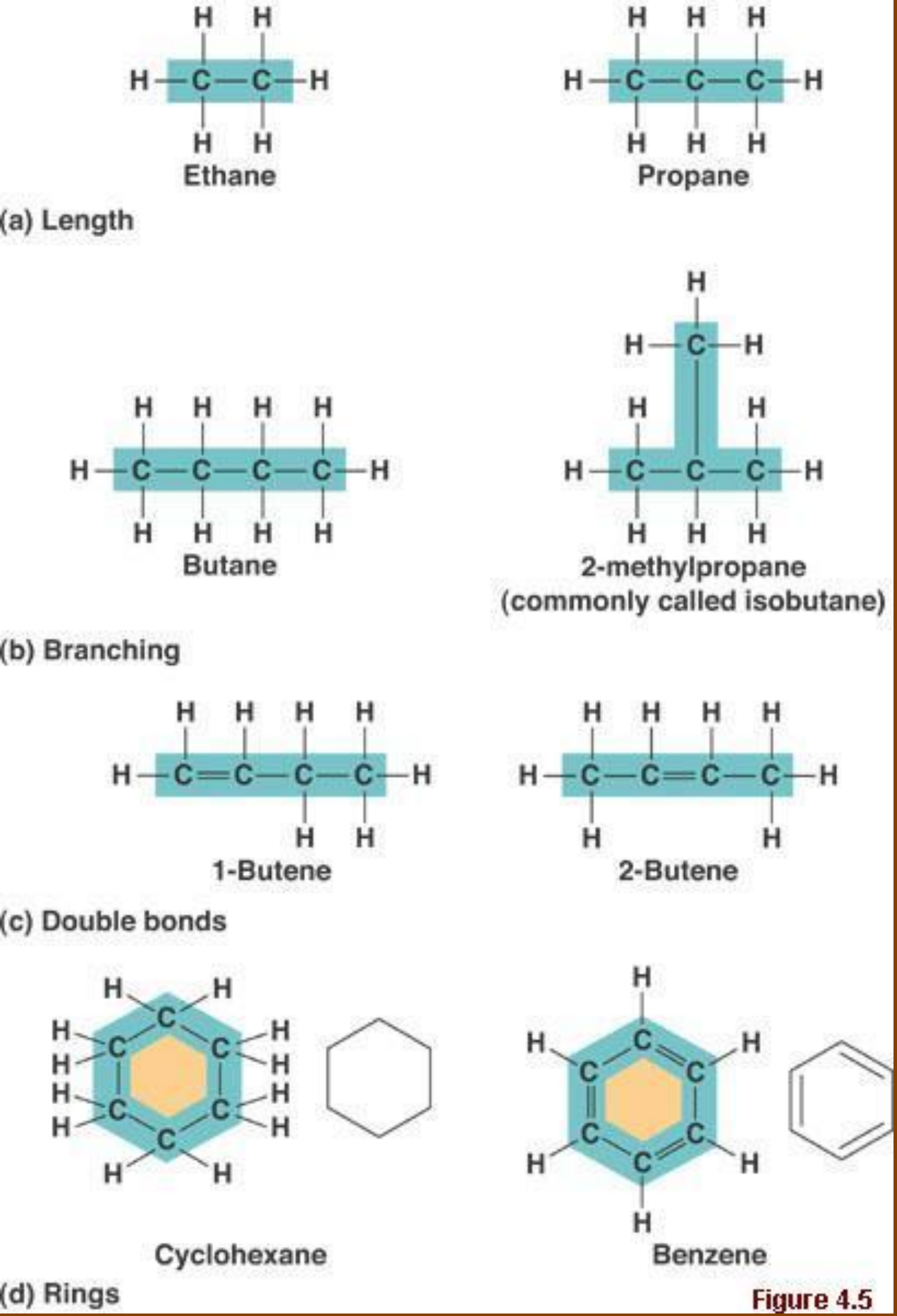
Structure of Carbon—The Backbone of Biological Molecules

- Carbon atoms can form diverse molecules by bonding to **four** other atoms.
  - Carbon has a total of **6 electrons**, with **2** in the first electron shell and **4** in the second electron shell.
  - This outermost (valence) shell can hold up to **8**. Thus, **carbon can share its 4 valence electrons** with 4 other atoms via **covalent bonds** (completing its valence shell).
  - Carbon can bond to a variety of atoms, including oxygen, hydrogen, and nitrogen.
  - Carbon atoms can also bond to other carbons, forming the carbon skeleton of organic compounds.

Carbon—The Backbone of Biological Molecules



- **Figure 4.4. Electron-shell diagrams showing valence for the major elements of organic molecules.** Valence is the number of covalent bonds an atom can form. It is generally equal to the number of electrons required to complete the atom's outermost (valence) electron shell.



Molecular Diversity Arising from Carbon Skeleton Variation

- The carbon skeletons of organic molecules vary in **length** and **shape** (straight, branched, rings) and have **bonding sites** for atoms of other elements.
- Some carbon skeletons have **double bonds**, which vary in number and location.
- Such variation in carbon skeletons is one important source of the molecular **complexity and diversity** that characterize living matter.

Carbon—The Backbone of Biological Molecules: **HYDROCARBONS**

- **Hydrocarbon** = An organic molecule consisting only of **carbon** and **hydrogen**.
- Hydrocarbons are not prevalent in living organisms, but many organic molecules have long regions of only carbon and hydrogen.
  - For example: **fats** and **petroleum** (a fossil fuel)
- These compounds are **hydrophobic**, they do not dissolve in water because the great majority of their bonds are ***nonpolar*** carbon-to-hydrogen linkages.
- Hydrocarbons can release a lot of **energy**.

The Role of Hydrocarbons in Fats

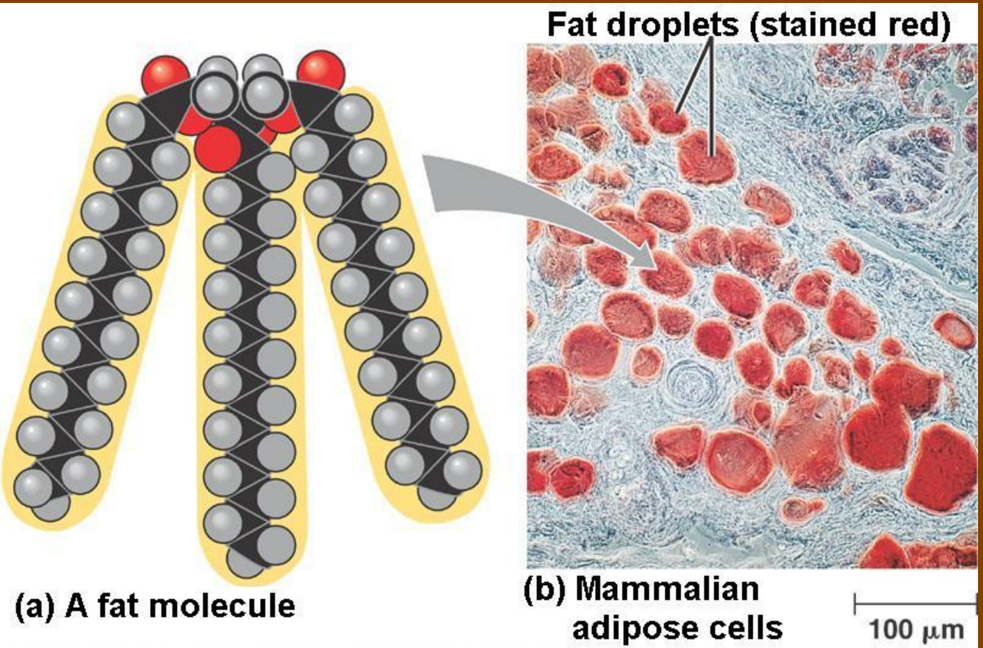


Figure 4.5 - The role of hydrocarbons in fats.

a) A **fat** molecule consists of a small, non-hydrocarbon component joined to three hydrocarbon tails. The tails can be broken down to provide energy. They also account for the hydrophobic behavior of fats. (*Black* = carbon; *gray* = hydrogen; *red* = oxygen.)

b) Mammalian adipose cells stockpile fat molecules as a fuel reserve. Each adipose cell in this micrograph is almost filled by a large fat droplet, which contains a huge number of fat molecules.

Carbon—The Backbone of Biological Molecules: **ISOMERS**

- **Isomers** are compounds that have the same number of atoms of the same elements, but **different structures** and hence **different properties**. Variation in the architecture of organic molecules can be seen in isomers.

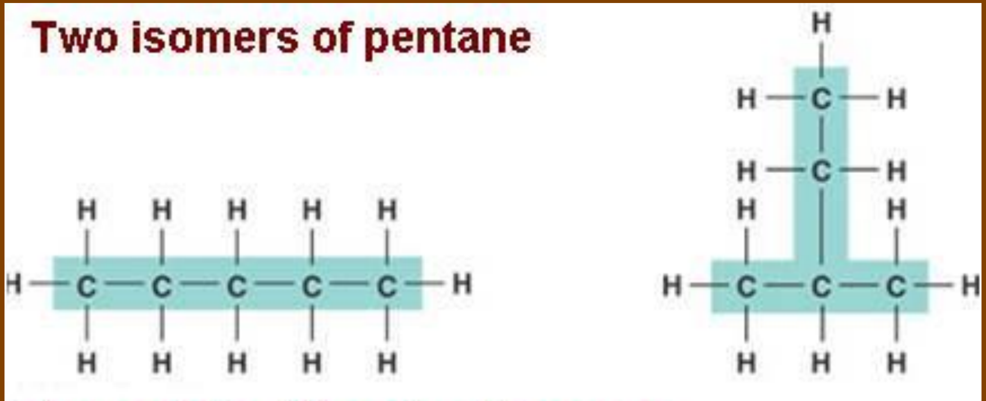


Figure 4.7a - Structural isomers.

- **Structural isomers** differ in the **covalent arrangements** of their atoms (shown in the figure are 2 isomers of C_5H_{12}: pentane and 2-methyl butane).
  - The number of possible isomers increases tremendously as carbon skeletons increase in size.
  - Structural isomers may also differ in the location of double bonds.

Carbon—The Backbone of Biological Molecules: **ISOMERS**

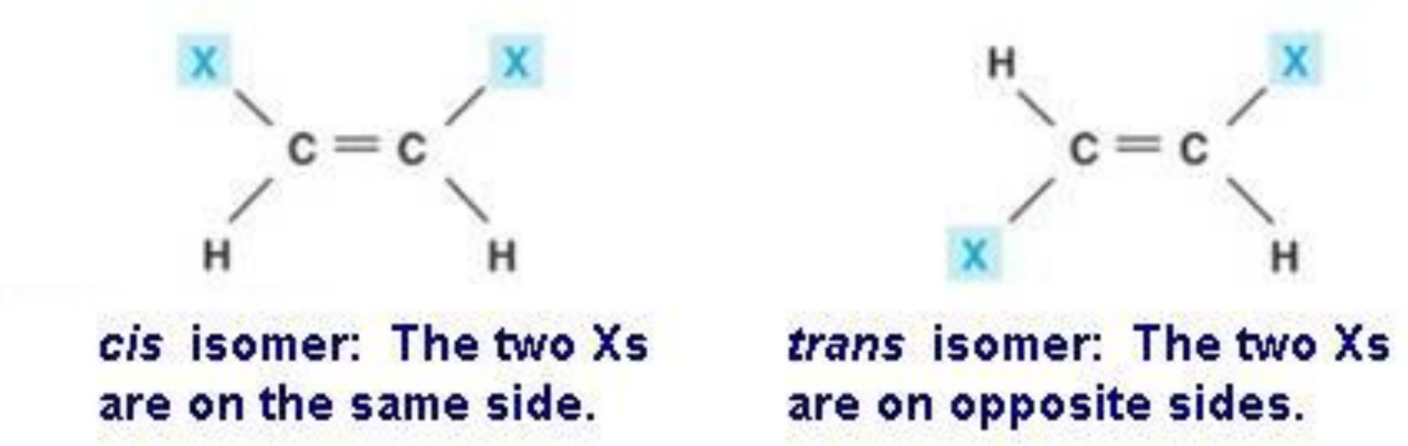


Figure 4.7b - Geometric isomers.

- **Geometric isomers** have the same molecular formula but differ in the **spatial arrangement** of their atoms about a double bond.
  - In this diagram, **X** represents an atom or group of atoms attached to a double-bonded carbon.
  - Example: the biochemistry of vision involves a light-induced change of rhodopsin, a chemical compound in the eye, from the *cis* isomer to the *trans* isomer.

Carbon—The Backbone of Biological Molecules: **ISOMERS**

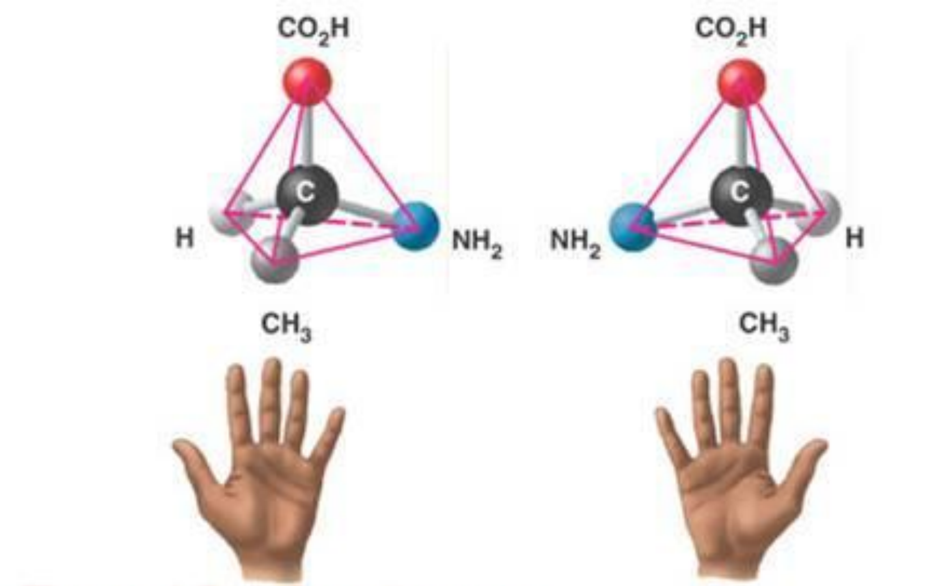
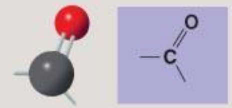
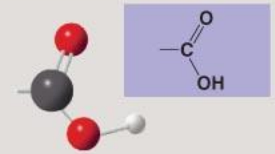
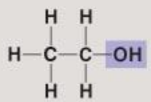
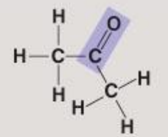
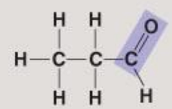
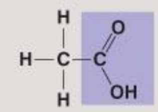
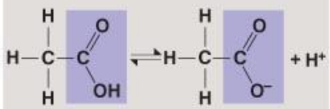


Figure 4.7c - Enantiomers.

- **Enantiomers** are molecules that are **mirror images** of each other (like left and right hands). They differ in the spatial arrangement around an *asymmetric carbon*—a carbon attached to 4 different atoms or groups of atoms.
  - Example: Two enantiomers of a drug may not be equally effective. The drug **thalidomide**, prescribed for pregnant women in the 1950-60s, was a mixture of two enantiomers. One enantiomer reduced morning sickness, but the other caused severe birth defects.

FUNCTIONAL GROUPS:
The Chemical Groups Most Important in the Processes of Life

- **Functional group** = A specific **chemically reactive group** of atoms within an organic molecule that gives the molecule distinctive chemical properties.
- Each functional group **behaves consistently** from one organic molecule to another, and the number and arrangement of the groups help give each molecule its unique properties.
- The functional groups most important in biological molecules are:
  - **Hydroxyl (alcohol)**, **carbonyl**, **carboxyl**, **amino**, **sulfhydryl**, and **phosphate**.
  - These groups are ***hydrophilic*** and thus increase the solubility of organic compounds in water.
  - A seventh group, **methyl**, is not reactive, but instead often acts as a recognizable tag on biological molecules.

CHEMICAL GROUP	Hydroxyl	Carbonyl	Carboxyl
STRUCTURE	 (may be written HO—) In a hydroxyl group (—OH), a hydrogen atom is bonded to an oxygen atom, which in turn is bonded to the carbon skeleton of the organic molecule. (Do not confuse this functional group with the hydroxide ion, OH^-.)	 The carbonyl group (>CO) consists of a carbon atom joined to an oxygen atom by a double bond.	 When an oxygen atom is double-bonded to a carbon atom that is also bonded to an —OH group, the entire assembly of atoms is called a carboxyl group (—COOH).
NAME OF COMPOUND	Alcohols (their specific names usually end in *-ol*)	Ketones if the carbonyl group is within a carbon skeleton Aldehydes if the carbonyl group is at the end of the carbon skeleton	Carboxylic acids, or organic acids
EXAMPLE	 Ethanol, the alcohol present in alcoholic beverages	 Acetone, the simplest ketone  Propanal, an aldehyde	 Acetic acid, which gives vinegar its sour taste
FUNCTIONAL PROPERTIES	• Is polar as a result of the electrons spending more time near the electronegative oxygen atom. • Can form hydrogen bonds with water molecules, helping dissolve organic compounds such as sugars.	• A ketone and an aldehyde may be structural isomers with different properties, as is the case for acetone and propanal. • These two groups are also found in sugars, giving rise to two major groups of sugars: aldoses (containing an aldehyde) and ketoses (containing a ketone).	• Has acidic properties because the covalent bond between oxygen and hydrogen is so polar; for example,  Acetic acid Acetate ion • Found in cells in the ionized form with a charge of 1– and called a carboxylate ion (here, specifically, the acetate ion).

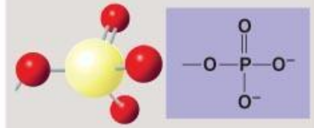
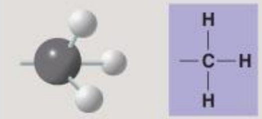
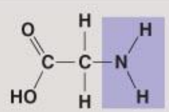
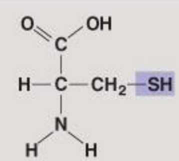
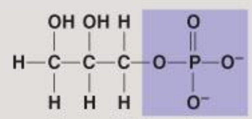
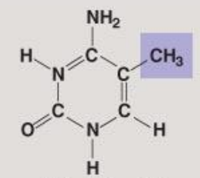
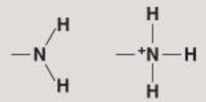
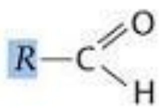
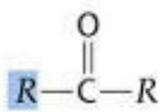
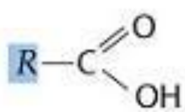
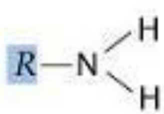
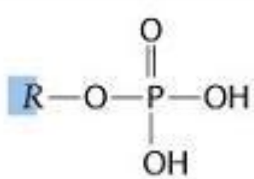
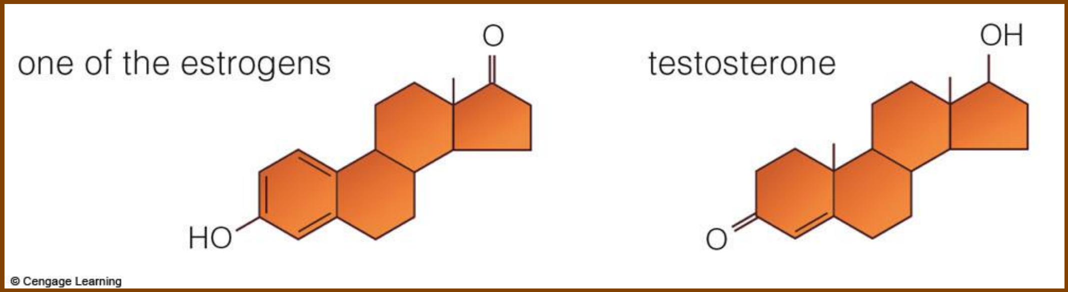
CHEMICAL GROUP	Amino	Sulfhydryl	Phosphate	Methyl
STRUCTURE		 —SH (may be written HS—)		
	The amino group (—NH_2) consists of a nitrogen atom bonded to two hydrogen atoms and to the carbon skeleton.	The sulfhydryl group consists of a sulfur atom bonded to an atom of hydrogen; resembles a hydroxyl group in shape.	In a phosphate group, a phosphorus atom is bonded to four oxygen atoms; one oxygen is bonded to the carbon skeleton; two oxygens carry negative charges. The phosphate group (—OPO_3^{2-}, abbreviated Ⓟ) is an ionized form of a phosphoric acid group (—OPO_3H^2; note the two hydrogens).	A methyl group consists of a carbon bonded to three hydrogen atoms. The methyl group may be attached to a carbon or to a different atom.
NAME OF COMPOUND	Amines	Thiols	Organic phosphates	Methylated compounds
EXAMPLE	 Glycine	 Cysteine	 Glycerol phosphate	 5-Methyl cytidine
	Because it also has a carboxyl group, glycine is both an amine and a carboxylic acid; compounds with both groups are called amino acids.	Cysteine is an important sulfur-containing amino acid.	In addition to taking part in many important chemical reactions in cells, glycerol phosphate provides the backbone for phospholipids, the most prevalent molecules in cell membranes.	5-Methyl cytidine is a component of DNA that has been modified by addition of the methyl group.
FUNCTIONAL PROPERTIES	• Acts as a base; can pick up an H^+ from the surrounding solution (water, in living organisms).  (nonionized) (ionized) • Ionized, with a charge of 1+, under cellular conditions.	• Two sulfhydryl groups can react, forming a covalent bond. This "cross-linking" helps stabilize protein structure. • Cross-linking of cysteines in hair proteins maintains the curliness or straightness of hair. Straight hair can be "permanently" curled by shaping it around curlers, then breaking and re-forming the cross-linking bonds.	• Contributes negative charge to the molecule of which it is a part (2– when at the end of a molecule; 1– when located internally in a chain of phosphates). • Has the potential to react with water, releasing energy.	• Addition of a methyl group to DNA, or to molecules bound to DNA, affects expression of genes. • Arrangement of methyl groups in male and female sex hormones affects their shape and function.

FIGURE 3.2 - Functional Groups

Functional Groups			
Group	**Structure**	**Compound**	**Significance**
Hydroxyl	R—OH	Alcohol as in ethanol	Polar, forms hydrogen bond Present in sugars, some amino acids
Carbonyl		Aldehyde as in formaldehyde	Polar Present in sugars
		Ketone as in acetone	Polar Present in sugars
Carboxyl (acidic)		Carboxylic acid as in acetic acid	Polar, acidic; Present in fatty acids, amino acids
Amino		Amine as in tryptophan	Polar, basic, forms hydrogen bonds Present in amino acids
Sulfhydryl	R—SH	Thiol as in ethanethiol	Forms disulfide bonds Present in some amino acids
Phosphate		Organic phosphate as in phosphorylated molecules	Polar, acidic; Present in nucleotides, phospholipids

R = remainder of molecule

Chemical Functional Groups



- Functional groups give molecules distinctive properties and functions.
- **Figure 3.4.** Observable differences in traits between female and male wood ducks, influenced by estrogen and testosterone. These two sex hormones have the same carbon ring structure. They differ only in the position of functional groups attached to the rings.

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