Organic Chemistry and Biochemistry (06 and 08 November 2007)

- Principles of carbon chemistry
- Principle of polymers
- Hydrocarbons
- Organic chemistry in living systems: biochemistry
- Carbon metabolism and energy

Abundance of Elements in Solar System

Covalent Bonds and Carbon

- $^6\text{C}$ is a special case
- Valence electrons for C are four (one in each orbit of the 2nd shell)
- $\text{C} - \text{C}$: single covalent bond (one orbit; two atoms)
- $\text{C} - \text{C} - \text{C}$: two covalent bonds; two orbits; three atoms

Principles of Carbon Chemistry: Functional Groups

- Features of C macromolecules
  - Carbon skeleton (chains, branches, rings)
  - Groups of atoms attached to carbon skeleton - functional groups
    - Hydroxyl (OH)
    - Amino (NH$_2$)
    - Phosphate (P)
Principle of Polymers

- Small molecules joined together to form large molecules up to 1,000’s of carbon atoms (macromolecules)
- Array of combinations, each with its own unique chemistry
- Principle of hierarchy theory and emergent properties

Simple to Complex Polymers of Carbon

- Methane – 1 C atom
- Ethane – 2 C atoms
- Fullerene – 60 + C atoms (Buckyballs)

Complex Carbon Polymers

- aspirin
- caffeine
- taxol

Hierarchy Theory and Emergent Properties

- Number of macromolecules, each with its own chemistry
- Carbon Skeletons (e.g., branch, chains, etc.)
- Functional Groups (e.g., OH, NH2, etc.)
- Carbon Atoms

Principle of Polymers

- In living systems, polymers of carbon result in four major classes of macromolecules
  - Carbohydrates
  - Proteins
  - Nucleic acids
  - Lipids
- Potential diversity of carbon polymers

Hydrocarbons

- Carbon compounds with only two elements (carbon and hydrogen)
- Most simple compound: methane (CH₄)
Hydrocarbons: C to C Bonding

- C to C bond can be single bond (C=C)
- Ethane
- C to C bond can be double bond (C = C)
  - Ethene or ethylene
- C to C bond can be triple bond (C == C)
  - Ethyne
- Saturated/unsaturated

Hydrocarbons

- Alkanes (C – C bonds only)
  - Methane (C_1H_4)
  - Ethane (C_2H_6)
  - Propane (C_3H_8)
  - Butane (C_4H_10)
  - Pentane (C_5H_12)
  - Octane (C_8H_18) Gasoline
  - Decane (C_{10}H_{22})
  - Pattern: C_{n}H_{2n+2}
- Triple bond (C == C)
- Double bond (C = C)
- Aromatics (cyclic C atoms/aromatics)
  - C_6H_6

Aromatic Hydrocarbons

Question

There are millions of organic compounds but only a few thousand inorganic compounds because ____?

A. Organic compounds are formed by living critters
B. There is more C on the Earth’s surface than most other elements
C. Atoms of elements other than C never combine with themselves
D. C atoms combine with up to four other atoms, including other C atoms

Functionality of Hydrocarbons

- Carbon skeleton
- Functional groups (e.g., OH)

Organic Chemistry and Biochemistry

- Introduction to organic chemistry
- Principles of carbon chemistry
- Principle of polymers
- Hydrocarbons
- Organic chemistry in living systems: biochemistry
- Carbon metabolism and and energy
Organic Chemistry and Biochemistry

- **Keys:**
  - Structure of basic unit (monomer)
  - Polymer structure (macromolecule)
  - Functional group (e.g., OH, PO$_3$, or NH$_2$)
- **Types of carbon polymers in living systems**
  - Carbohydrates
  - Lipids
  - Proteins
  - Nucleic acids

Biochemistry

- **Carbohydrates**
  - Monomer: monosaccharide (glucose or C$_6$H$_{12}$O$_6$)
  - Polymer: polysaccharide
  - Functional unit: hydroxyl or OH
- **Proteins**
  - Monomer: amino acid (peptide)
  - Polymer: polypeptide and protein
  - Functional unit: amine or NH$_2$
- **Nucleic Acids**
  - Monomer: nucleotide
  - Polymer: polynucleotide - DNA (deoxyribonucleic acid) and RNA (ribonucleic acid)
  - Functional units: organic N base, carbohydrate, and phosphate
- **Lipids**
  - Monomer: fatty acid + glycerol unit
  - Polymer: fats, phospholipids, and steroids
  - Functional unit: glycerol (3 OH groups)

iClicker Question

- **Fatty acids and glycerols are part of**
  - A Carbohydrates
  - B Proteins
  - C Nucleic Acids
  - D Lipids

iClicker Question

- **The monomer “monosaccharide” is what type of molecular polymer?**
  - A Carbohydrate
  - B Protein
  - C Nucleic Acid
  - D Lipid

iClicker Question

- **Amino acids are portions of**
  - A Carbohydrates
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iClicker Question

- **Nucleotides are portions of**
  - A Carbohydrates
  - B Proteins
  - C Nucleic Acids
  - D Lipids
Biochemistry: Carbohydrates

**Keys**
- Monosaccharide or Glucose ($\text{C}_6\text{H}_{12}\text{O}_6$)
- Functional unit: hydroxyl or OH-

**Polysaccharide: Glycogen**

**Biochemistry: Proteins**

**Keys**
- Amino acid (monomer)
- Polypeptide (polymer)
- Functional unit: amine or NH$_2$
- Polypeptide bond

serine - lysine - arginine - tryptophan - glutamic acid - etc.

Proteins: Linear Structure
Protein Conformation (1 and 2nd)

Protein Conformation (3rd & 4th)

Biochemistry: Nucleic Acids

Keys
Nucleotides
Functional units: organic N base, carbohydrate, and phosphate

Nucleic Acids as Polymers: DNA Double Helix
Biochemistry: Lipids

Fatty acids C_{16-18}
Functional unit: glycerol (2 OH groups)

Saturated Fats

(a) Palmitic acid

(b) Stearic acid

Unsaturated Fats

(c) Oleic acid

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Carbon Metabolism
Biosynthesis (Anabolism)
\[ \text{CO}_2 + \text{H}_2\text{O} + \text{Energy} \xrightarrow{\text{light}} \text{CH}_2\text{O} + \text{O}_2 \]
Catabolism
\[ \text{CH}_2\text{O} + \text{O}_2 \xrightarrow{\text{heat + chemical energy \text{-- ATP}}} \text{CO}_2 + \text{H}_2\text{O} + \text{Energy} \]

Key is the C-C covalent bonding, which in turn is determined by electrons in the valence state, which in turn is underpinned by energy of electrons in their respective shells (storage and processing of energy via the making and breaking of C-C bonds).
Granola Bar and the Carbon Atom

The energy of a “granola bar” is a function of multiple excited electrons being kicked to a higher quantum level in a chlorophyll molecule; subsequently, that “potential energy” is snatched and stored chemically in a carbohydrate molecule. When you digest the carbohydrate polymer and break the covalent bonds, the potential energy of the electron in an elevated state is released as heat/chemical energy in metabolism.

<table>
<thead>
<tr>
<th>Question</th>
<th>Hierarchy in Biochemistry</th>
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<tbody>
<tr>
<td>Hearing is a process that is best categorized as being ______.</td>
<td>Protein</td>
</tr>
<tr>
<td>What bonds are likely to be involved in hearing if sound is best characterized as being ______?</td>
<td>Polypeptide</td>
</tr>
<tr>
<td>How might those bonds operate in the inner ear and brain, and what macromolecule is likely to be involved?</td>
<td>Amino Acid</td>
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<table>
<thead>
<tr>
<th>Take Home Message</th>
<th>Omissions</th>
</tr>
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<tbody>
<tr>
<td>Carbon is unique in its chemistry</td>
<td>Alkenes and Alkynes (pp. 429 - 430)</td>
</tr>
<tr>
<td>Unusual behavior of carbon results in an huge array of simple to complex molecules</td>
<td>Ethers, Aldehydes, and Ketones (pp. 434 - 436)</td>
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<td>Life as we know it is hard to imagine without carbon behaving as a polymer</td>
<td>Synthetic Polymers (pp. 448 - 450)</td>
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<td>The chemistry of carbon is a case study of the principle of hierarchy theory and emergent properties</td>
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<td>Carbon metabolism is the “currency” by which energy is processed, stored and used</td>
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<td>Weak chemical bonds (covalent carbon bonds) play a critical role in the chemistry of life</td>
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