The Origin and Chemistry of Life

Chapter 2

Spontaneous Generation?

- Life was thought to have first come from spontaneous generation – nonliving material forming living beings.
- Supported by observation:
  - Frogs from mud
  - Mice from rotten grain
  - Maggots from rotting meat
- In 1861, Louis Pasteur developed a test that excluded air and other organisms, and proved that life begets life.
- Although, at one point 4 billion years ago, a series of prebiotic assemblies took place to create the living cells.

Organic Structure

- Since life cannot spontaneously arise, how did it occur?
- Alexander Oparin and J. B. S. Haldane proposed that life occurred after a long period of "abiogenic molecular evolution".
- Atoms formed molecules
- Molecules formed macromolecules
- Macromolecules interacted to form the cellular structures that make up basic cells.
Organic Molecules
- What does a molecule have to have to be “organic”?
- Carbon (C)
- Can also possess:
  - Hydrogen (H), Oxygen (O), Nitrogen (N), Sulfur (S), Phosphorus (P), salts, and other elements
- More than 1 million organic molecules have been identified by science.
- Represented by carbohydrates, lipids, amino acids, and nucleic acids.

Carbohydrates
- Nature’s most abundant organic substance.
- Made of carbon, oxygen, and hydrogen in 1C: 2H: 1O ratio and grouped as H-C-OH
- Usually placed into three classes
  - Monosaccharides – single sugars
  - Disaccharides – double sugars
  - Polysaccharides – complex sugars

Simple sugars
- Generally made of carbon chains containing 4 (tetrose), 5 (pentose), and 6 (hexose) carbons.
- Can be drawn as a straight chain, cyclic compound, or a chair configuration.
Simple Sugars

- The most important simple sugars are glucose, galactose, and fructose.

Disaccharides

- Two sugars bonded together with the removal of a water molecule.

Polysaccharides

- Made of many simple sugars linked in chains called polymers.
- Examples of polymers are:
  - Starch – common food storage in plants and food for animals
  - Glycogen – storage form of sugar in animals
  - Cellulose – main structural carbohydrate in plants

Other common double sugars are sucrose (glucose and fructose) and lactose (glucose and galactose).
Lipids

- Fats
  - Have a low polarity, thus are insoluble in water
  - They are soluble in organic solvents, like acetone and ether.
- Three main types
  - Neutral fats
  - Phospholipids
  - Steroids

Neutral Fats

- Major fuel for animals
- Oxidized for energy, especially in muscle
- A common neutral fat is a triglyceride, formed from a glycerol and three fatty acids

Neutral fats

- Triglycerides can be either saturated or unsaturated.
- Saturated fatty acids have 2 H on each C.
  - More common in animals, and is solid at room temperature.

\[
\text{CH}_3\text{-CH}_2\text{-CH}_2\text{-CH}_2\text{-CH}_2\text{-CH}_2\text{-COOH}
\]

- Unsaturated fatty acids have at least 2 C double bonded together (i.e., Not H saturated)
  - Typical in plant oils, and liquid at room temperature.

\[
\text{CH}_3\text{-CH}_2\text{-CH}_2\text{-CH}_2\text{-CH}\equiv\text{CH}_2\text{-CH}_2\text{-CH}_2\text{-CH}_2\text{-COOH}
\]
**Phospholipids**
- Important structural lipid, especially in membranes.
- Looks like a triglyceride, except the fatty acid is replaced with a phosphoric acid and a base.
- Is both polar/water soluble (phosphate) and nonpolar/water insoluble (fatty acid).
- Often bridges solubility for other compounds.

**Steroid**
- Actually alcohols, but have fat-like properties.
- They include cholesterol, Vitamin D, and many hormones.

**Amino Acids**
- The basic structure of an amino acid is an alpha C, an H, an amino group (NH₂), a carboxyl group (COOH), and a side chain (R).
- There are 20 different amino acids for cells to use.
Proteins
- Made of amino acids linked in chain with peptide bonds.

Levels of Protein Structure
- Primary Structure
  - Simply chain of amino acids
- Secondary Structure
  - Stable angles formed by chain
    - Alpha-helix
    - Beta-sheet
- Tertiary Structure
  - Shapes formed by helix or sheet folding on itself and forming bonds between the side chains.
    - Disulfide bond of 2 cysteines
- Quaternary Structure
  - Multiple peptides bonding together to form a single protein.
Enzymes

- Special proteins that perform metabolic functions in animals.
- Biological catalysts that lower the activation energy of nearly all reactions that occur in the body.
  - Will be discussed in detail in Chapter 4.

Nucleic Acids

- Compounds that carry the genetic information in cells.
- Made of repeated units called nucleotides, each containing a sugar, a nitrogenous base, and phosphate group.
- Two main types, based on type of sugar
  - Deoxyribonucleic acid (DNA)
  - Ribonucleic acid (RNA)

Water – The stuff of life

- Water has several properties that have allowed organic life to exist as we know it.
  - Maximum density above freezing
  - High specific heat
  - High heat of vaporization
  - High surface tension
  - Low viscosity
  - Universal solvent
How did all these come about?

- Haldane and Oparin suggested that early Earth atmosphere was a reducing one (more H than O), made of methane (CH₄), Ammonia (NH₃), water, and hydrogen.
- Thought that high UV light from the sun and electricity from light could create organic molecules out of this sort of air.

Prebiotic Synthesis

- Miller (1953) tested this with shown device.
- After a week of “lightning”, 15% of the C in the system had been converted into amino acids, urea, and simple fatty acids!

Current Idea

- We know believe the early atmosphere to be very different that Oparin-Haldane.
- However, early organic molecules may have not been formed in the air, but near deep ocean hydrothermal vents.
- These vents release heat, energy, hydrogen sulfide and methane, thus providing the ingredients to start building life.
Early Assembly

- Early Earth needed moisture (X), organic molecules (X), and heat to construct life.
- Thermal studies show that by heating the 20 amino acids to 180° C, proteinoids form.

**Are proteinoids the pre-cell?**

Source of Energy

- Once cells were living, they had to eat/metabolize.
- Autotrophs – animals that synthesize their food from inorganic sources, like light or H₂S.
- Heterotrophs – animals that must consume organic molecules for food.
  - The earliest heterotrophs were primary heterotrophs – feeding off of organic molecules that existed in the primordial soup.

Photosynthesis

- Autotrophs evolved into photosynthetic plants and animals.
- The process of using light to condense CO₂ and H₂O into sugars and O allowed for production and storage of energy.

\[
6\text{CO}_2 + 6\text{H}_2\text{O} \xrightarrow{\text{light}} \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2
\]
Oxidative metabolism

- In the early reducing atmosphere, organisms freed up energy in sugars with anaerobic respiration.
- As oxygen increased in the atmosphere, the air became oxidizing, and a new, efficient way to release energy was formed.
- Oxidative (aerobic) metabolism
  \[ C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O \]

Timeline of Life

- Appearance of Prokaryotes
  - 3.5 billion years ago – earliest bacteria begin
  - 3.0 BYA – cyanobacteria arise
  - Prokaryotes lack a nucleus and membrane bound organelles.
  - Today, prokaryotes are recognized as belonging to two kingdoms or domains (Eubacteria and Archaeabacteria (Archaea))
**Rise of Eukaryotes**

- Have cells with membrane bound organelles and nuclei.
- First arose around 1.5 BYA
- Theory of symbiosis (mitochondria and plasmids)