Chapter 4: Carbon and the Molecular Diversity of Life

1. Organic Molecules
2. Chemical Groups

1. Organic Molecules

Chapter Reading – pp. 57-62

Elements in Biological Molecules

Biological macromolecules are made almost entirely of just 6 elements:

- Carbon (C)
- Hydrogen (H)
- Oxygen (O)
- Nitrogen (N)
- Phosphorus (P)
- Sulfur (S)

The central element of macromolecules is Carbon!
Hydrogen (valence = 1)

Oxygen (valence = 2)

Nitrogen (valence = 3)

Carbon (valence = 4)

The valence (i.e., number of “unpaired” electrons) of these elements determines how many covalent bonds each will form.

The Element Carbon

Carbon has key properties necessary for the formation of complex biological macromolecules:

• each carbon atom can form 4 covalent bonds
• equally spaced bond angles (tetrahedral, 109.5°)
  • no unshared electron pairs in outer shell
• free rotation around single bonds
• intermediate electronegativity
  • covalent bonds relatively non-polar, stable in water
• its abundance in nature!

Organic Chemistry

Organic chemistry is the study of carbon-based compounds, in particular hydrocarbons (C\textsubscript{n}H\textsubscript{n}) and their derivatives.

• hydrocarbon derivatives have something else in place of one or more hydrogens:
  • e.g., CH\textsubscript{4} vs CH\textsubscript{3}Cl

Organic molecules contain C & H:

• methane (CH\textsubscript{4}), glucose (C\textsubscript{6}H\textsubscript{12}O\textsubscript{6}) are organic
• water (H\textsubscript{2}O), carbon dioxide (CO\textsubscript{2}) are inorganic
• organic molecules are typically derived from living things, hence the term “organic”
Hydrocarbon Structure

Hydrocarbons come in an almost limitless variety with some of the simpler hydrocarbons shown below:

<table>
<thead>
<tr>
<th>Name</th>
<th>Molecular Formula</th>
<th>Structural Formula</th>
<th>Ball-and-Stick Model</th>
<th>Space-Filling Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Methane</td>
<td>CH₄</td>
<td>H—C—H</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(b) Ethane</td>
<td>C₂H₆</td>
<td>H—C—C—H</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(c) Ethene (ethylene)</td>
<td>C₂H₄</td>
<td>H—C=CH</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(a) Methane
(b) Ethane
(c) Ethene (ethylene)

Hydrocarbons and their derivatives are essentially carbon skeletons “filled in” with hydrogen atoms or other chemical groups.

Isomers

Isomers are molecules with identical molecular formulas yet different structural formulas:

- Butane (C₄H₁₀)

\[
\text{butane} \quad \begin{array}{c}
\text{H} \\
\text{H} \\
\text{C—C—C—C—H} \\
\text{H—H—H—H—H}
\end{array}
\]

- Iso-butane (C₄H₁₀)

\[
\text{iso-butane} \quad \begin{array}{c}
\text{H} \\
\text{H} \\
\text{H} \\
\text{H} \\
\text{C—C—H—C—H} \\
\text{H—H—H—H—H}
\end{array}
\]
Structural Isomers

_Structural isomers have different structural arrangements of their carbon skeleton:_

![Structural isomers](image)

(cis-trans) Isomers

_Cis-trans_ isomers involve different arrangements of non-hydrogen atoms or chemical groups around carbons connected by a double bond:

- **Cis** = "same side"
- **Trans** = "opposite side"

![cis-trans isomers](image)

Enantiomers

_Enantiomers are_ isomers with asymmetric carbons that are mirror images of each other:

- asymmetric carbons are connected to 4 different atoms or groups and have 2 possible arrangements

![Enantiomers](image)
2. Chemical Groups

Chapter Reading – pp. 62-64

Chemical Groups

Chemical groups are common groups or arrangements of atoms that substitute for hydrogen on carbon skeletons:

- Estradiol
- Testosterone

**Alcohols**

(Their specific names usually end in -ol.)

<table>
<thead>
<tr>
<th>NAME OF COMPOUND</th>
<th>FUNCTIONAL PROPERTIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanol</td>
<td>- Is polar as a result of the electrons spending more time near the electronegative oxygen atom.</td>
</tr>
<tr>
<td></td>
<td>- Can form hydrogen bonds with water molecules, helping dissolve organic compounds such as sugars.</td>
</tr>
</tbody>
</table>

**The Hydroxyl Group**

**Hydroxyl**

(may be written HO—)

**Ethanol**

Alcohols (Their specific names usually end in -ol)
### The Carbonyl Group

**Carbonyl**

**Structure:** If the carbonyl group is within a carbon skeleton, it is a ketone. If the carbonyl group is at the end of the carbon skeleton, it is an aldehyde.

**Example:**
- Ketones: if the carbonyl group is within a carbon skeleton
- Aldehydes: if the carbonyl group is at the end of the carbon skeleton

**Functional Properties:**
- Ketones and aldehydes may be structural isomers with different properties, as is the case for acetone and propanal.
- Ketone and aldehyde groups are also found in sugars, giving rise to two major groups of sugars: ketoses (containing ketone groups) and aldoses (containing aldehyde groups).

### The Carboxyl Group

**Carboxyl**

**Structure:** Carboxylic acids, or organic acids.

**Example:**
- Acts as an acid; can donate an H⁺ because the covalent bond between oxygen and hydrogen is so polar.
- Found in cells in the ionized form with a charge of 1⁻ and called a carboxylate ion.

### The Amino Group

**Amino**

**Structure:** Amines

**Example:**
- Acts as a base; can pick up an H⁺ from the surrounding solution (water, in living organisms).
- Found in cells in the ionized form with a charge of 1⁺.
The Sulfhydryl Group

**Sulfhydryl**

**NAME OF COMPOUND**

**EXAMPLE**

- 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 and then breaking and re-forming the cross-linking bonds.

Disulfide Bonds

Two sulfhydryl groups can undergo a reduction reaction to form a disulfide bond or bridge:

**NAME OF COMPOUND**

**FUNCTIONAL PROPERTIES**

- 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 and then breaking and re-forming the cross-linking bonds.

The Phosphate Group

**Phosphate**

**NAME OF COMPOUND**

**FUNCTIONAL PROPERTIES**

- Molecules containing phosphate groups have the potential to react with water, releasing energy.
The terminal phosphate group of ATP (adenosine triphosphate) provides the energy that fuels cell activities.

\[
\text{ATP} \rightarrow \text{ADP} + \text{Energy}
\]

The Methyl Group

<table>
<thead>
<tr>
<th>Methylated compounds</th>
<th>NAME OF COMPOUND</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methyl</td>
<td></td>
</tr>
</tbody>
</table>

- Addition of a methyl group to DNA, or to molecules bound to DNA, affects the expression of genes.
- Arrangement of methyl groups in male and female sex hormones affects their shape and function.

S-Methyl cytidine
c

Key Terms for Chapter 4

- organic vs inorganic
- isomers: structural, cis-trans, enantiomer
- hydroxyl group
- carboxyl group
- carboxyl group
- amino group
- sulfhydryl group, disulfide bond
- phosphate group
- methyl group

Relevant Chapter Questions

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