I. Water and Carbon: The Chemical Basis of Life

- **Chemical Evolution**: The theory that simple chemical compounds in the early atmosphere and ocean combined via chemical reactions to form larger, more complex substances, eventually leading to the origin of life and the start of biological evolution.
- **Dalton**: the mass of a proton or neutron roughly equals one Dalton.

A. 2.4 Investigating Chemical Evolution: Approaches and Model Systems

- In the **top-down approach**, researchers examine modern cells to identify chemistry that is shared throughout the tree of life.
- Ancient reactions are prime candidates for being involved in the chemical evolutions that led up to LUCA.
- In the **bottom-up approach**, the primary focus is on the small molecules and environmental conditions that were present in early earth.
- Bottom-up approach has researchers identify reactions that could build the molecules found in life using only what was available at the time, without regard to reactions used by modern cells.
- Two models to explain the process component of the theory of chemical evolution:
  - 1. The **prebiotic soup model**: certain molecules were synthesized from gases in the atmosphere or arrived via meteorites. Afterward, they would have condensed with rain and accumulated in oceans. This process would result in an organic soup that allowed for continued construction of larger, even more complex molecules.
  - 2. The **surface metabolism model** suggest that dissolved gases came in contact with minerals lining the walls of deep-sea vents and formed more complex, organic molecules.

1. Early Origins-of-Life Experiments

- 1953 Stanley Miller performed a break through prebiotic soup model experiment.
- Miller was able to synthesize amino acids by adding intense electrical energy to his early earth microcosm.

2. Recent Origin-of-Life Experiments

- Synthesis of formaldehyde from carbon dioxide and hydrogen may have played a role in chemical evolution: $CO_2(g) + H_2(g) + sunlight \rightarrow CH_2O(g) + H_2O(g)$
- While this process does not occur in cells, when molecules of formaldehyde are heated, they reacts with one another to produce larger organic compounds.
- When energy from photons breaks up molecules by knocking apart shared electrons, the fragments that result are called *free radicals*.
- **Free radicals** have unpaired electrons in their outermost shell and are extremely reactive.
- According to research, large quantities of potential precursors for chemical evolution would have formed in the atmosphere laying the groundwork for the prebiotic soup model.
- One major stumbling block to the prebiotic soup theory is that the precursor molecules would not have concentrated enough to react when diluted in the ocean.

- In the **surface metabolism model**, reactants are recruited to a defined space- a layer of reactive minerals deposited on the walls of deep-sea vent chimneys. Dissolved gases would be attracted by the minerals and concentrated on vent-wall surfaces.
- Not only would the vent-walls bring reactants together, they would also be critical to the rate at which reaction products formed. Even if a potential reaction were spontaneous, it would probably not occur at a level useful for chemical evolution without the support of a catalyst.
- A **catalyst** provides the appropriate chemical environment for reactants to interact effectively.
- The synthesis of acetic acid is an example of a reaction with a catalyst that may have some importance in chemical evolution: $2CO_2(aq)+4H_2(aq)\rightarrow CH_3COOH(aq)+2H_2O(l)$
- This reaction is driven by the chemical energy stored in H2 and is spontaneous despite the increase in entropy.
- The synthesis of acetic acid is employed by certain groups of Bacteria and Archaea today as a step towards building even more complex organic molecules
- The synthesis of acetic acid is important for two reasons:
    - 1. Acetic acid can be formed under the conditions that simulate a hydrothermal vent environment (bottom-up approach).
    - 2. It is a key intermediate in an ancient pathway that produces acetyl CoA, which is a molecule used by cells throughout the tree of life (top-down approach).
- Precursors for nucleotides were also able to be formed under these early earth conditions.

B. 2.5 The Importance of Organic Molecules

- **Organic molecules**: molecules that contain carbon.
- Carbon is versatile because it can form four bonds.
- Carbon provides the structural framework for virtually all the important compounds associate with life (except water).
- The formation of carbon-carbon bonds was an important step toward the production of molecules found in living organisms.

1. Functional Groups

- In general, the carbon atoms in an organic molecule furnish a skeleton that gives the molecule its overall shape.
- Chemical behavior of a compound is dictated by groups of H, N, O, P, or S atoms that are bonded to one of the carbon atoms in a specific way.
- **Functional groups**: groups of H, N, O, P, and S which dictate the composition and properties of organic compounds.

Functional groups

Functional Groups			
Name	**Structure**	**Found in**	**Chemical characteristics**
hydroxyl (alcohol)	*R*–OH	some amino acids, nucleotides, sugars	polar, forms hydrogen bonds
carboxyl (acid)	*R*–C(=O)–OH	fats amino acids	polar, acidic
ketone	*R*–C(=O)–*R*	some sugars	polar
aldehyde	*R*–C(=O)–H	some sugars	polar
amino	*R*–N(H)–H	amino acids proteins	polar, basic, forms hydrogen bonds
sulfhydryl	*R*–SH	some amino acids proteins	forms disulfide bonds
phosphate	*R*–O–P(=O)(OH)–OH	phospholipids nucleotides nucleic acids	polar, acidic
R = remainder of molecule			

- **Amino** and **carboxyl** functional groups tend to attract or drop a proton, respectively, when in solution. Amino functions as a base and carboxyl functions as an acid. Amino acids contain both the amino and carboxyl functional groups and are the most important types of molecules during chemical evolution.
- Amino acids can be linked together by covalent bonds that form between amino and carboxyl groups. In addition, both these groups function in hydrogen bonding.
- **Carbonyl** groups are found in **aldehyde** and **ketone** molecules such as formaldehyde, acetaldehyde, and acetone. This functional group is the site of reactions that link these molecules into larger, more complex organic compounds.
- **Hydroxyl** groups are important because that act as weak acids. Because hydroxyl groups are polar, molecules contain hydroxyl groups will form hydrogen bonds and tend to be soluble in water.
- **Phosphate** groups carry two negative charges. When phosphate groups are transferred from one organic compound to another, the change in in charge often dramatically affect the structures of the recipient molecule. In addition, phosphates that are bonded together store chemical energy that can be use in chemical reactions.
- **Sulfhydryl** groups consist of a sulfur atom bonded to a hydrogen atom. They are important because sulfhydryl groups can link to one another via disulfide S-S bonds.
- When encountering an organic molecule that is new do these three things:
    - 1. Examine the overall size and shape provided by the carbon framework.