The “Tree of Life”
Metabolic Pathways
Calculation Of Energy Yields

OCN 401 - Biogeochemical Systems
8/25/15

Reading: Schlesinger & Bernhardt, Chapters 1 & 2

Outline

1. Earth’s history and the evolution of life
2. The “Tree(s) of Life”
3. Metabolic strategies by organisms
4. Linkages between reductions and oxidations (redox)
5. Calculation of energy yields
Earth's History

Ga = billions of years ago

Miller – Urey Experiment
Other Possibilities

**Interplanetary sources of organic matter** - interplanetary dust particles, carbonaceous chondrites (meteorites) - a small amount of material, but may have a major catalytic effect, speeding the rate of abiotic organic matter synthesis.

**Clay minerals** - may have aided in concentrating simple organics, making the assembly of complex organic compounds more favorable.

**Icy comets crashing into earth’s atmosphere** - can produce complex organics from simple inorganic compounds (water, ammonia, methanol, carbon dioxide) due to elevated temp and pressure.

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The Tree of Life – A Traditional Approach

[Diagram of the Tree of Life]

www.msnucleus.org
A Modern Approach

Determined from sequencing of ribosomal RNA (as opposed to morphology and physiology)

Bacteria  \hspace{1cm}  Archaea  \hspace{1cm}  Eucaryotes

"Last universal common ancestor"

Archaea – most "primitive", commonly live in extreme environments

A further complication – *endosymbiosis* due to *lateral gene transfer*:

Modified from Chan et al. (1997)
Metabolic Strategies for Sustaining Life

We can classify organisms by function -- how they obtain energy and cell-carbon:

1. Method of energy generation (reactions that convert ADP to ATP):
   - Photosynthesis -- *Phototroph*
     
     *e.g.:* Oxic photosynthesis:  \( 6 \text{CO}_2 + 6 \text{H}_2\text{O} \rightarrow C_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2 + \text{ATP} \)
   - Oxidation/reduction of inorganic compounds -- *Lithotroph (Chemotroph)*
     
     *e.g.:* Ammonia oxidation:  \( \text{NH}_4^+ + \frac{1}{2} \text{O}_2 \rightarrow \text{NO}_2^- + 2 \text{H}^+ + \text{H}_2\text{O} + \text{ATP} \)
   - Oxidation of organic compounds -- *Organotroph*
     
     *e.g.:* Glucose oxidation:  \( C_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2 \rightarrow 6 \text{CO}_2 + 6 \text{H}_2\text{O} + \text{ATP} \)

2. **Carbon** source:
   - Carbon dioxide -- *Autotroph*
   - Organic compounds -- *Heterotroph*
Metabolic Strategies - Examples

**Photoautotrophs**
- Green plants: Most algae
- Cyanobacteria: Some purple and green bacteria

**Lithoautotrophs (Autolithotrophs)**
- Methane oxidizing bacteria: \( \text{CH}_4 + \text{O}_2 \rightarrow \text{CO}_2 + 4\text{H}^+ + 4e^- \)
- Hydrogen oxidizing bacteria
- Iron oxidizing bacteria
- Nitrifying bacteria: \( \text{NO}_2^- + \frac{1}{2} \text{O}_2 \rightarrow \text{NO}_3^- \)

**Photoheterotrophs**
- Most purple and green non-sulfur bacteria
- Some cyanobacteria

**Lithoheterotrophs (Heterolithotrophs)**
- Sulfide oxidizing bacteria

**Organoheterotrophs**
- Animals
- Most bacteria
- Fungi
- Protozoa

**Linkages Between Oxidations and Reductions**

In this course we will see that global biogeochemical cycles are driven by transformations of substances between oxidized and reduced forms in different environments.
Calculation of Energy Yields

Consider this general reaction:

\[ \text{aA + bB} \rightarrow \text{cC + dD} \]

The free-energy change of the reaction at “standard state” can be calculated as:

\[ \Delta G_r^\circ = \left( cG_C^\circ + dG_D^\circ \right) - \left( aG_A^\circ + bG_B^\circ \right) \]

where \( G_x^\circ \) is the free energy of formation for a product or reactant “X” at standard state (which can be looked up)

Standard state: 1 atm pressure
25°C
Concentrations = 1 mole/kg

Thus, \( \Delta G_r^\circ \) is a powerful tool to predict if a reaction will occur!

However, we are commonly interested in conditions other than standard state....
We calculate the \textit{in-situ} \( \Delta G_r \) using this equation:

\[
\Delta G_r = \Delta G_r^\circ + RT \ln \frac{[C]^c}{[A]^a [B]^b}
\]

R = ideal gas constant = 1.987 cal \( ^\circ \text{K}^{-1} \text{ mol}^{-1} = 8.31 \text{ J} \( ^\circ \text{K}^{-1} \text{ mol}^{-1} \\
T = ^\circ \text{K} \\
[ \text{ ]} = \text{concentration}

Thus, using the same criteria used on the previous slide, we can predict whether a reaction will occur under real-world conditions!

\textbf{The next lecture:} \\
\textbf{“Atmospheric deposition, atmospheric models”}

This will begin our investigation of biogeochemical systems on Earth:

- Atmosphere
- Terrestrial systems
- Aquatic systems
  - Lakes
  - Streams and rivers
  - Estuaries
  - Oceans