Biological macromolecules

- Proteins
- Carbohydrates
- Lipids
- Nucleic acids
The ingredients of life

- Cells do almost all of their work with six types of atoms: carbon (C), oxygen (O), nitrogen (N), sulfur (S), phosphorous (P) and hydrogen (H).

<table>
<thead>
<tr>
<th>Element</th>
<th>Proportion (by mass)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen</td>
<td>65%</td>
</tr>
<tr>
<td>Carbon</td>
<td>18%</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>10%</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>3%</td>
</tr>
<tr>
<td>Calcium</td>
<td>1.5%</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>1.2%</td>
</tr>
<tr>
<td>Potassium</td>
<td>0.2%</td>
</tr>
<tr>
<td>Sulfur</td>
<td>0.2%</td>
</tr>
<tr>
<td>Chlorine</td>
<td>0.2%</td>
</tr>
<tr>
<td>Sodium</td>
<td>0.1%</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.05%</td>
</tr>
<tr>
<td>Iron</td>
<td>&lt; 0.05%</td>
</tr>
<tr>
<td>Cobalt</td>
<td>&lt; 0.05%</td>
</tr>
<tr>
<td>Copper</td>
<td>&lt; 0.05%</td>
</tr>
<tr>
<td>Zinc</td>
<td>&lt; 0.05%</td>
</tr>
<tr>
<td>Iodine</td>
<td>&lt; 0.05%</td>
</tr>
<tr>
<td>Selenium</td>
<td>&lt; 0.01%</td>
</tr>
</tbody>
</table>

- **Water**: the solvent of life
  - Makes up 70% of the cell mass
  - Able to dissolve a large number of solutes;
  - Large specific heat
  - High dielectric constant, etc.
The contents of a cell

- Water: 70%
- Small molecules: 4%
- Biological macromolecules: 26%
  - Carbohydrates
  - Lipids
  - Nucleic Acids
  - Proteins

Even 30% occupancy by volume is **dense!**

\[(80 \text{ nm})^3\]


http://www.nature.com/scitable/content/the-composition-of-a-bacterial-cell-14705043
Biological macromolecules

- Proteins
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- Nucleic acids
**Nucleic acids**

one oxygen atom distinguishes RNA from DNA, increases reactivity (so DNA is more **stable**)

base attaches at 1′, phosphate at 5′

**purines**

- Adenine
- Guanine

**pyrimidines**

- Cytosine
- Thymine

Replace methyl group with H to get RNA base uracil
polymerization and base pairing

- anti-parallel strands (one runs 3’ to 5’, the other 5’ to 3’)
- bases pair through hydrogen bonds: 3 for C-G and 2 for A-T
- bases also stack with each other for added stability of helix
expanding the genetic alphabet

base pairs through **hydrophobic interactions** instead of hydrogen bonds

challenges included

1) getting the nucleotides into the bacterium

2) ensuring that they could be replicated

synthetic organisms could store more information and be engineered to carry out very specific tasks

expanding the genetic alphabet

"Hachimoji" (eight letters) DNA and RNA

Crystal structures show new bases behave similar to old ones in DNA double helix

raises the question: why are there only two natural base pairs?

Ribozymes
Reactivity and flexibility of RNA makes it capable of acting as an enzyme as well as an information carrier.

Sidney Altman
Tom Cech

1989 Nobel Prize in Chemistry

leadzyme - cleaves itself in the presence of lead ions (why???)

twister - also self-cleaves; no known function but 2700 examples in nature
RNA world hypothesis

Which came first - the chicken or the egg?

restated: *Which came first - the protein or the DNA?*

Maybe RNA was BOTH the chicken (enzyme) and the egg (information carrier)...

Origin of Life on Earth
Alonso Ricardo and Jack W. Szostak
Scientific American 301, 54 - 61 (2009)
RNA world hypothesis

...or maybe not?

If RNA is the chicken and the egg, then what made RNA?

“The original RNA world model is dead”

Loren Williams, Georgia Tech Chemistry, Ribo Evo Astrobiology Center

“Amino acids are plentiful in the abiotic universe

Loren’s work supports a “dirty RNA world” in which proteins co-evolve with RNA

Biological macromolecules

- Proteins
- Carbohydrates
- Lipids
- Nucleic acids
Proteins are the workhorses of the cell

Enzymes, signaling and transport, and structural support

Eukaryotic cell (~10-30 µm)

Trypsin - digests proteins

Myoglobin - transports oxygen

Titin - a muscle protein
Basics of protein structure

Backbone

Side chain

Amino acid (phenylalanine)
20 types, usually

Polypeptide chain

peptide-bond formation

Peptide bond

Dipeptide

Water
Basics of protein structure

Side-chains give amino acids a diverse set of properties

They can be:
- charged (negative)
- charged (positive)
- polar
- hydrophobic
- big or small
- ionizable
- rigid or flexible
- etc!
Biological macromolecules
Carbohydrates

Used for energy storage and as structural building blocks

also known as saccharides (sugars); can form long polymers

two anomers of glucose ($\text{C}_6\text{H}_{12}\text{O}_6$), the most common monosaccharide

- lactose (milk sugar) glucose + galactose
- sucrose (table sugar) glucose + fructose
Biological uses of carbohydrates

starch (branched chain of glucose molecules; plants)

glycogen (also glucose; animals)

cellulose (plant cell wall)

chitin (insect shells)

glycosylation of proteins (post-translational)
Biological macromolecules

- Proteins
- Carbohydrates
- Lipids
- Nucleic acids
Lipids

- Primarily used to form cellular and organelle membranes; also energy storage and signaling
- Amphiphilic - polar head group and hydrophobic tail(s)
- Membranes form barriers through which transport of ions, small (hydrophilic) molecules, etc. can be regulated

DPPC (1,2-dipalmitoyl-sn-glycero-3-phosphocholine)

- Amphiphilic naturally leads to formation of bilayers (and other structures)

- Non-polar tails (e.g., palmitoyl x2 - DP)
- Headgroup (e.g., phosphocholine - PC)
Types of fatty acids

- **saturated (no double bonds)**
- **mono-unsaturated** (one double bond in *cis* conformation)
- **poly-unsaturated**

* cis - hydrogens on same side

* trans - hydrogens on opposite sides
Classification of bonds

- **Ionic Bond (Sodium Chloride [table salt]):**
  - Electrons exchanged, $\sim 10 \text{ kT}$
  
- **Covalent Bond (Chlorine Gas):**
  - Electrons shared, $\sim 100 \text{ kT}$

- **Hydrogen Bond (Water Molecules):**
  - Dipole-dipole interaction, $\sim 2-5 \text{ kT}$

**most important “bond” in biology!**
Water is a biomolecule itself!

- Hydrophobic effect
- Binding
- Structure
- Transport
- Grotthuss mechanism
- Electrostatics/polarity