The chemistry of cells: an overview

• Restricted to a subset of known elements, dominated by the chemistry of carbon...
• Reactions occur over a narrow range of temperatures (0-100°C)...
• Dominated by macromolecules and polymers (-X-X-X-X-)...
• Many reactions facilitated by protein catalysts: "enzymes"...
• Chemical reactions are often localized to a specific cell surface or compartment...

"Strong" and "weak" chemical bonds contribute to the structure of biomolecules...

• Covalent bonds are strong bonds (50-110 kcal/mol)
  - Covalent bonds are formed when atoms share pairs of electrons...
  - -C-C- bonds ~85 kcal/mol...
• Weak "bonds" (<5 kcal/mol)
  - Ionic bonds (~3 kcal/mol)...
  - Hydrogen bonds (~1 kcal/mol)...
  - van der Waals interactions (~0.1 kcal/mol atom)...
  - Hydrophobic interactions (NA)...

Atoms joined by "covalent" bonds share electron pairs...

Distance at which attraction and repulsion are equal is bond length
Opposites attract: ions and ionic bonds...

Weak chemical "bonds" play a significant role in biomolecules:

Van der Waals interactions...

Summation of many weak bonds makes a significant contribution to structure, stability, and binding specificity of biological macromolecules...

Three elements comprise >95% of the atoms in living cells...
Valences and bond configurations for some “biological” elements…

Oxygen (5)
Nitrogen (3)
Carbon (4)

ECB Fig. 2-10

Functional groups common in biomolecules: carbon atoms form the backbone of many biomolecules…

ECB Panel 2-1

Functional groups common in biomolecules: compounds of carbon and oxygen or nitrogen…

ECB Panel 2-1
## Electronegativity and Bonding

<table>
<thead>
<tr>
<th>Atomic Number</th>
<th>Element</th>
<th>Electronegativity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>H</td>
<td>2.2</td>
</tr>
<tr>
<td>2</td>
<td>He</td>
<td>0.93</td>
</tr>
<tr>
<td>3</td>
<td>Li</td>
<td>1.0</td>
</tr>
<tr>
<td>5</td>
<td>B</td>
<td>2.0</td>
</tr>
<tr>
<td>6</td>
<td>C</td>
<td>2.6</td>
</tr>
<tr>
<td>7</td>
<td>N</td>
<td>3.0</td>
</tr>
<tr>
<td>8</td>
<td>O</td>
<td>3.5</td>
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<tr>
<td>9</td>
<td>F</td>
<td>4.0</td>
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<tr>
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<td>Na</td>
<td>2.7</td>
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<tr>
<td>12</td>
<td>Mg</td>
<td>2.2</td>
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<td>13</td>
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<td>1.9</td>
</tr>
<tr>
<td>14</td>
<td>Si</td>
<td>1.8</td>
</tr>
<tr>
<td>15</td>
<td>P</td>
<td>2.2</td>
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<tr>
<td>16</td>
<td>S</td>
<td>2.6</td>
</tr>
<tr>
<td>17</td>
<td>Cl</td>
<td>3.1</td>
</tr>
<tr>
<td>18</td>
<td>Ar</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Electronegativity decreases as we move down a column; e.g., O vs S.

Atomic nuclei vary in their "electronegativity" (the strength of their attachment to electrons). 

E奥 Fig. 2-8
Electronegativity and bonding

Atomic nuclei vary in their "electronegativity" (the strength of their attachment to electrons).

- O and N cannot steal electrons... but "borrow" them from their partners (C and H).
- Polar covalent bond

Water molecules interact via "Hydrogen bonds"...

H-bonding affects the solubility of molecules in water...

They are considered "hydrophilic (water loving)".

"Amphiphilic" molecules contain both hydrophilic and hydrophobic domains.
**Review: Chemical bonds in cell biology...**

<table>
<thead>
<tr>
<th>Bond type</th>
<th>Length (nm)</th>
<th>Bond strength (kcal/mol in water)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Covalent</td>
<td>0.1-0.2</td>
<td>50-110</td>
</tr>
<tr>
<td>Non-covalent (weak)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ionic</td>
<td>0.25-0.35</td>
<td>3</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>0.25-0.35</td>
<td>1-3</td>
</tr>
<tr>
<td>van der Waals</td>
<td>0.3-0.4</td>
<td>0.1</td>
</tr>
<tr>
<td>Hydrophobic effect</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

**Acids and bases...**

Liquid H₂O is heavily H-bonded...

\[
\text{H}^+ + \text{H}_2\text{O} \rightleftharpoons \text{H}_3\text{O}^+ + \text{H}_2\text{O} 
\]

\[-\log([H^+]) = \text{pH}\]

- Acids increase [H⁺] and lower pH...
- Bases lower [H⁺] and increase pH...
- Carboxylic acids donate a proton...
- Amino groups accept a proton...

In pure water
\[\text{[H}^+] = 10^{-7} \text{ M}\]

The stuff cells are made of: the approximate chemical composition of a mammalian cell...

- **Water** 70%
- **Chemicals** 30%
- Protein 18%
- Polysaccharides 2%
- Lipids 2%
- DNA 0.25%
- RNA 1.1%
- Inorganic ions 1%

Plant cells - much more polysaccharide due to cell wall.
Small organic molecules are the building blocks of biological macromolecules...

Building blocks

- Sugars
- Fatty acids
- Amino acids
- Nucleotides

Larger units

- Polysaccharides
- Fats/lipids/Membranes
- Proteins
- Nucleic acids

Condensation reactions = monomer to polymer
Hydrolysis reactions = polymer to monomer

Location of the 4 major groups of macromolecules:

- Polyaccharide = carbohydrate

Adapted from ECB 2-15
Monosaccharides:

Aldohexose or ketohexose.

Invert C4 = galactose.
Invert C2 = mannose.

Sugar molecules react with themselves to form rings:

(Rings open and close rapidly in solution)

The hydroxyl group on the carbon carrying the aldehyde (C1) or ketone (C2) can rapidly interchange...
Monosaccharides are linked by "glycosidic bonds" to form polysaccharides...

Polysaccharides are used for energy storage and structural support...

Glycogen: α(1→4) glucose with α(1→6) branches
Starch: Amylose: α(1→4) glucose (unbranched)
Cellulose: β(1→4) glucose (straight chain, unbranched)
(Dietary fiber... most animals cannot digest cellulose)

Next two lectures
- Lipids and membranes...
- Amino acids and proteins...
- Protein structure and function...