CHEM 153A Week 1

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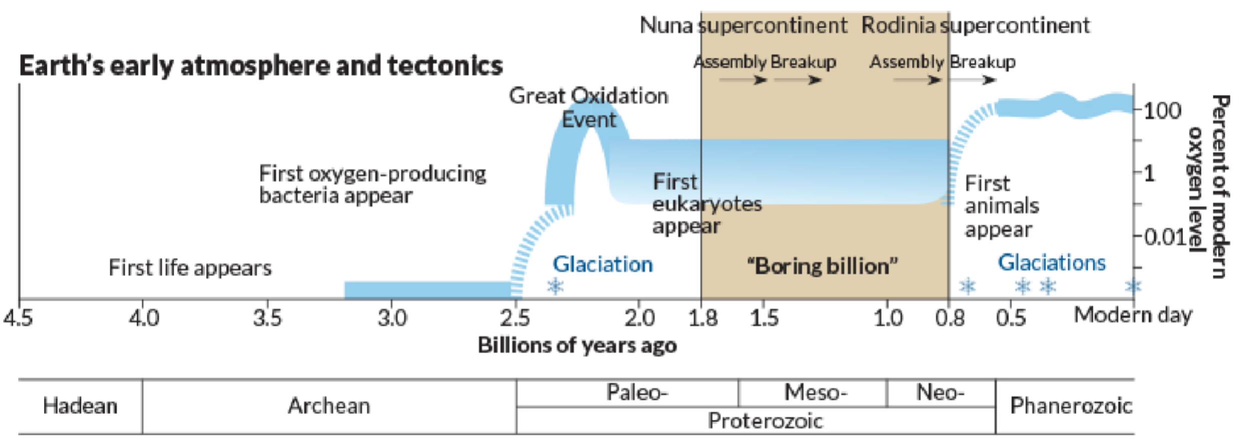
Biochemistry

- It describes in molecular terms the structures, mechanisms, and chemical processes shared by all organisms and **provides organization principles** that underlie life in all its diverse forms.

How Molecular Processes Evolved

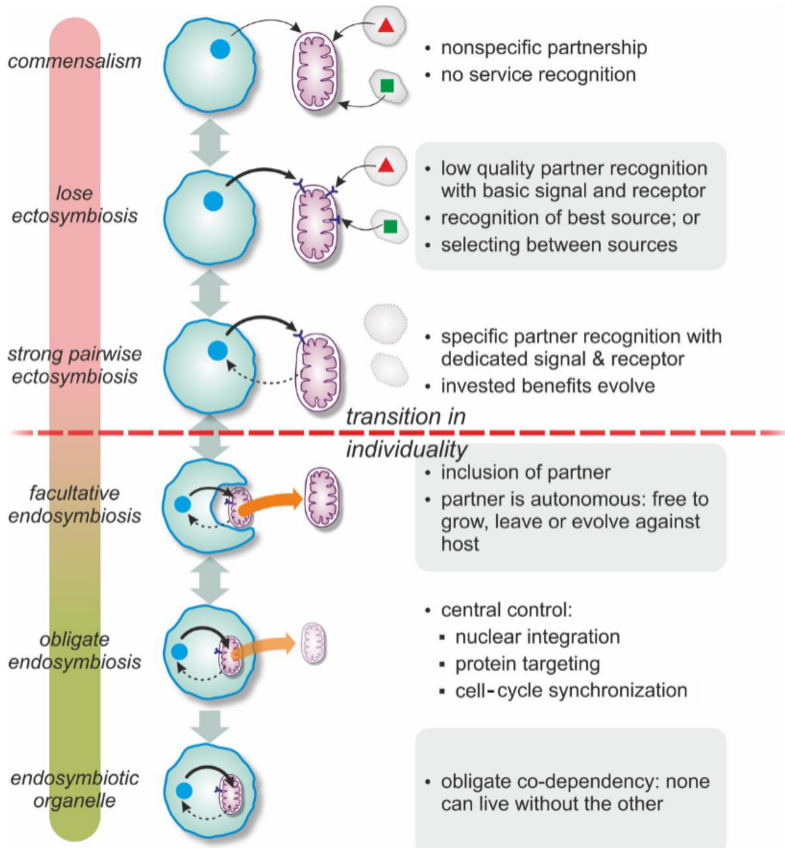
The Great Oxidation Event (2.4-2.1B years ago)



During this event, a few things happened:

- Lots of species went extinct because of the change in atmosphere
- Animals can now exist, since aerobic respiration became possible
- Mitochondria began appearing.

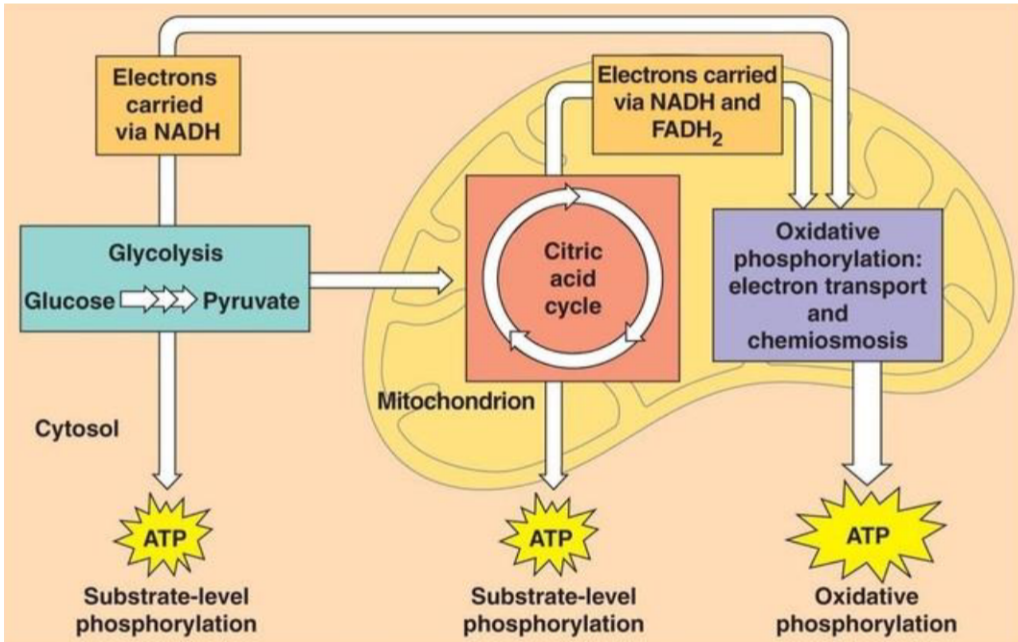
Endosymbiotic Theory



Zachar & Boza, 2020
https://doi.org/10.1007/s00018-020-03462-6

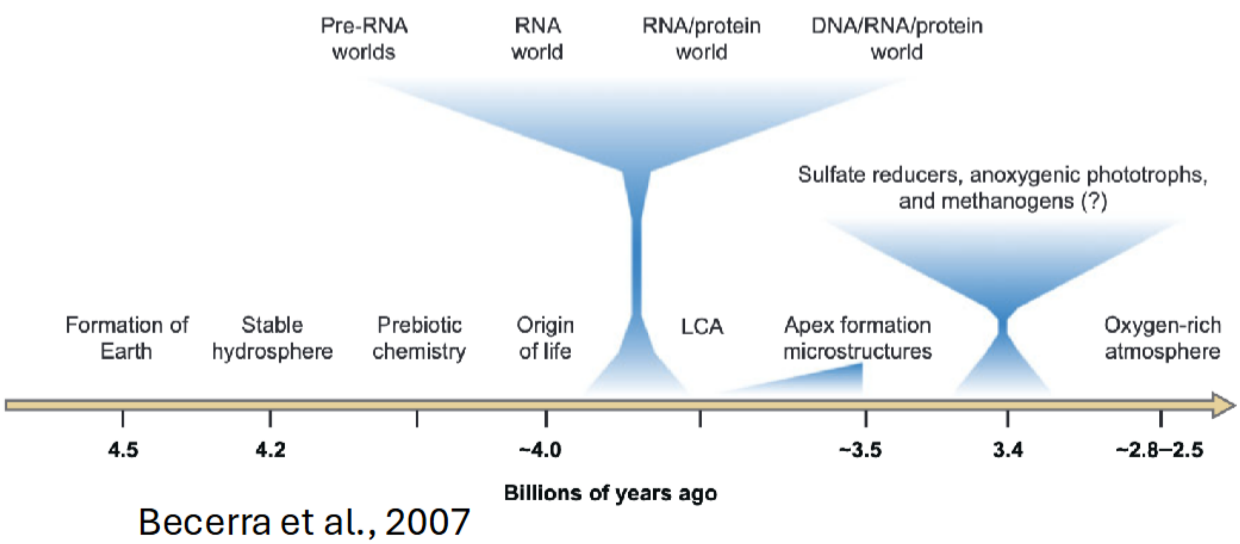
- Mitochondria used to be separate cells, rather than an organelle.
- At some point, one cell engulfed the other, and evolution occured.

Mitochondria

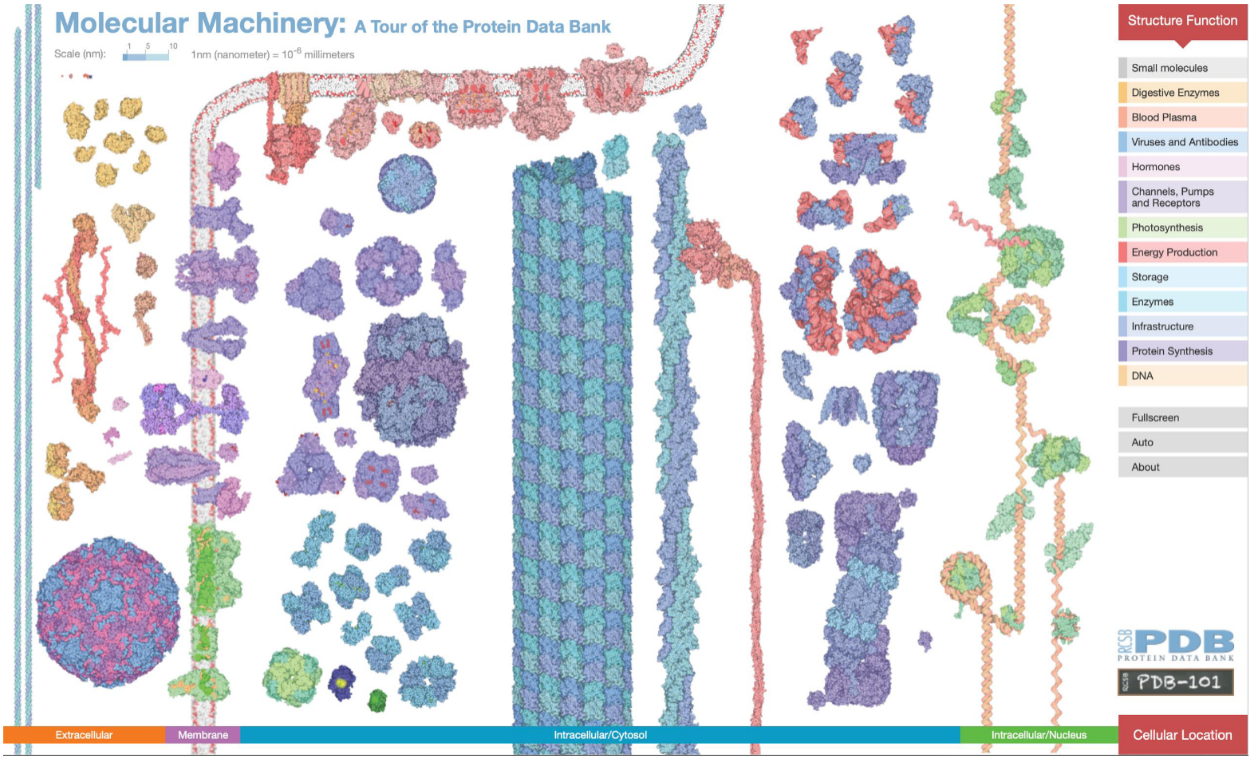


Evolution of Metabolism

- This example alone demonstrates the transformative impact of oxygen in life
- **Biochemistry can be divided into two eras: one before oxygen, and one after**
- Modern processes depend on oxygen, while older, more ancient pathways functioned in its absence.

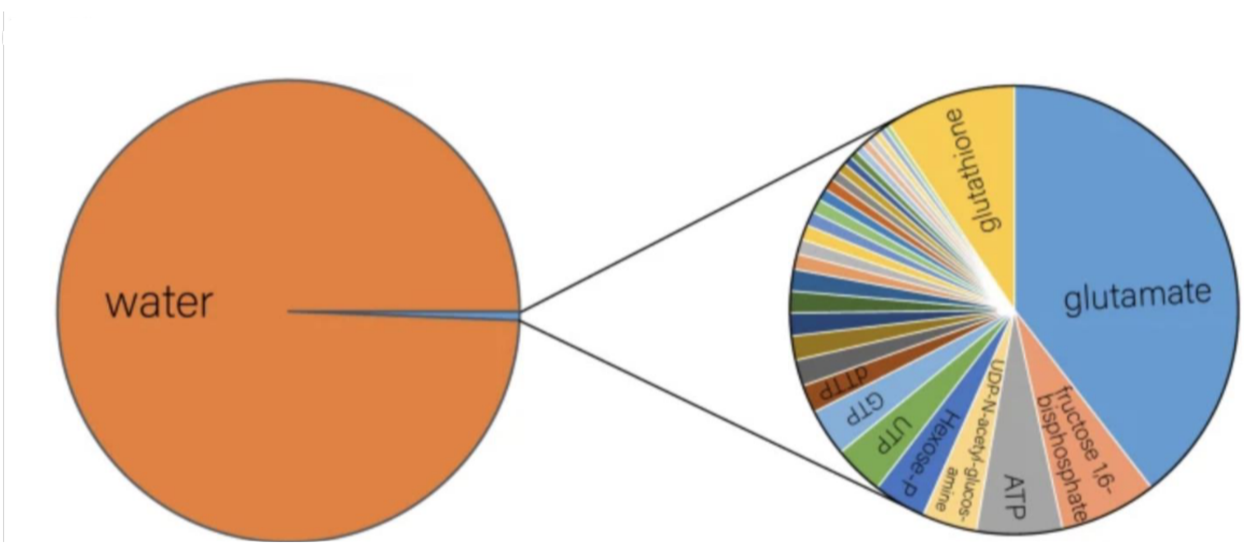


Proteins



- The above diagram shows proteins, an important part of cells and metabolism.
- This class aims to study the metabolic pathways in cells, many of which are catalyzed by proteins (specifically enzymes).
- RNA can also be a catalyst. (RNA is not a protein)

Water



- Water is a dominant metabolite in biochemistry, accounting for 99.4% by molarity of metabolites within an *E. coli.* bacteria. Water in an *E. coli* cell is around 40 M. The sum of the concentrations of all other metabolites is 240 mM.

Proteins Exist in Aqueous Environments

- Our first major topic in this class is **protein synthesis and structure**
  - The **amino acids** of proteins are affected by the **pH** of aqueous environments (protonation state!)
  - These amino acids often form different **intermolecular interactions** amongst themselves and with their environment
  - The folding of proteins is a **thermodynamic** problem

Importance of Water

- Physical and chemical properties of water influence every biochemical interaction
  - The medium for most biochemical reactions
  - Participates directly in many biochemical reactions
  - Affects folding (structure) of biomolecules

Aside: Quantifying the amount of substance dissolved in a solvent

- Concentration measures how much **solute** (the substance being dissolved) is present in a certain volume of **solvent** (usually water)
- Use Molarity (M).
  - Definition: Moles of solute per liter of solution
  - Formula: $M = \frac{\text{Moles solute}}{\text{Liters solution}}$
  - Example: A 1M NaCl solution contains 1 mole of NaCl in 1 liter of water.
  - Square brackets are used in chemistry to represent the concentration of a substance.

Our Watery Origins

Water as Essential but Problematic

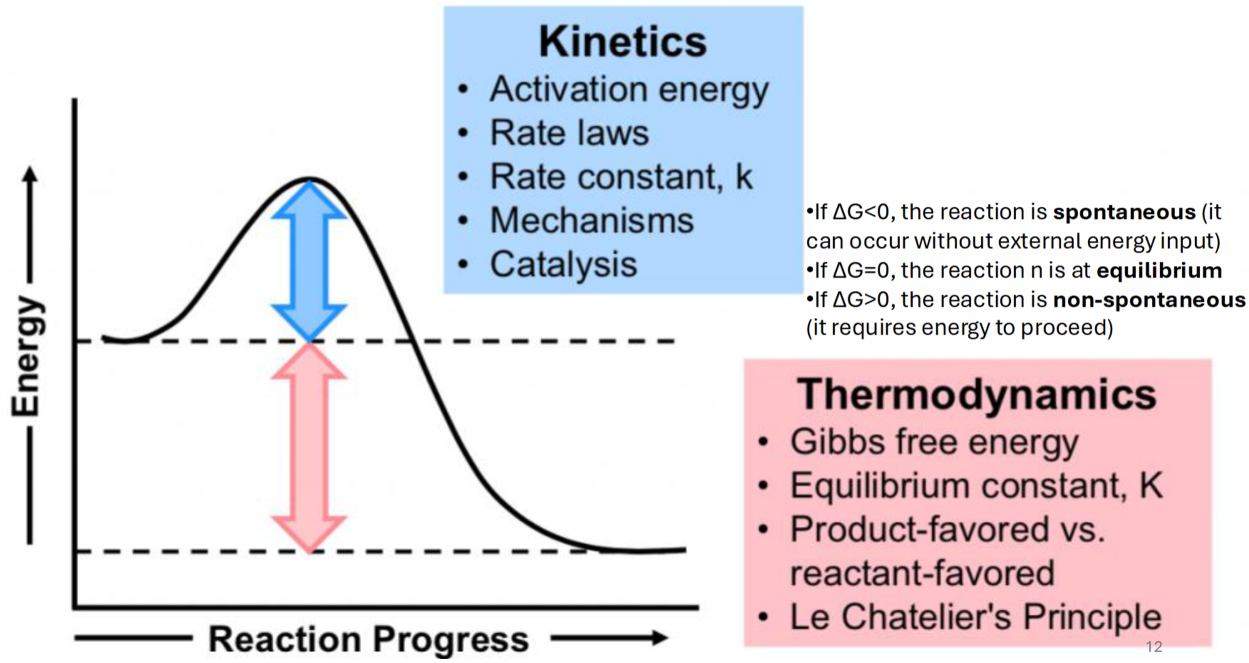
- **Essential for Life:** Water is crucial for life because it acts as a solvent, facilitates biochemical reactions, and is involved in virtually all life processes
- **Problematic for Life's Origins:** Paradoxically, water can hinder the formation of important biomolecules, such as proteins and nucleic acids, because both are **condensation polymers**. This means that their formation involves reactions that produce water as a byproduct. In an aqueous environment, water tends to promote the reverse reaction, hydrolysis, which breaks down these polymers
- The key to overcoming this challenge lies in **balancing thermodynamic activation** (making the formation of polymers energetically favorable) with **kinetic stability** (preventing them from breaking down too easily)

> **Prebiotic chemistry** could bypass fully hydrolyzed monomers and use energy-rich intermediates for polymer formation
>
> Example: **ATP**, though thermodynamically unstable in water, remains kinetically stable enough to drive biochemical reactions

- Liquid water is an extraordinary molecule that plays a central role in the chemistry of life due to its unique properties.
- The most important among them probably are the ability to establish hydrogen bonds, a high polarity and a high dielectric constant

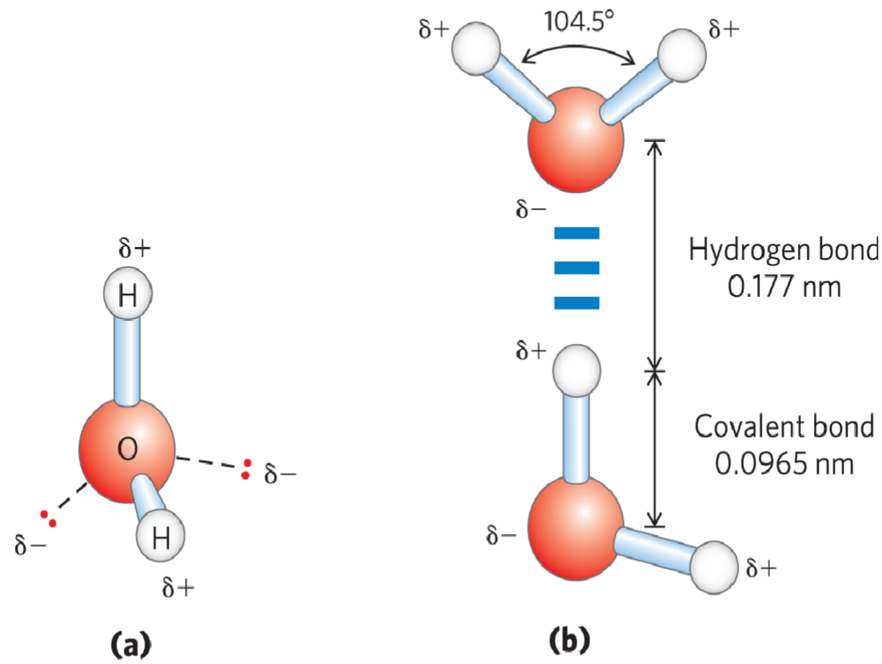
Kinetic vs. Thermodynamic Stability

- **Thermodynamic Stability:** Determines whether a reaction will be energetically favorable, or spontaneous, based on the overall energy of the system. A thermodynamically stable molecule is one that is in a lower energy state compared to its potential products
- **Kinetic Stability:** Refers to how quickly (or slowly) a reaction proceeds. A kinetically stable molecule is one that reacts very slowly, even if the reaction would be favorable (thermodynamically stable).



Hydrogen Bonds

- Water molecules can form hydrogen bonds because of the polarity in their O-H bonds. Oxygen, being more electronegative, pulls shared electrons closer, creating a partial negative charge on the oxygen and partial positive charges on the hydrogen atoms
- This polarity allows water to generate a cohesive hydrogen-bond network, resulting in phenomena such as high surface tension and capillary action, and enabling it to dissolve many polar substances effectively. Hydrogen bonding also stabilizes biological macromolecules (e.g., proteins, nucleic acids)
- Water has a higher melting point, boiling point, and heat of vaporization than most other common solvents (due to polarity and H-bonds)
- Hydrogen bond (H-bond) = **electrostatic attraction between the oxygen atom of one water molecule and the hydrogen of another**



Strength of Hydrogen Bonds

- Hydrogen bonds are **relatively weak**
  - bond dissociation energy (energy req uired to break a bond) = 23 kJ/mol in liquid H_2O (470 kJ/mol for a covalent O-H bond)
  - 1% covalent, 90% electrostatic
- Hydrogen bonds are fleeting
  - lifetime of each hydrogen bond is just 1 to 20 picoseconds in liquid (1 picosecond = 10^{-12} seconds)
  - when one hydrogen bond breaks, another forms

Number of Hydrogen Bonds Formed

- In liquid, each H_2O molecule forms hydrogen bonds with an average of 3.4 other molecules
- In ice, each H_2O molecule forms 4 hydrogen bonds.