# Lecture 2– Carbon and Energy Transformations

**READINGS FOR NEXT LECTURE:**

- ☐ Krebs Chapter 25: Ecosystem Metabolism I: Primary Productivity
- ☐ Luria. 1975. Overview of photosynthesis. (H, W)
- ☐ Stowe, S. 2003. When swans inspire not a ballet, but a battle. *NY Times*. September 3. (H,W)
- ☐ Kaiser, J. 1995. Can deep bacteria live on nothing but rocks and water? *Science*. **270**:377. (L)
- ☐ Stevens, TO and JP McKinley. 1995. Lithoautotrophic microbial ecosystems in deep basalt aquifers. *Science*. **270**: 450. (L)
- ☐ Pace, N. 1997. A molecular view of microbial diversity and the biosphere. *Science*. **276**:734. (L)
- ☐ Newman, DK and JF Banfield. 2002. Geomicrobiology: How molecular-scale interactions underpin biogeochemical systems. *Science*. **296**:1071. (L)
- ☐ Sarbu, S *et al*. 1996. A chemoautotrophically-based cave ecosystem. *Science*. **272**:1953. (L)

"Nature has put itself the problem of how to catch in flight light streaming to earth and to store the most elusive of all powers in rigid form."

*Mayer, 1842, discovered law of conservation of energy*

**Outline for today:**

I. Evolution
II. Autotrophs
  A. Photosynthesis
  B. Bacterial photosynthesis
  C. Chemosynthesis
III. Heterotrophs
  A. Aerobic respiration
  B. Fermentation
  C. Anaerobic respiration

Main question: How do organisms obtain carbon and energy needed to grow and function?

## I. Evolution

Old view of the world: 5 Kingdoms.
Development of new perspective on life.
  Novel genetic identification techniques (C Woese in the 1970s)
  "Tree of Life" with 3 Domains: Eubacteria, Archaea, Eukaryotes
  Hydrothermal vents and hot springs
  Genotypic not phenotypic classifications

**Universal phylogenetic tree based on SSU rRNA sequences**
Sixty-four rRNA sequences representative of all known phylogenetic domains were aligned, and a tree was produced using FASTDNAML (43, 52). That tree was modified, resulting in the composite one shown, by trimming lineages and adjusting branch points to incorporate results of other analyses. The scale bar corresponds to 0.1 changes per nucleotide. (Pace, N. 1997. *Science*. **276**:734-740)

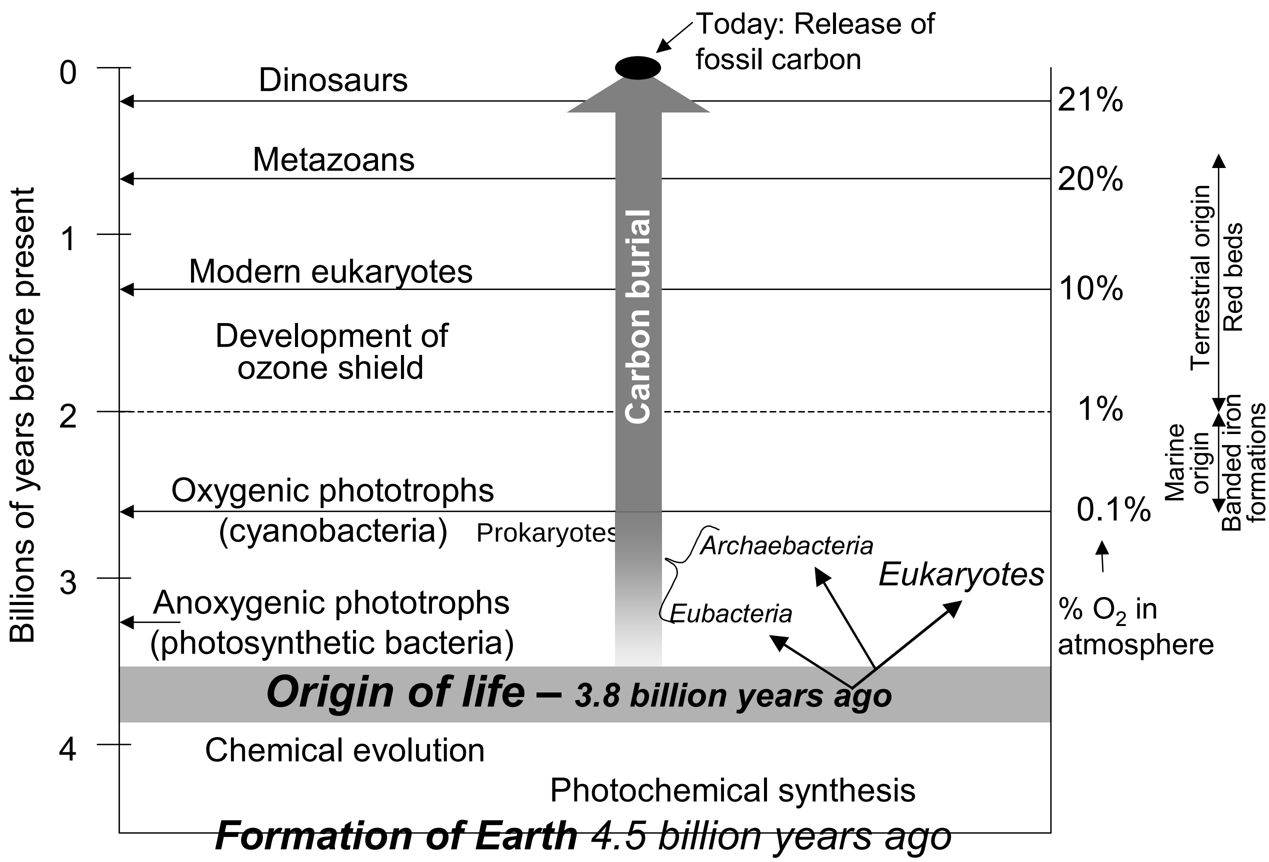
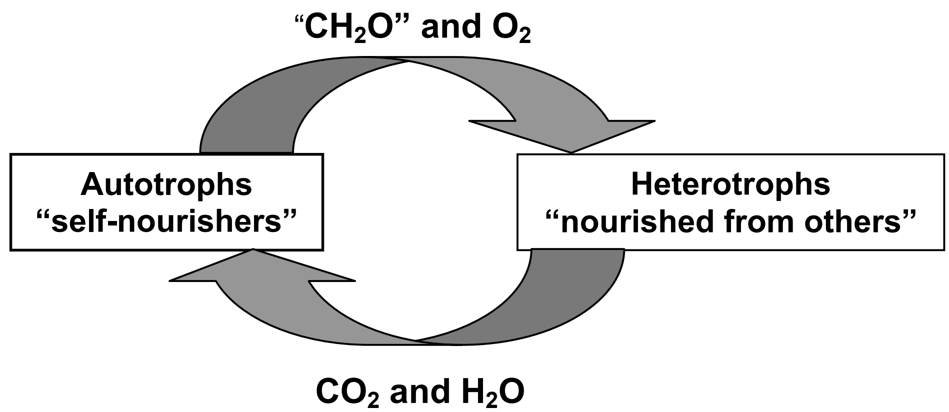



Figure 2. Adapted from Brock and Madigan, *Biology of Microorganisms*. Major landmarks in biological evolution.

## Basic picture of life:

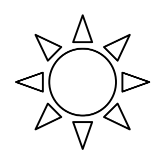



### II. Autotrophs

These "self-nourishers" get their energy from the sun (photoautotrophs) or from reduced inorganic compounds (chemoautotrophs), and they get their carbon from $CO_2$.

These organisms undergo two reactions. The first reaction produces ATP* and NADPH**, which provide stored energy and reducing power. For photosynthetic organisms, this is known as the Hill reaction. The second reaction, the Calvin Cycle, is common to all autotrophs, and uses stored energy and reducing power to convert $CO_2$ to $CH_2O$ (sugar).

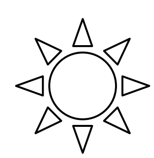
### A. Photosynthesis (aerobic)



**Who?** Plants, cyanobacteria, eukaryotic algae
**C Source?** $CO_2$
**Energy Source?** Sunlight
**Electron Donor?** $H_2O$
**Where?** In aerobic, light conditions

$$CO_2 + H_2O + h\nu \longrightarrow CH_2O + O_2$$

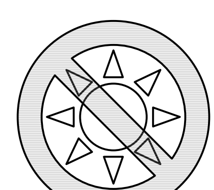
### B. Bacterial Photosynthesis (anaerobic)



**Who?** Bacteria (e.g. Purple sulfur bacteria)
**C Source?** $CO_2$
**Energy Source?** Sunlight
**Electron Donor?** $H_2S$
**Where?** In anaerobic, light conditions

$$CO_2 + 2\ H_2S + h\nu \longrightarrow CH_2O + 2\ S + H_2O$$

### C. Chemosynthesis



**Who?** Chemoautotrophic bacteria, aka chemolithoautotrophs
**C Source?** $CO_2$

**Energy Source?** Reduced inorganic compounds ($CH_4$, $NH_4$, $H_2S$, $Fe^{2+}$)
**Electron Donor?** Reduced inorganic compounds
**Where?** In microaerobic or anaerobic, dark conditions

*Sulfur oxidizing bacteria*: $H_2S \rightarrow S \rightarrow SO_4^{2-}$
*Methanotrophs*: $CH_4$ (methane) $\rightarrow CO_2$
*Nitrifying bacteria*: $NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-$
*Iron oxidizing bacteria*: $Fe^{2+} \rightarrow Fe^{3+}$

*ATP = adenosine triphosphate. (ADP = adenosine DI phosphate)
**NADPH = nicotinamide adenine dinucleotide phosphate

## III. Heterotrophs

These organisms ("nourished by others") get their energy and carbon from reduced organic compounds.

ATP and NADH*** are produced, which can then be used elsewhere in the cells.

### A. Aerobic respiration

**Who?** Aerobic eukaryotes and prokaryotes
**C Source?** $CH_2O$
**Energy Source?** $CH_2O$
**Electron Acceptor?** $O_2$
**Where?** Aerobic conditions

These reaction is essentially the reverse of the Calvin cycle. $O_2$ is the final electron acceptor. Plants also carry out this reaction to get energy for their growth and metabolic processes.

$$CH_2O + O_2 \longrightarrow CO_2 + H_2O$$

### B. Fermentation

**Who?** Eukaryotes and prokaryotes
**C Source?** $CH_2O$
**Energy Source?** $CH_2O$
**Electron Acceptor?** organic compounds
**Where?** Anaerobic conditions

This is only the first part of respiration and results in partial breakdown of glucose. The products are organic acids or alcohols (*e.g.*, lactic acid, ethanol, acetic acid) rather than $CO_2$.

## C. Anaerobic respiration

**Who?** Prokaryotes only
**C Source?** $CH_2O$
**Energy Source?** $CH_2O$
**Electron Acceptor?** Oxidized inorganic compounds ($SO_4^{2-}$, $Fe^{3+}$, $NO_3^{+}$, etc.)
**Where?** Anaerobic conditions

Very similar to aerobic respiration, except that $O_2$ is not the final electron acceptor. Instead, another oxidized compound such as $SO_4^{2-}$, $NO_3^{-}$, or $CO_2$ is the final electron acceptor.

| | |
|---|---|
| *Iron reducing bacteria:* | $Fe^{3+} \rightarrow Fe^{2+}$ |
| *Denitrifying bacteria*: | $NO_3^{-} \rightarrow NO_2^{-}$ |
| | $NO_2^{-} \rightarrow N_2$ |
| *Sulfate reducing bacteria*: | $H_2S \rightarrow S \rightarrow SO_4^{2-}$ |
| *Methanogens*: | $CO_2 \rightarrow CH_4$ (methane) |

***NADH = nicotinamide adenine dinucleotide (a relative of NADPH. NADH is used for ATP production, while NADPH is associated with biosynthesis)

## Study Questions:

- What is a Winogradsky column? What are the light, oxygen and sulfide levels in each layer, and which organisms dominate each layer? What are the energy and carbon sources for each kind of organism?
- Describe the significance of the discovery of deep-sea hydrothermal vents.
- Why has Rubisco been called the most important protein on Earth?
- What is unique about the cave ecosystems described in Sarbu's article? What are the differences and similarities to hydrothermal vents?
- Banfield and Newman's article mentions the benefits of advances in genetic techniques for understanding microbial community structure and the identities of microorganisms. Given what you know about metabolic diversity, why is it so hard to culture most microorganisms in a laboratory?
- If a lake is covered in algae, how do anoxygenic photosynthetic bacteria, which live underneath the algae, manage to obtain sufficient light to carry out photosynthesis?