# 7.014 Lectures 16 &17: The Biosphere & Carbon and Energy Metabolism

## *Simplified Summary of Microbial Metabolism*

The metabolism of different types of organisms drives the biogeochemical cycles of the biosphere. Balanced oxidation and reduction reactions keep the system from "running down".

All living organisms can be ordered into two groups[1], autotrophs and heterotrophs, according to what they use as their carbon source. Within these groups the metabolism of organisms can be further classified according to their source of energy and electrons.

**Autotrophs**: Those organisms get their energy from light (*photoautotrophs*) or reduced inorganic compounds (*chemoautotrophs*), and their carbon from $CO_2$ through one of the following processes:

Photosynthesis (aerobic) — Light energy used to reduce $CO_2$ to organic carbon using $H_2O$ as a source of electrons. $O_2$ evolved from splitting $H_2O$. (*Plants, algae, cyanobacteria)*

Bacterial Photosynthesis (anaerobic) — Light energy used to reduce $CO_2$ to organic carbon (same as photosynthesis). $H_2S$ is used as the electron donor instead of $H_2O$. (*e.g. purple sulfur bacteria*)

Chemosynthesis (aerobic) — Energy from the oxidation of inorganic molecules is used to reduce $CO_2$ to organic carbon (*bacteria only)*.

*e.g. sulfur oxidizing bacteria* $H_2S \rightarrow S \rightarrow SO_4^{-2}$

*nitrifying bacteria* $NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-$

*iron oxidizing bacteria* $Fe^{+2} \rightarrow Fe^{+3}$

*methane oxidizing bacteria (methanotrophs)* $CH_4 \rightarrow CO_2$

**Heterotrophs:** These organisms get their energy and carbon from organic compounds (supplied by autotrophs through the food web) through one or more of the following processes:

Aerobic Respiration (aerobic) — Oxidation of organic compounds to $CO_2$ and $H_2O$, yielding energy for biological work. $O_2$ is the final electron acceptor (All aerobic organisms -- *eukaryotes and prokaryotes).*

Fermentation (anaerobic) — Glucose converted to pyruvate (yielding energy) which is then converted to a variety of end products (e.g. yeast oxidize glucose to ethanol, and anaerobic muscle oxidizes it to lactic acid). Glucose is not oxidized all the way to $CO_2$ as it is in aerobic respiration (*eukaryotes and prokaryotes)*.

Anaerobic Respiration (anaerobic) — Oxidation of organic compounds to $CO_2$ yielding energy for biological work. Final electron acceptor is not $O_2$, but rather $NO_3^-$, $SO_4^{-2}$ etc. (*prokaryotes only)*

*denitrifying bacteria* $NO_3^- \rightarrow NO\ (g) \rightarrow N_2O\ (g) \rightarrow N_2\ (g)$

*sulfate reducing bacteria* $SO_4^{-2} \rightarrow H_2S$

*methanogens* $CO_2 \rightarrow CH_4$

Thus all life is run on the free energy difference between $O_2$ and organic carbon (glucose). The autotrophs synthesize glucose using solar or chemical energy, which is broken down through respiration (either their own or that of the organisms that eat them) to provide the energy necessary for "biological work". Redox reactions are central to all of these energy transformations, and the resulting flows of electrons manifest themselves in the form of biogeochemical cycles. The activities of bacteria keep these cycles moving. For example, the chemosynthetic bacteria oxidize many essential elements in the process of getting the energy required to reduce $CO_2$. Certain anaerobic bacteria in turn reduce these compounds in the process of anaerobic respiration — i.e., they use them as an electron acceptor in the absence of oxygen. **This keeps the element cycles flowing and keeps the system from "running down".**

[1] This summary is over-simplified. There are microbes that don't fit into this scheme. Some organisms are "mixotrophs" — i.e., they can switch between different modes of metabolism depending on the circumstances. Also, there are associations between organisms — i.e., "symbioses" which behave as a single organism with multiple modes of metabolism. Finally, there are microorganisms that have managed to break out of this general framework. Basically, if it can work thermodynamically, Nature has created a microbe that can do it.

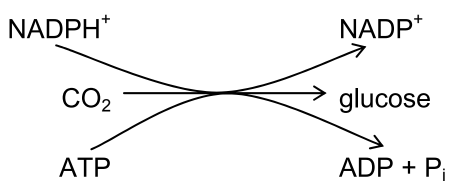
# GENERAL CLASSIFICATION OF MICROORGANISMS

| | Carbon Source | | Energy Source | | Electron Donor | |
|---|---|---|---|---|---|---|
| General classification | Inorganic ($CO_2$)<br>Autotroph | Organic<br>Heterotroph | Light<br>Phototroph | Chemical<br>Chemotroph | Inorganic<br>Lithotroph | Organic<br>Organotroph |
| Organisms | | | | | | |
| Phytoplankton | X | | X | | $H_2O$ | |
| Green and purple sulfur bacteria | X | | X | | $H_2S$ | |
| Fungi & protozoa | | X | | X | | X |
| Most bacteria (heterotrophic) | | X | | X | | X |
| Nitrifying bacteria | X | | | $NH_4$ | NH4 | |
| Sulfur oxidizing bacteria | X | | | $H_2S$ | $H_2S$ | |

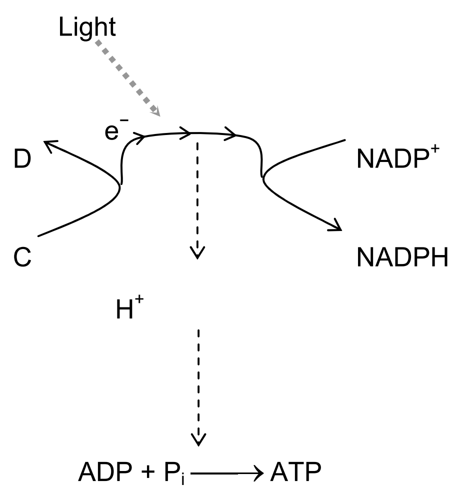
## Autotroph

(Quantities of compounds omitted for simplicity)

"Dark reactions"
(common to all)



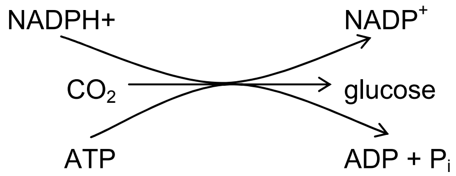

Photosynthesis



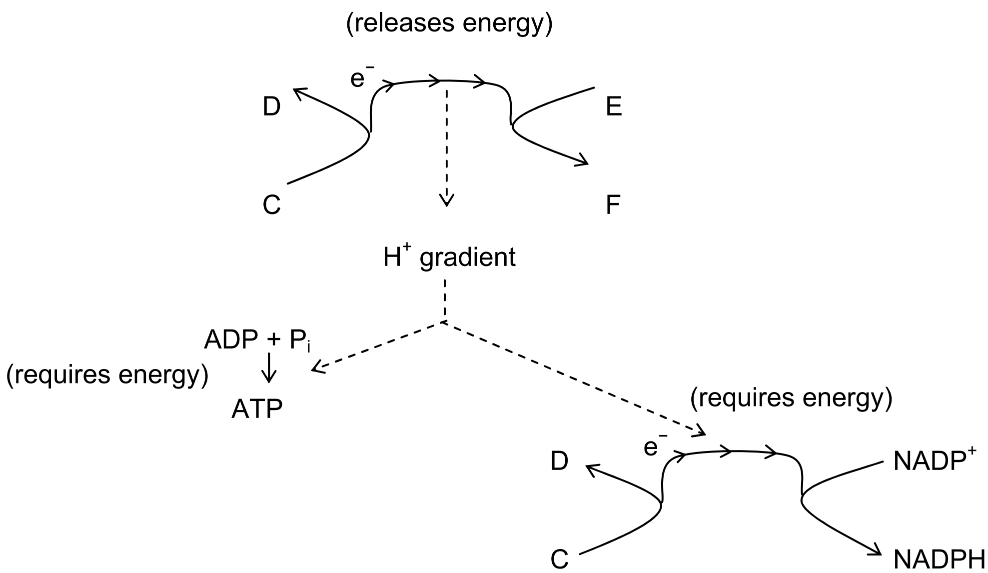

| **Type** | **A** | | **B** |
|---|---|---|---|
| oxygenic (plant) | $H_2O$ | $\Rightarrow$ | $O_2$ |
| anyoxygenic | $H_2S$ | $\Rightarrow$ | S, $SO_4^{2-}$ |

## **Autotrophs, continued** (Quantities of compounds omitted for simplicity)

"Dark reactions"
(common to all)



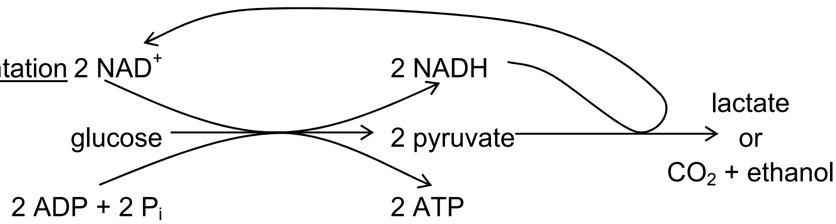

Chemosynthesis



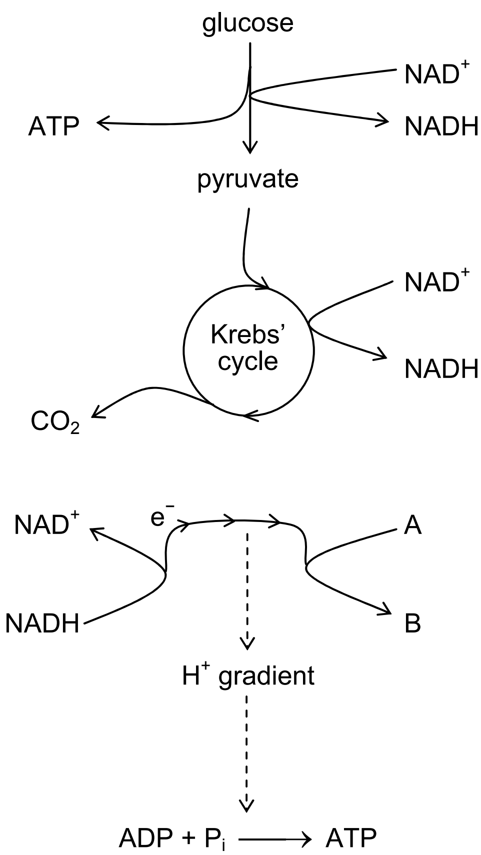

| **Type** | **C** | | **D** | **E** | | **F** |
|---|---|---|---|---|---|---|
| sulfur-oxidizing | $H_2S$ | ⇒ | S, $SO_4^{2-}$ | $O_2$ | ⇒ | $H_2O$ |
| | $H_2S$ | ⇒ | S, $SO_4^{2-}$ | $NO_3^-$ | ⇒ | $N_2O$ |
| nitrifying | $NH_3$<br>$NO_2$ | ⇒ | $NO_3^-$ | $O_2$ | ⇒ | $H_2O$ |

## Heterotrophs

Fermentation




Respiration (Quantities of compounds omitted for simplicity)




| **Type** | **A** | | **B** |
|---|---|---|---|
| aerobic | $O_2$ | ⇒ | $H_2O$ |
| sulfate-reducing | $SO_4^{2-}$ | ⇒ | $H_2S$ or S |
| denitrifying | $NO_3^-$ | ⇒ | NO, $N_2$, $N_2O$, $NH_3$ |