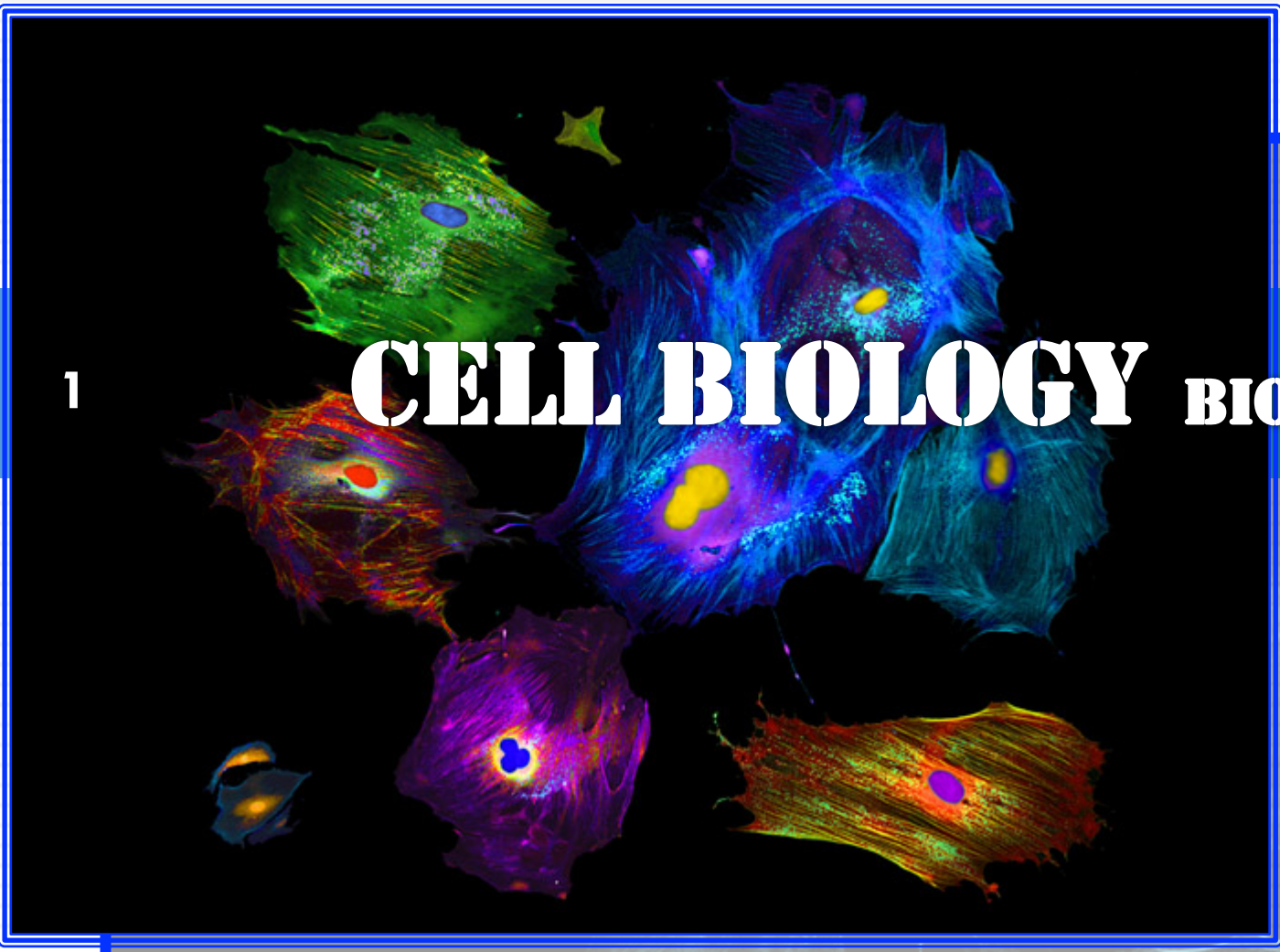
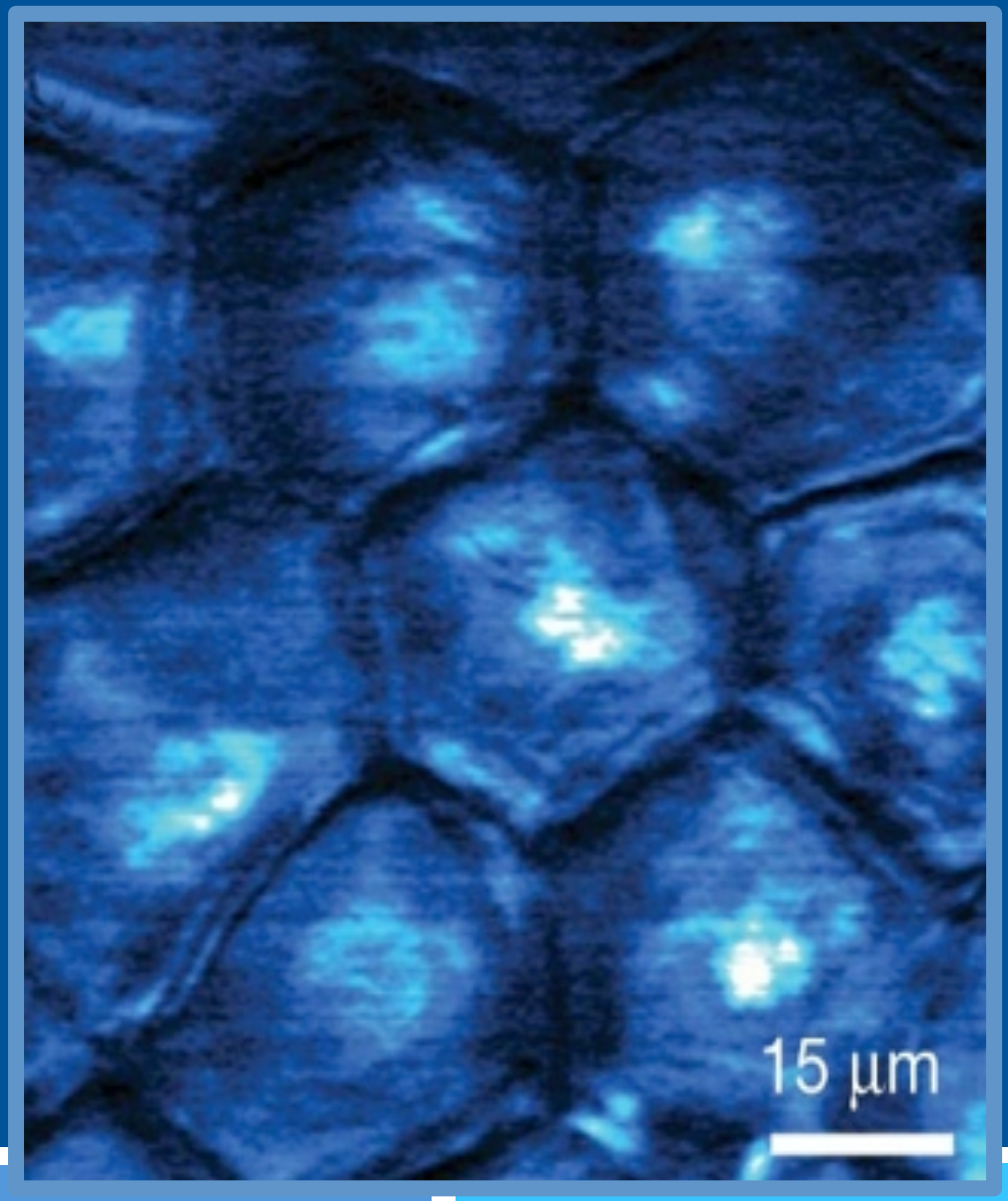


CELL BIOLOGY BIOL 266/4



PHOTOSYNTHESIS AND RESPIRATION

Lecture 2

BIOL 266/4

2014-15

Dr. S. Azam

Biology Department
Concordia University

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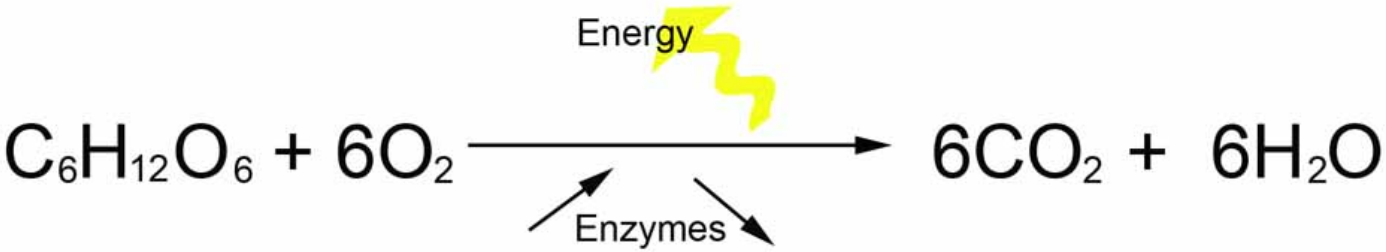
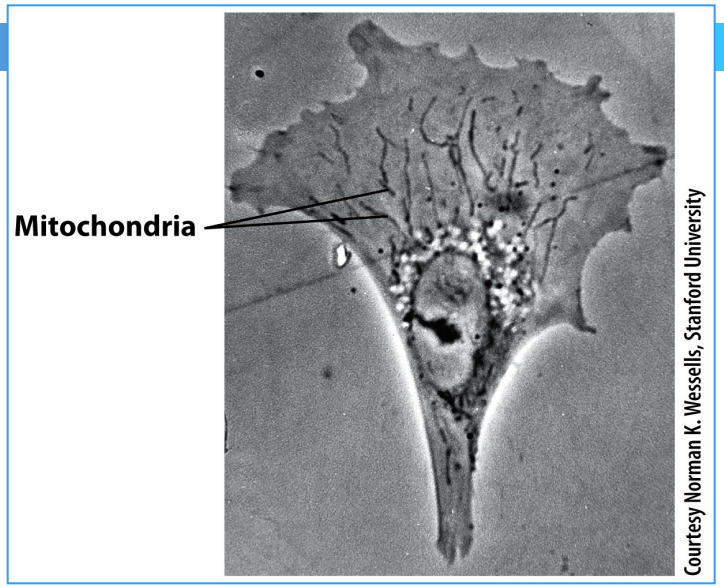
RESPIRATION



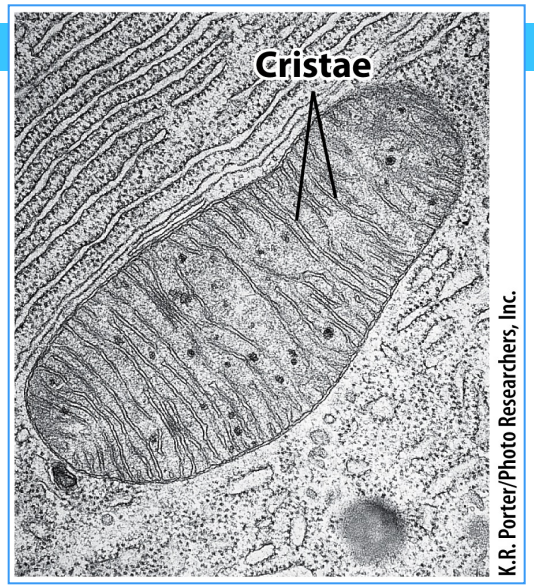
Aerobic and Anaerobic Respiration

- Early earth was populated by **anaerobes**: captured and utilized energy by oxygen-independent metabolism.
- Cyanobacteria added oxygen to the atmosphere
- **Aerobes** evolved: used oxygen to extract more energy from organic molecules.
- In eukaryotes, aerobic respiration takes place in the **mitochondrion**.

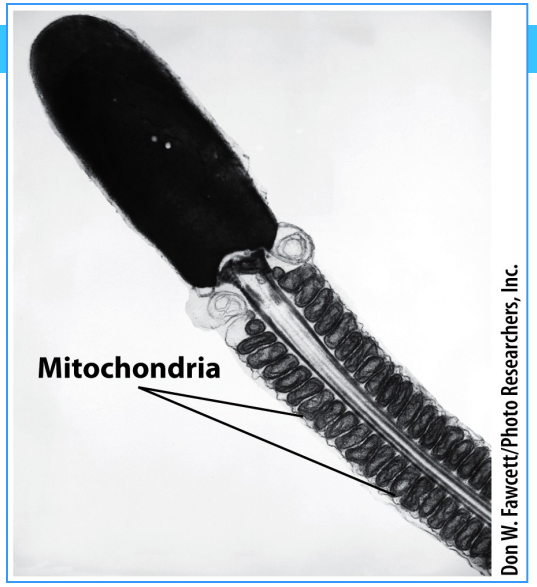
Mitochondrial Structure and Function



Elongated mitochondria of fibroblast



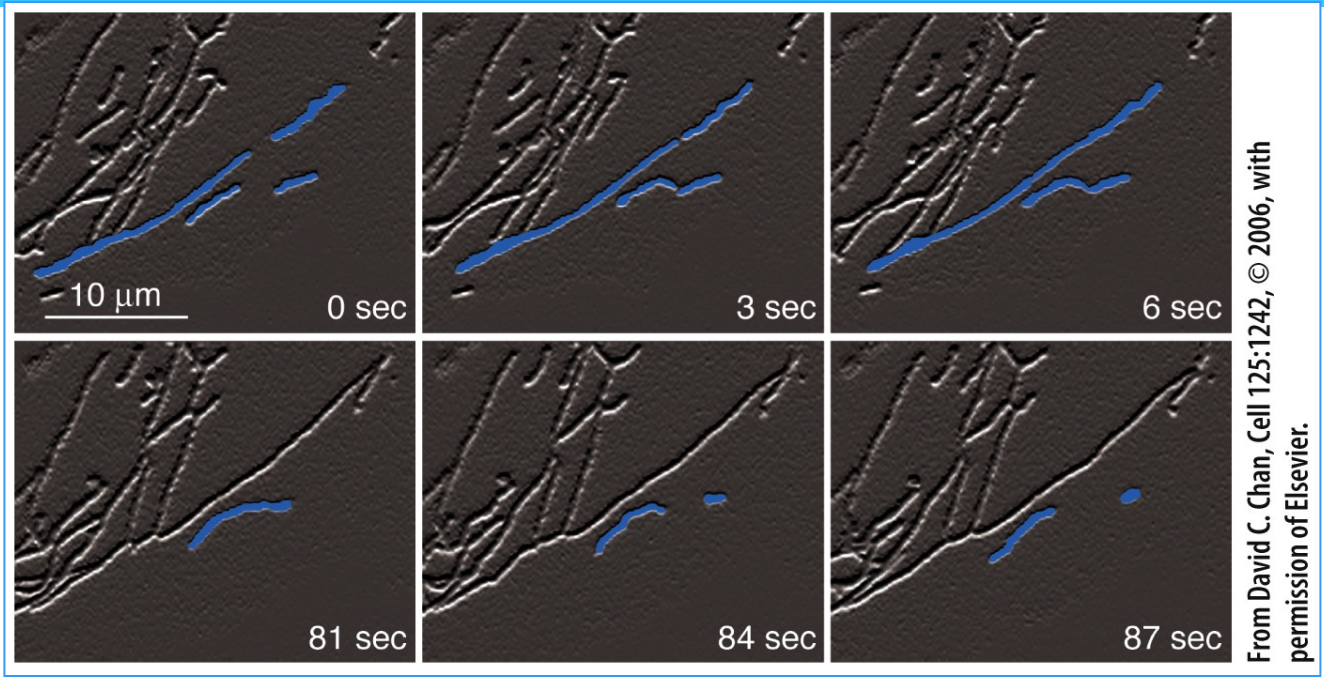
Transmission electron micrograph



Mitochondria in the sperm mid-piece

- Mitochondria: characteristic morphologies despite variable appearance.
  - Typical mitochondria are bean-shaped organelles but may be round or threadlike.
  - Size and number of mitochondria reflect the energy requirements of the cell.

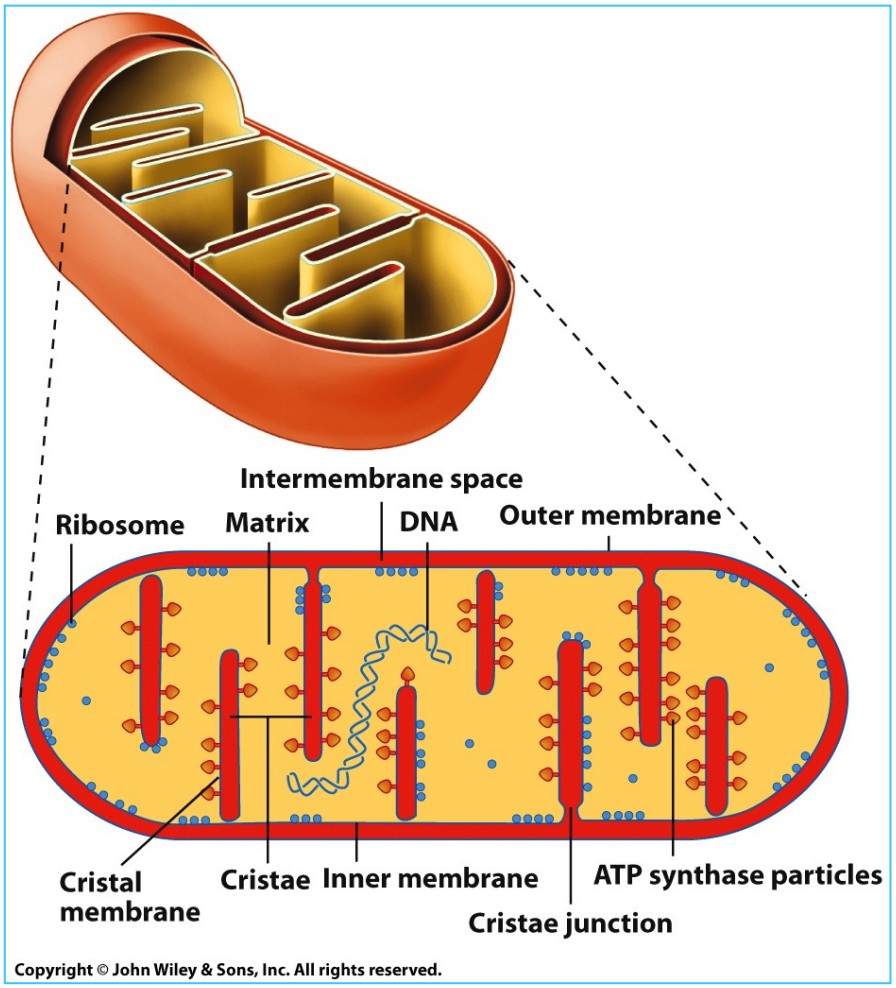
Mitochondrial Structure and Function



From David C. Chan, Cell 125:1242, © 2006, with permission of Elsevier.

- Mitochondria can fuse with one another, or split in two.
  - The balance between fusion and fission → major determinant of mitochondrial number, length and degree of interconnection.

Structure of a mitochondrion



Schematic diagrams showing the 3D internal structure and a thin section of a mitochondrion from bovine heart tissue

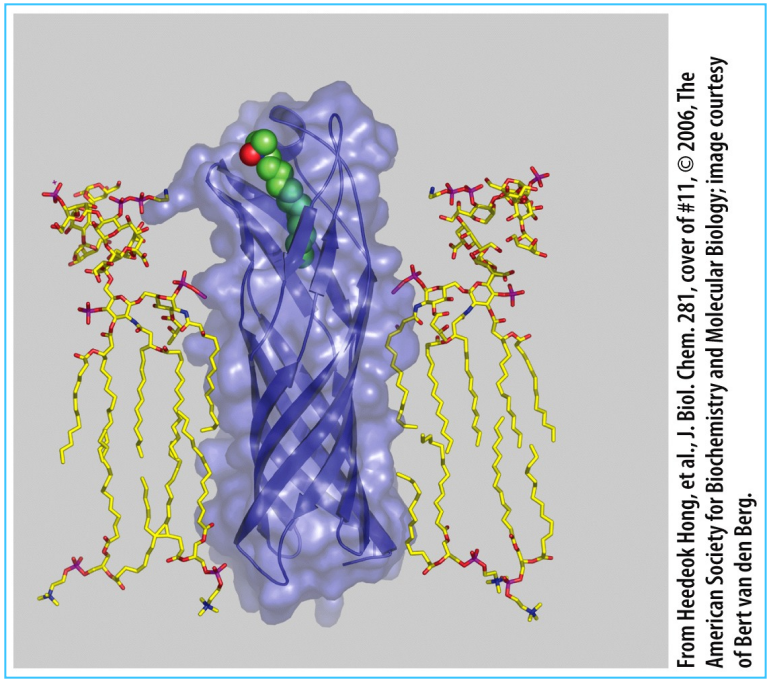
Structure of a mitochondrion

- Outer mitochondrial membrane: outer boundary.
- Inner mitochondrial membrane has two interconnected domains:
  - *Inner boundary membrane*
  - *Cristae*: where the machinery for ATP is located
- Inner and outer mitochondrial membranes enclose two spaces: the matrix and intermembrane space.
  - Mitochondrial matrix contains a circular DNA molecule, ribosomes and enzymes.

Structure of a mitochondrion

Mitochondrial Membranes

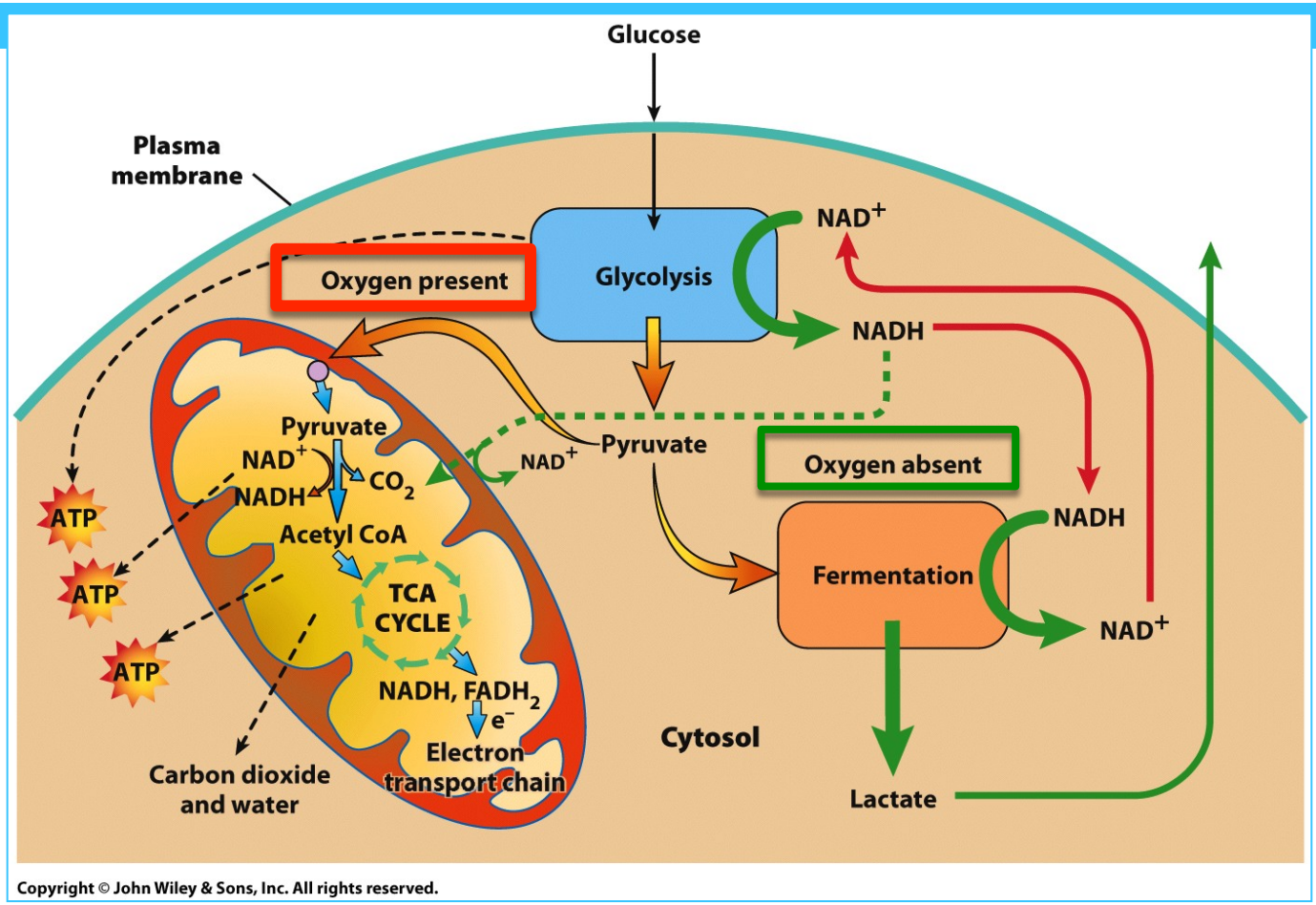
- The outer membrane is about 50% and the inner membrane is more than 75% protein
- The outer membrane contains a large pore-forming protein called *porin*.
- The outer membrane is permeable even to some proteins.
- The inner membrane is impermeable even to small molecules



From Heedeok Hong, et al., J. Biol. Chem. 281, cover of #11, © 2006, The American Society for Biochemistry and Molecular Biology; image courtesy of Bert van den Berg.

Porin motif: a β-sheet barrel that forms an opening for passage of moderate-sized molecules

Carbohydrate metabolism in eukaryotic cells

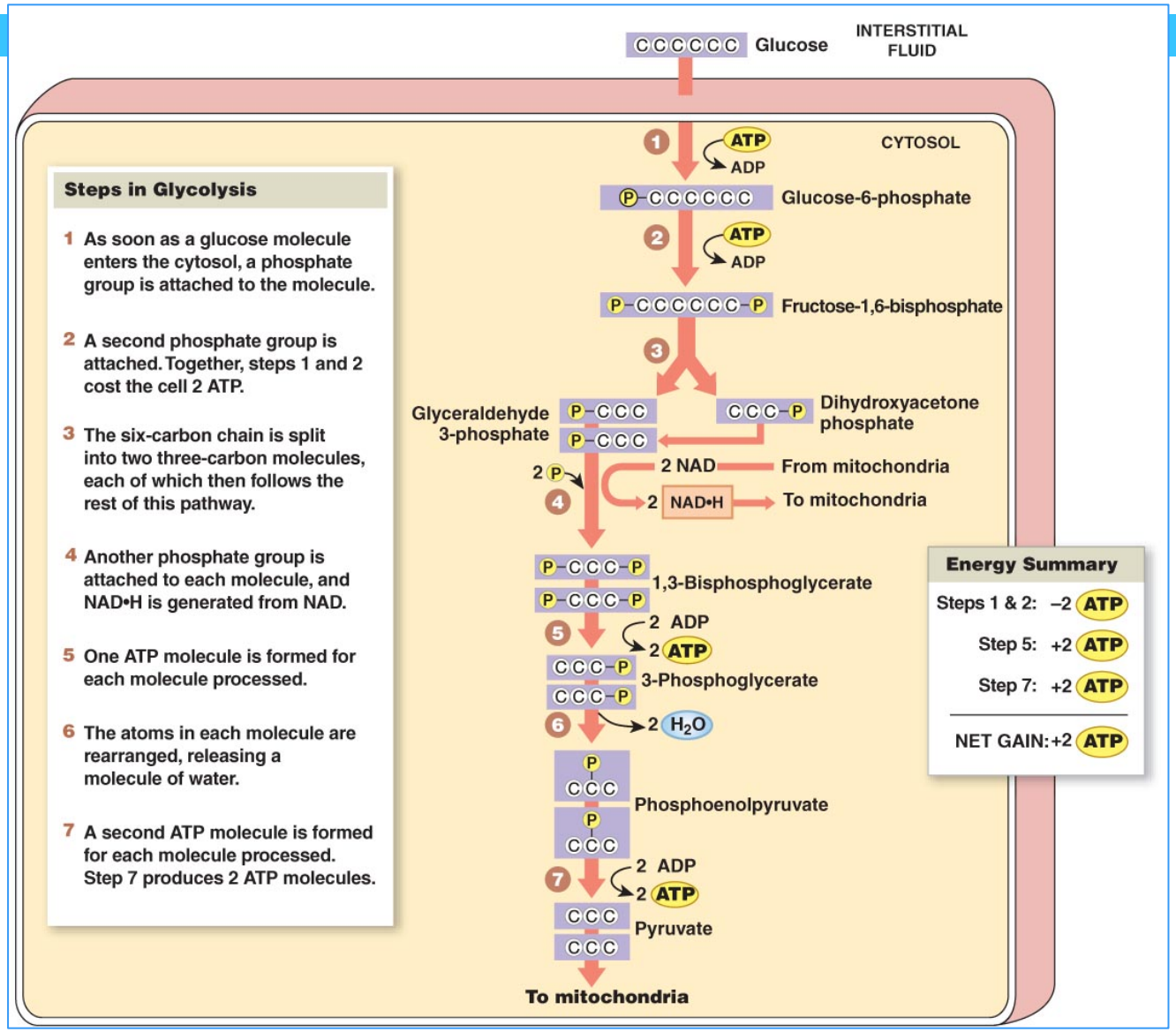


Coupling cytosolic glycolysis and pyruvate production to the mitochondrial TCA cycle and ATP formation

Oxidative Metabolism in the Mitochondrion

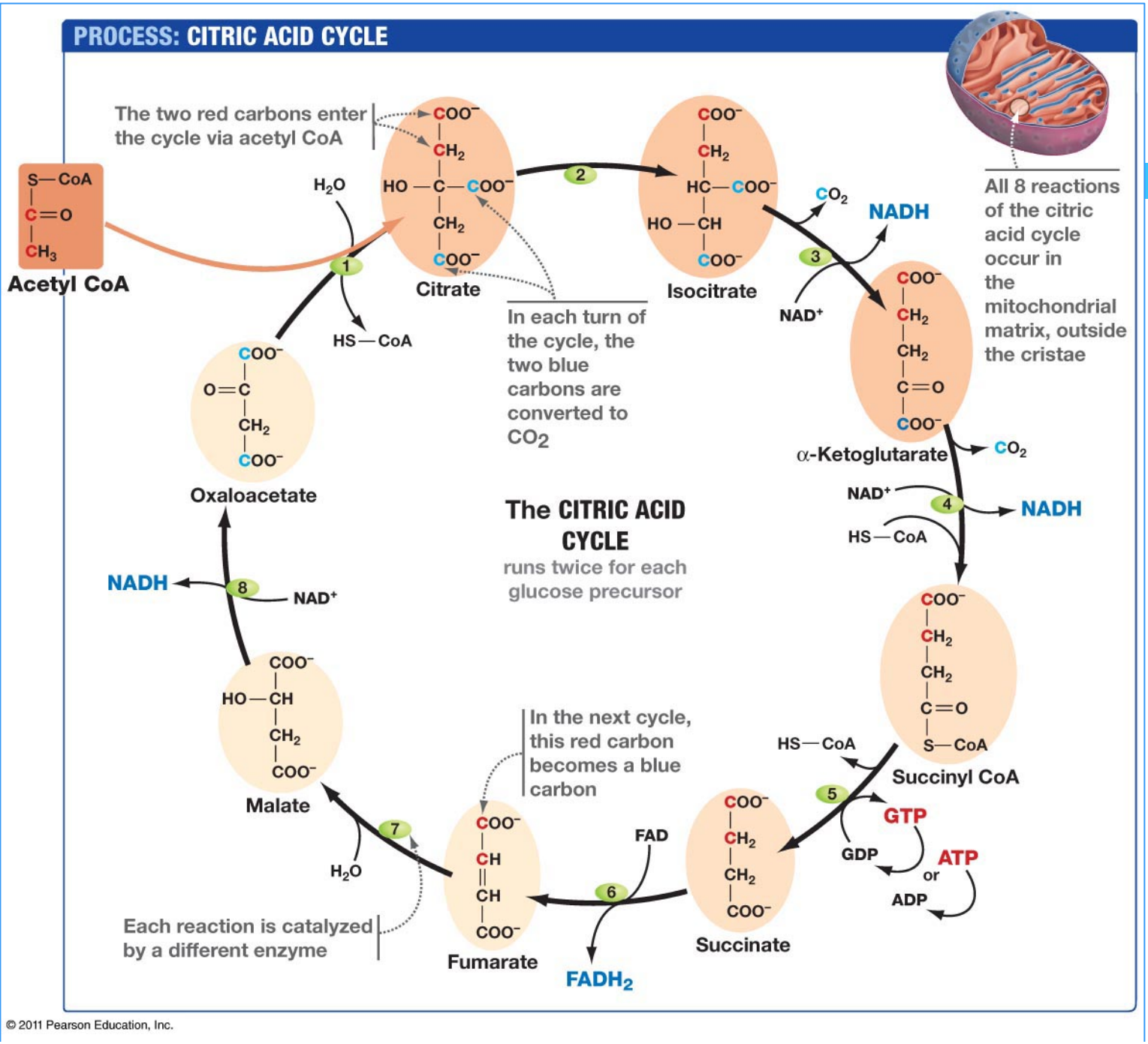
- The first steps in oxidative metabolism are carried out in **glycolysis**.
  - Glycolysis produces pyruvate, NADH, and two molecules of ATP.
  - Pyruvate is transported across the inner membrane and decarboxylated to form *acetyl CoA,* which enters the next stage.
  - Aerobic organisms use O_2 to extract more than 30 additional ATPs from pyruvate and NADH.

An overview of glycolysis



The Tri-carboxylic Acid Cycle (TCA)

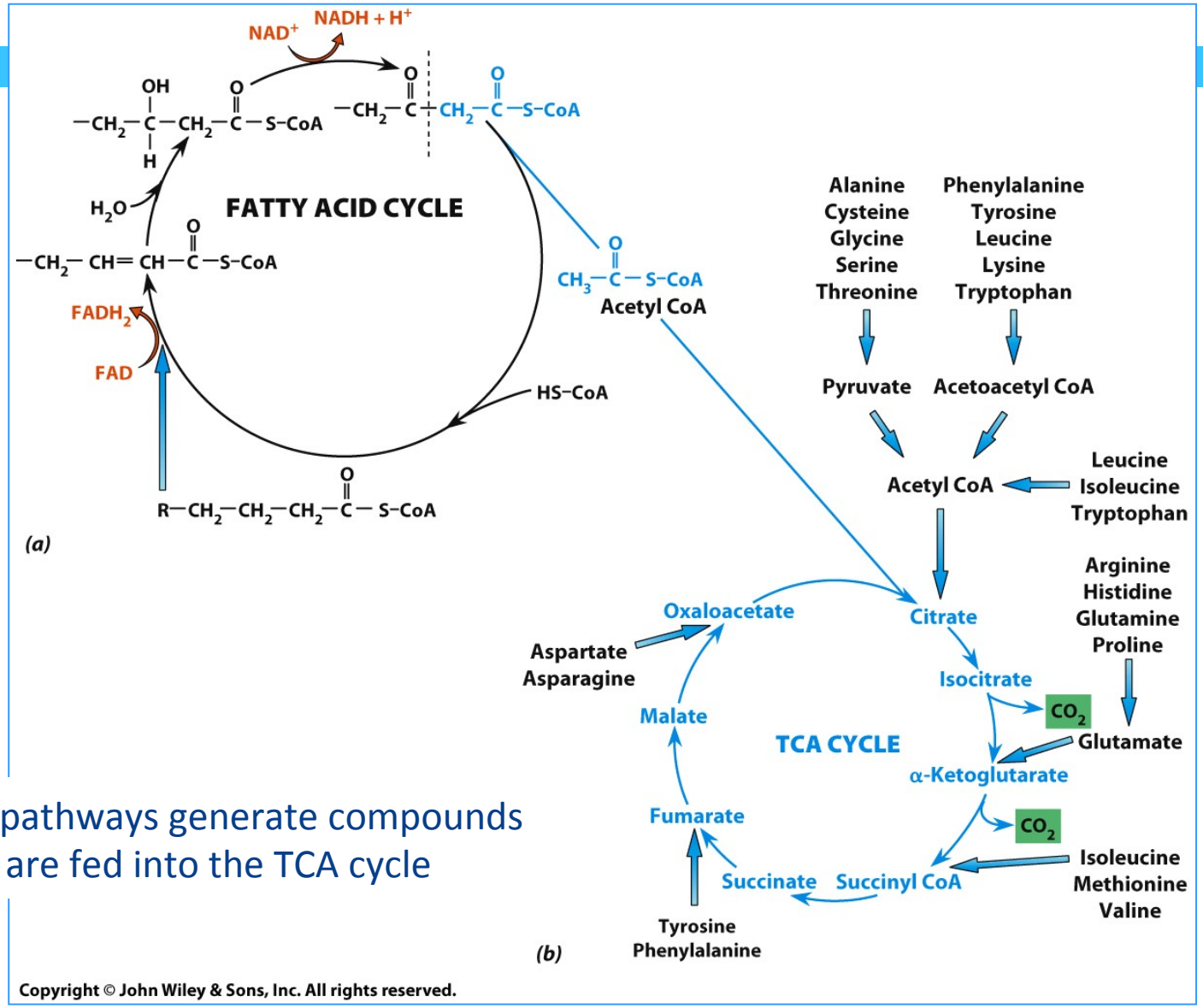
- Also known as Citric acid or Kreb's cycle
- The two-carbon acetyl group from acetyl CoA is condensed with the four-carbon oxaloacetate to form a six-carbon citrate.
- During the cycle, two carbons are oxidized to CO_2, regenerating the four-carbon oxaloacetate needed to continue the cycle.
- 1 $FADH_2$, 3 NADH and 1 GTP are produced after one round of TCA



The TCA cycle: Central Metabolic Pathway

Reaction intermediates in the TCA cycle are common compounds generated in other catabolic reactions making the TCA cycle the central metabolic pathway of the cell.

The TCA cycle: Central Metabolic Pathway



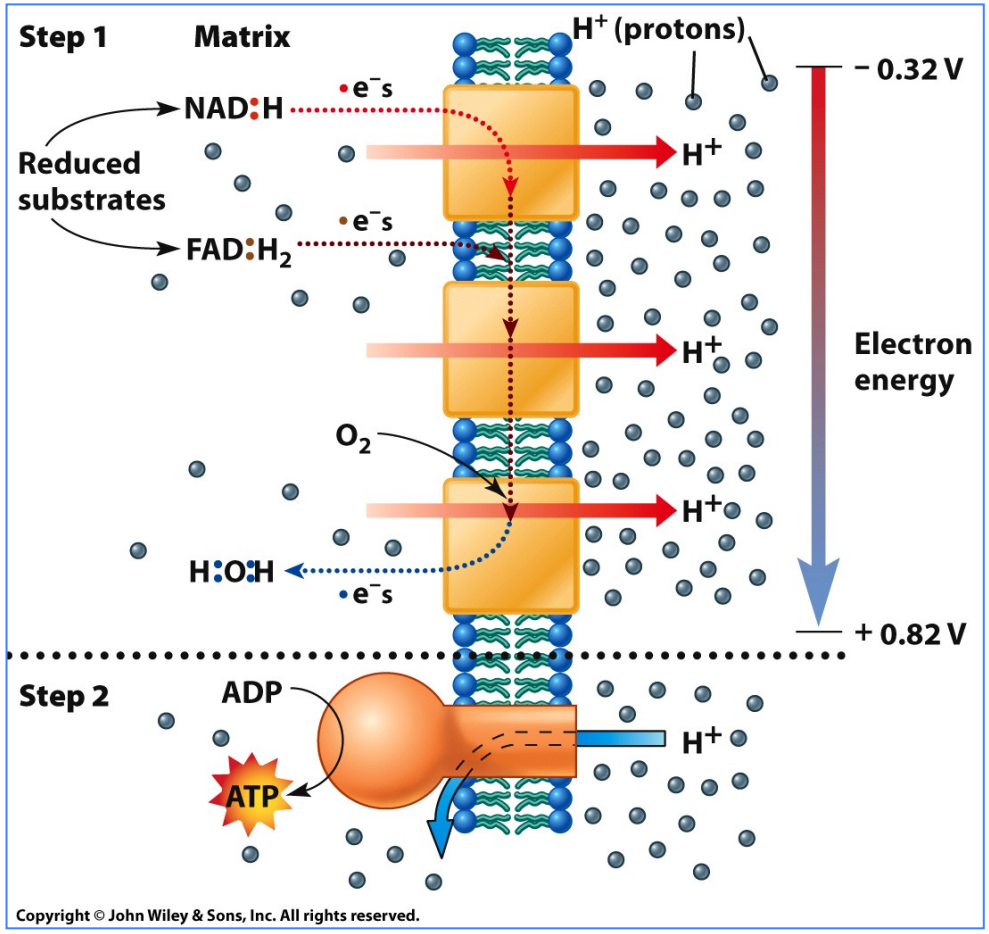
Catabolic pathways generate compounds that are fed into the TCA cycle

Summary of Oxidative Phosphorylation

Importance of Reduced Coenzymes (NADH & $FADH_2$)

- As electrons move through the electron-transport chain, H^+ are pumped out across the inner membrane.
- ATP is formed by the controlled movement of H^+ back across the membrane through the ATP synthase.
- Coupling of H^+ translocation to ATP synthesis is called **chemiosmosis**.
  - **Three molecules** of ATP are formed from each pair of electrons donated by NADH
  - **Two molecules** of ATP are formed from each pair of electrons donated by $FADH_2$.

Summary of Oxidative Phosphorylation

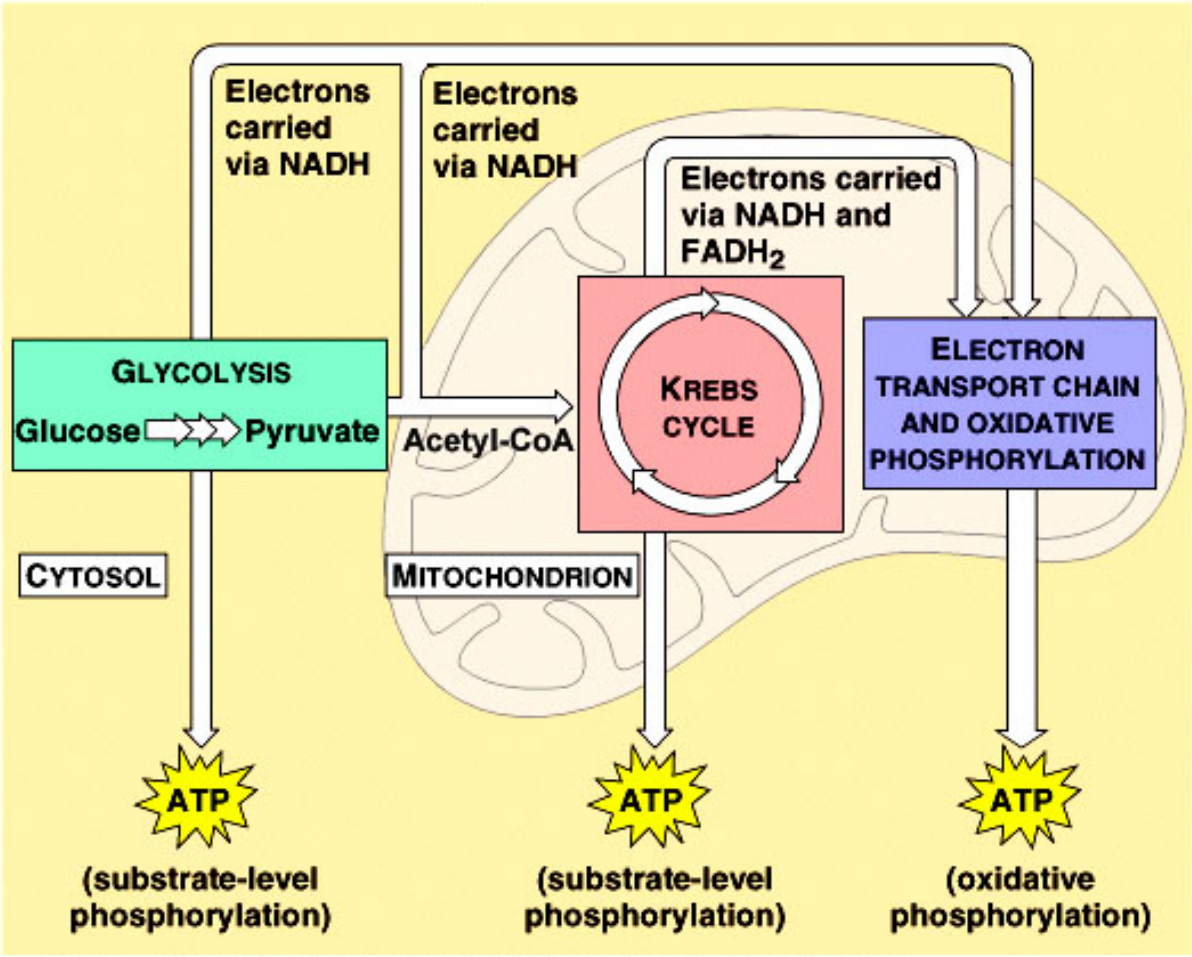


Two step process of oxidative phosphorylation:

1. Formation of proton gradient by the transfer of electrons from one protein complex to the other
2. Harnessing of proton gradient to form ATP

Overview of Cellular Respiration (Aerobic)

Figure 9.6 An overview of cellular respiration

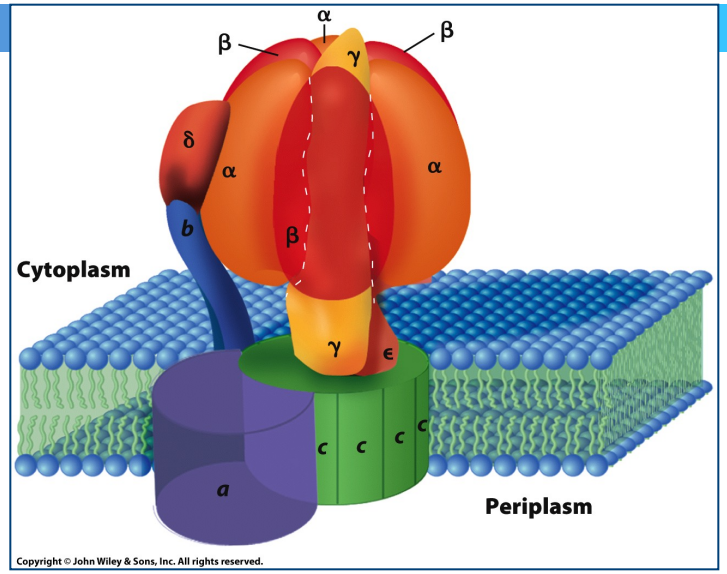


The Human Perspective:
The Role of Anaerobic and Aerobic Metabolism in Exercise

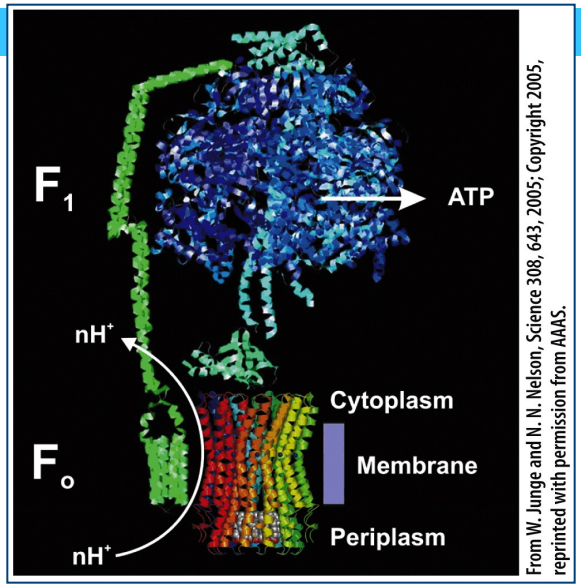
- ATP hydrolysis increases 100-fold during exercise, quickly exhausting ATP available.
- Muscles used stored ***creatine phosphate (CrP)*** to rapidly generate ATP

CrP + ADP → Cr + ATP

The Machinery for ATP Formation
The structure of the ATP synthase



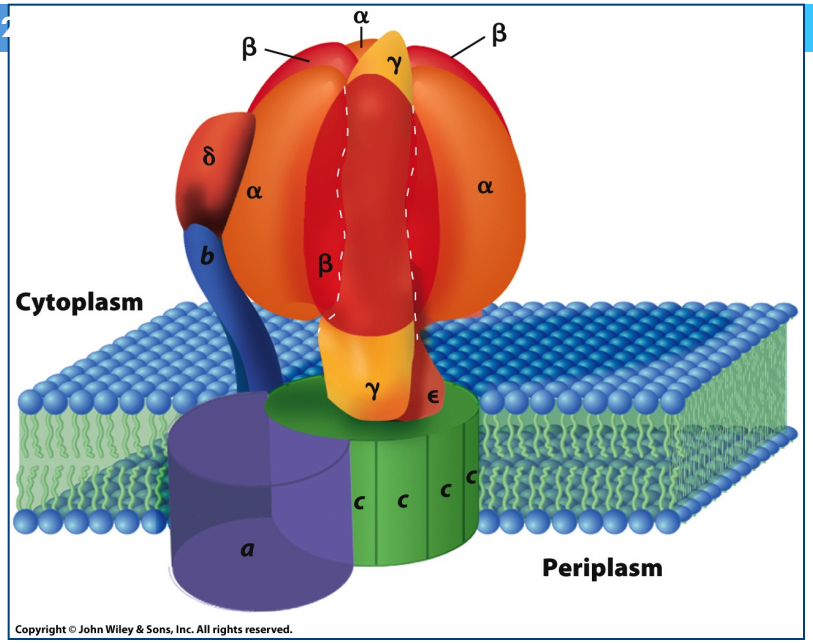
Schematic diagram and 3D structure of the bacterial ATP synthase. The enzyme consists of two major portions, called F_1 and F_0



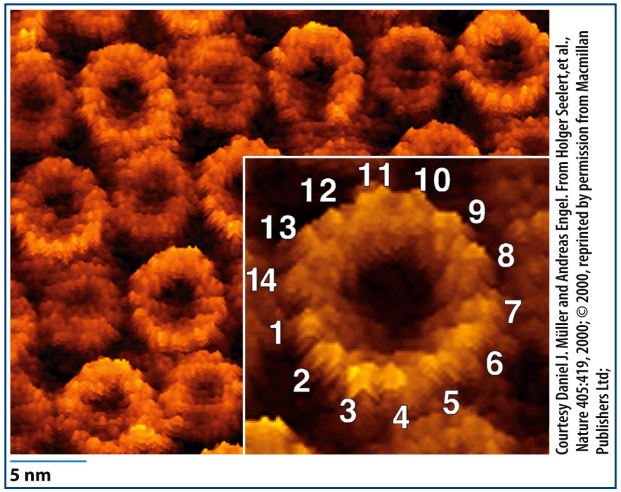
- The structure of the **ATP synthase**:
  - The F_1 particle contains catalytic sites for ATP synthesis.
  - The F_0 particle attaches to the F_1 and is embedded in the inner membrane.
  - The F_0 base contains a channel through which protons are conducted from the intermembrane space → matrix

The Machinery for ATP Formation

The structure of the ATP synthase



Atomic force microscopy of a "field" of *c* rings from chloroplast ATP synthases with 14 subunits

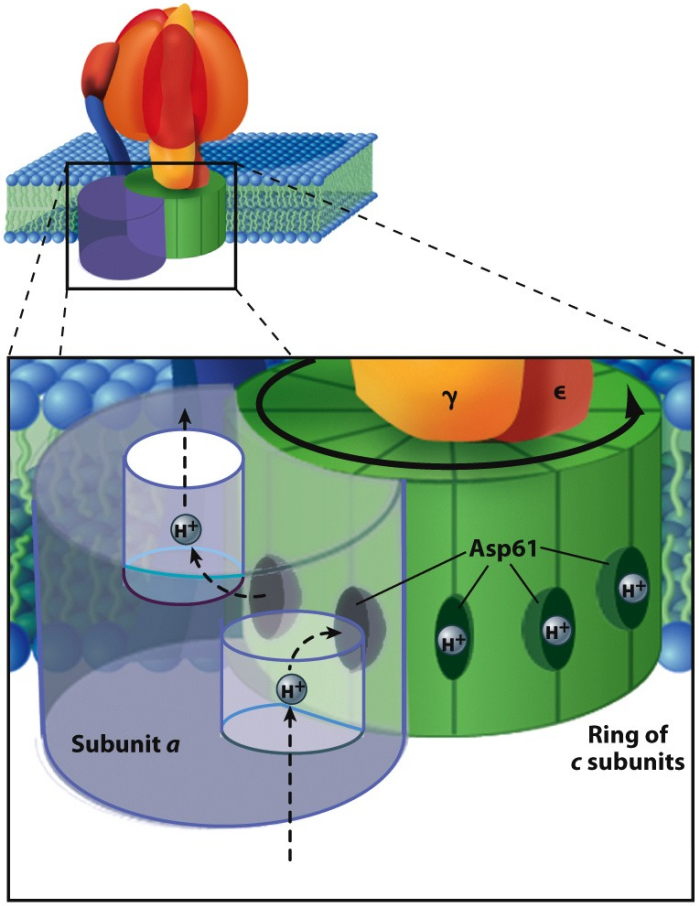


- The structure of the **ATP synthase**:
  - The number of subunits in the *c* ring is 10–14 because structural studies have revealed that this number can vary depending on the source of the enzyme.
  - Yeast mitochondrial and *E. coli* ATP synthase have 10 *c* subunits.
  - The chloroplast ATP synthase has 14 *c* subunits.

The Machinery for ATP Formation

Using the Proton Gradient to Drive the Catalytic Machinery: The Role of the F_0 Portion of ATP Synthase

- The c subunits of the F_0 base form a ring.
- The c ring is bound to γ subunit of the stalk.
- Protons moving through membrane rotate the ring.
- Rotation of the ring provides twisting force that drives ATP synthesis.

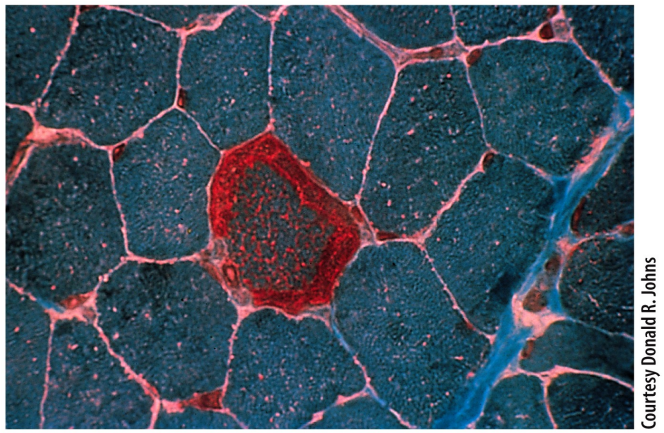


A model of the proton diffusion coupled to rotation of c ring in the F_0 complex

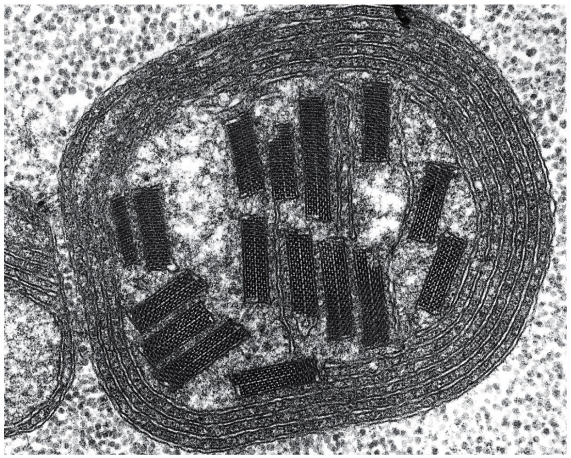
The Human Perspective:
Diseases that Result from Abnormal Mitochondrial

- A variety of disorders are known that result from abnormalities in mitochondria structure & function.
- Majority of mutations linked to mitochondrial diseases are traced to mutations in mtDNA.
- Mitochondrial disorders are inherited maternally.

Degenerating muscle shows red-staining "blotches" due to abnormal proliferation of mitochondria



Courtesy Donald R. Johns



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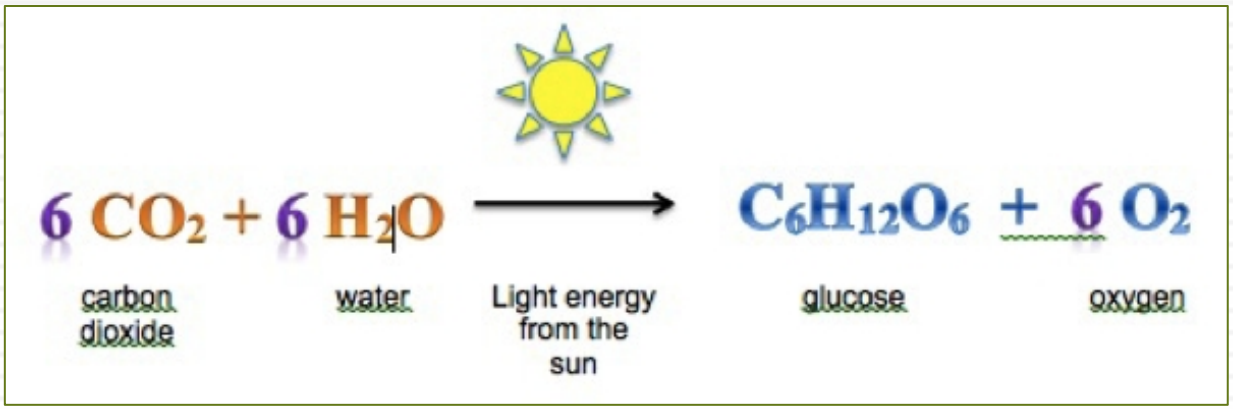
Electron micrograph showing crystalline structures within the mitochondrial matrix

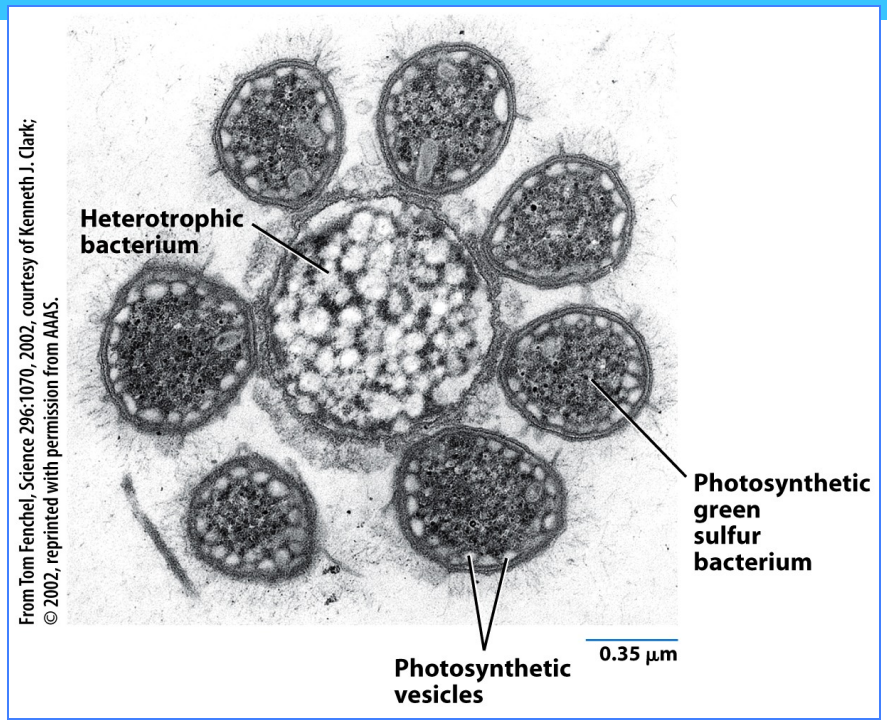
PHOTOSYNTHESIS



Introduction

Photosynthesis converts energy from sunlight into chemical energy stored in carbohydrates.

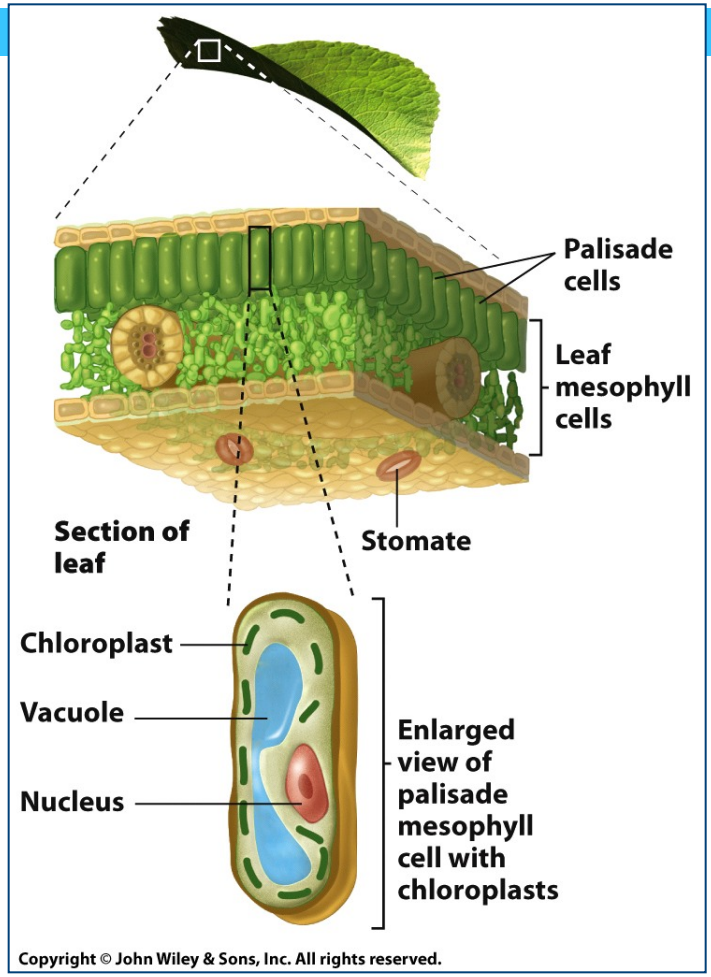
- Low energy electrons are removed from a donor molecule.
- First photoautotrophs used H_2S as electron source
- About 2.7 million years ago, cyanobacteria used electrons from water to produce oxygen as a waste product



Photosynthetic green sulfur bacteria in a symbiotic relationship with a single anaerobic, heterotrophic bacterium

Chloroplast Structure and Function
The functional organization of a leaf

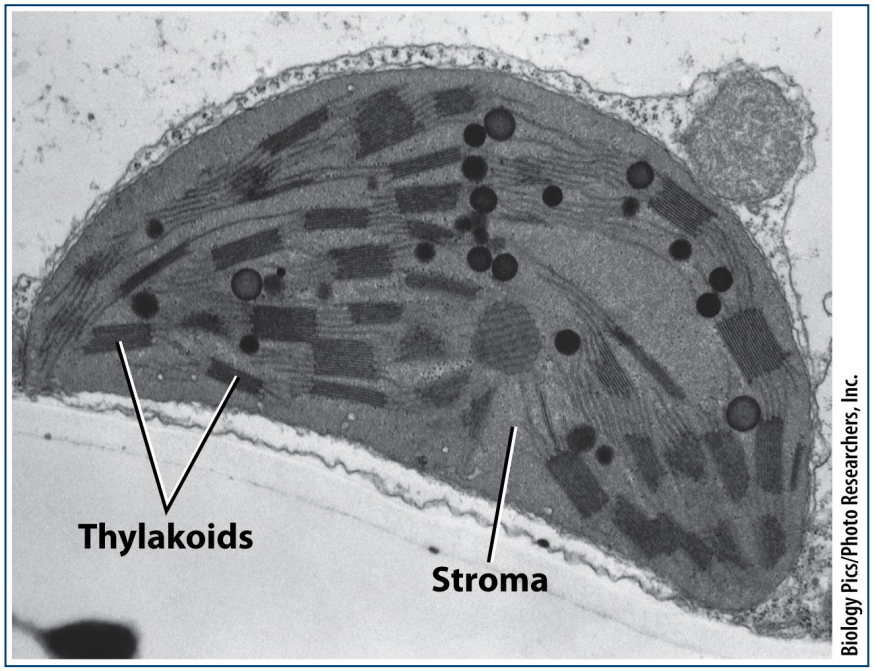
- Photosynthesis in eukaryotes takes place in the **chloroplast**, a cytoplasmic organelle.
- Chloroplasts have a double membrane.
  - The outer membrane contains porins and is permeable to large molecules.
  - The inner membrane contains light-absorbing pigment, electron carriers and ATP-synthesizing enzymes.

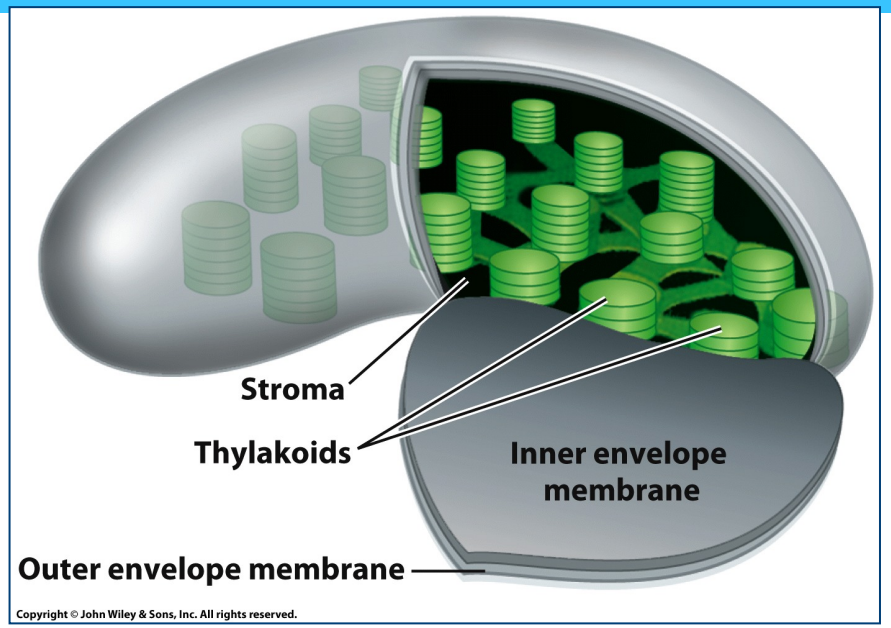


The functional organization of a leaf

Chloroplast Structure and Function

The internal structure of a leaf

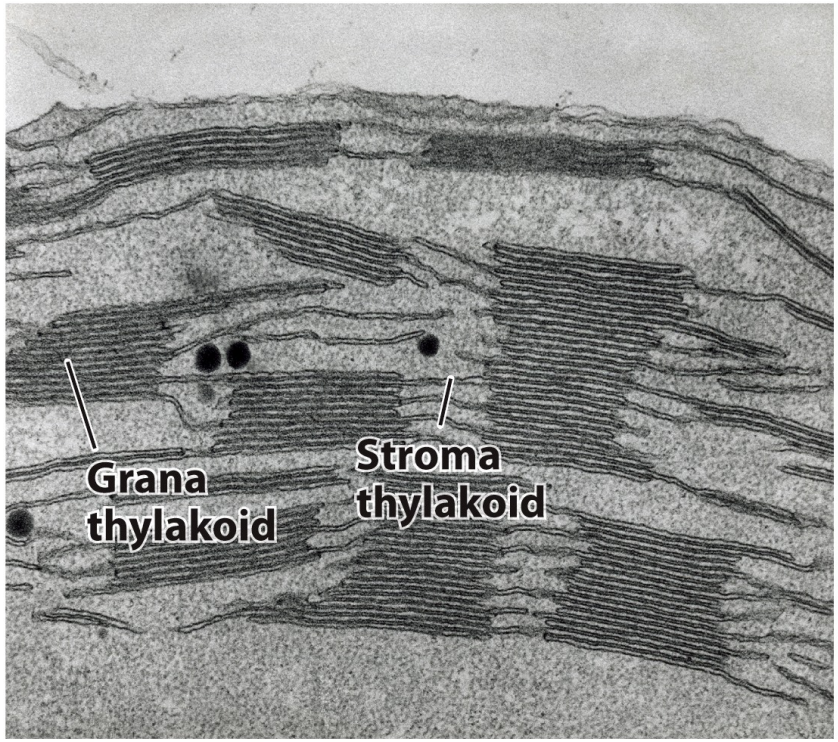




Internal structure of a chloroplast: Transmission electron micrograph and schematic diagram

Chloroplast Structure and Function
Thylakoid membranes

- The inner membrane of a chloroplast is folded into flattened sacs (**thylakoids**), arranged in stacks called **grana**.
- Chloroplasts are self-replicating organelles that contain their own DNA.



Dr. Kenneth R. Miller/Photo Researchers, Inc.

Electron micrograph of a spinach chloroplast showing stacked grana thylakoids

Overview of Photosynthetic Metabolism

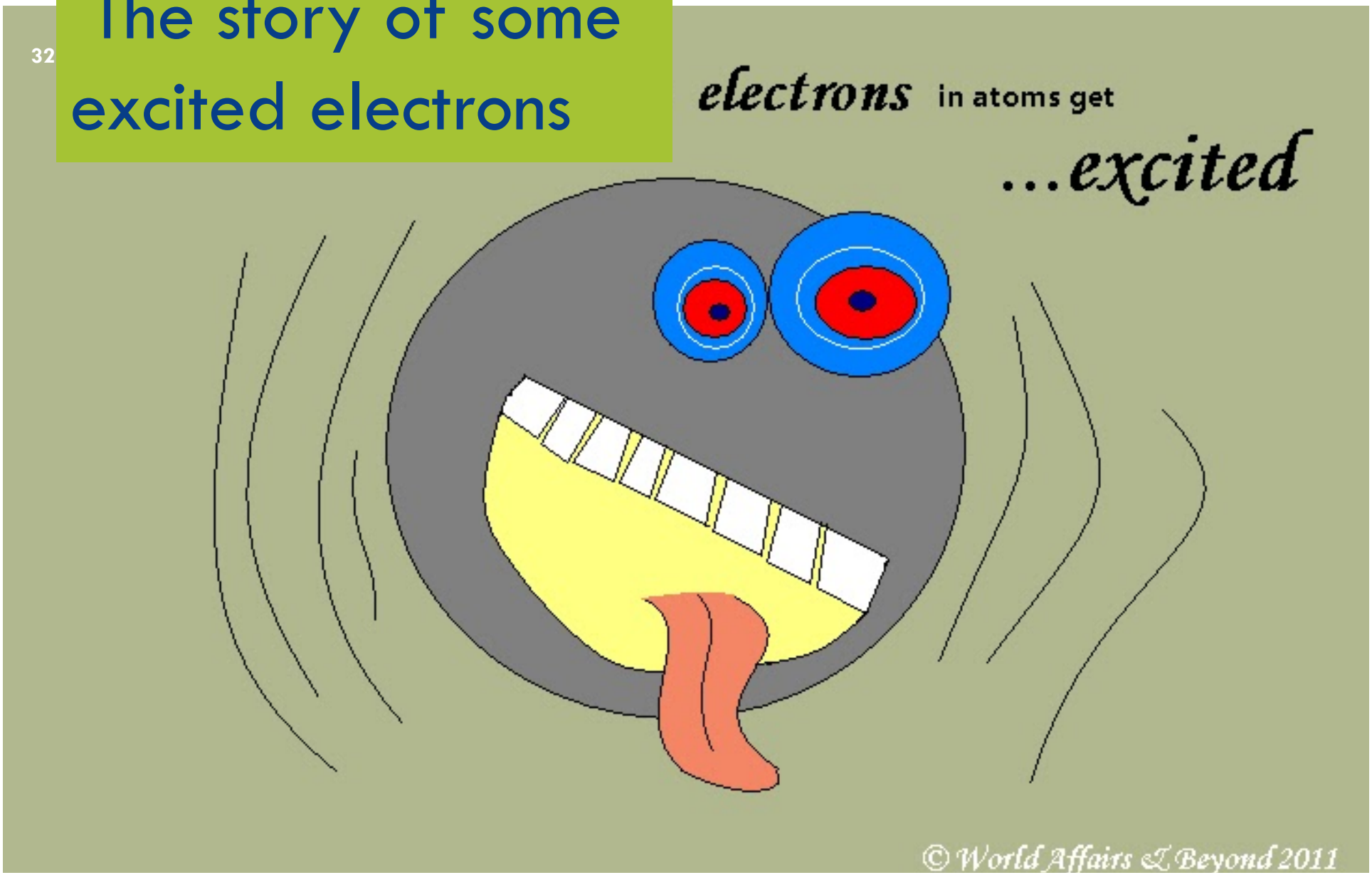
- Respiration removes high energy electrons from reduced organic substrates (sugar) to form ATP
- Photosynthesis uses low energy electrons to form ATP and NADPH, which are then used to reduce CO_2 to carbohydrate.

Photosynthesis: Light and Dark Reactions

Photosynthesis occurs in two stages:

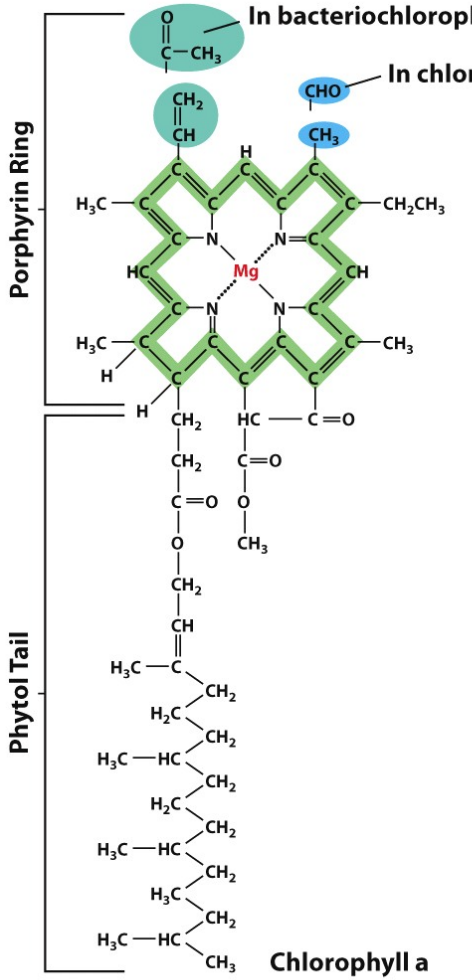
- **Light-dependent reactions** (light reactions) in which sunlight is absorbed, converting it into ATP and NADPH.
- **Light-independent reactions** (dark reactions) use the energy stored in ATP and NADPH to produce carbohydrate.

The story of some excited electrons



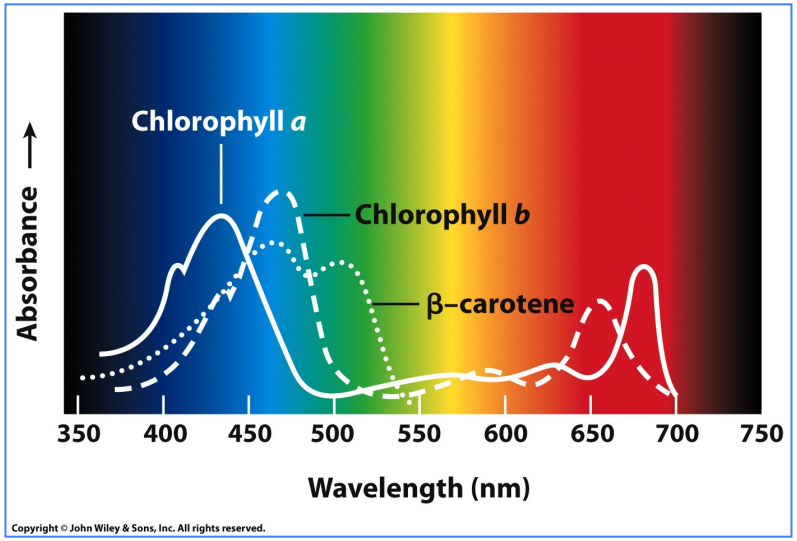
The Absorption of Light

- Absorption of **photons** (light "particles") by a molecule makes them go from **ground state** to **excited state**.
  - Energy in the photon depends on the wavelength of light.
- Photosynthetic **Pigments (e.g., chlorophyll)** – molecules that absorb light of particular wavelengths.
  - Chlorophyll contains a **porphyrin ring** that absorbs light and a hydrophobic tail embedding it to the photosynthetic membrane.

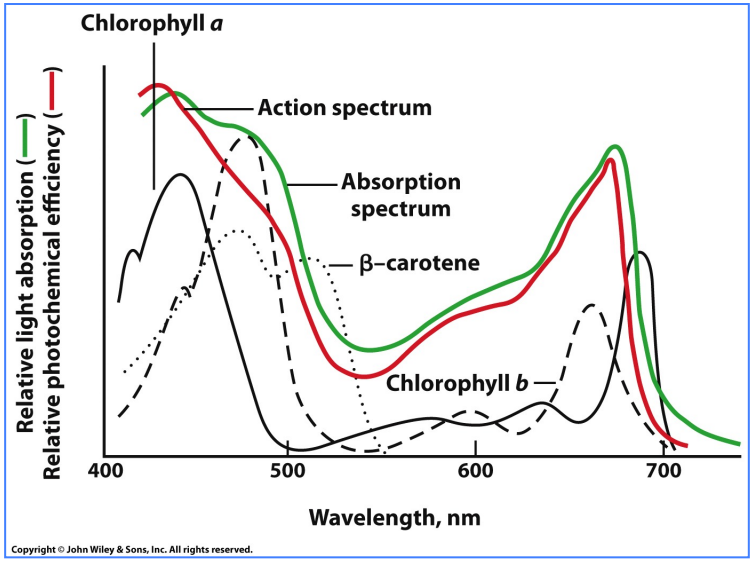


The structure of chlorophyll *a*

The Absorption of Light



Absorption spectrum: three photosynthetic pigments of higher plants

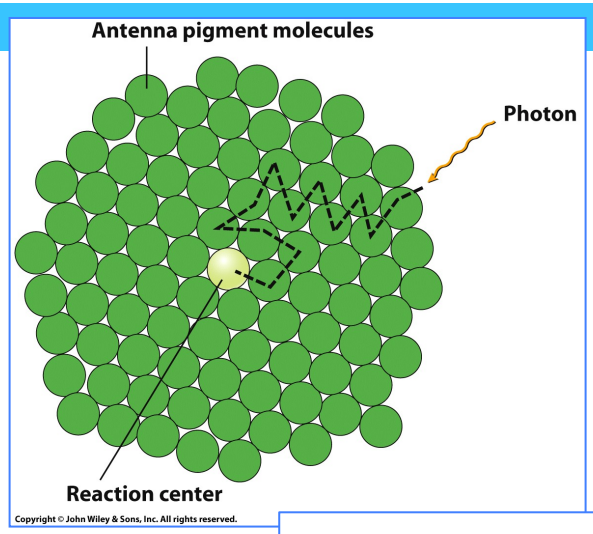


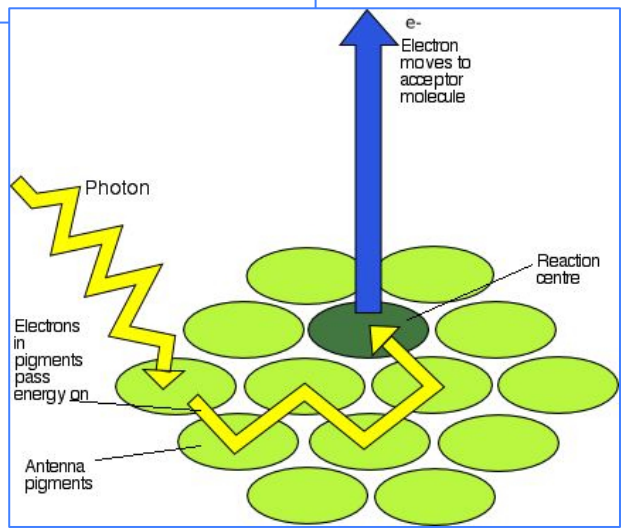
Action spectrum: efficiency of light wavelengths to promote photosynthesis

Photosynthetic Units & Reaction Centers

Each **photosynthetic unit** contains several hundred chlorophyll molecules.

1. **Antenna pigments:** Pigments responsible for light absorption and transfer of the energy to the reaction center
2. **Reaction-center chlorophyll**: electron absorbs energy, gets excited, leaves its orbit and is transferred to an electron acceptor.

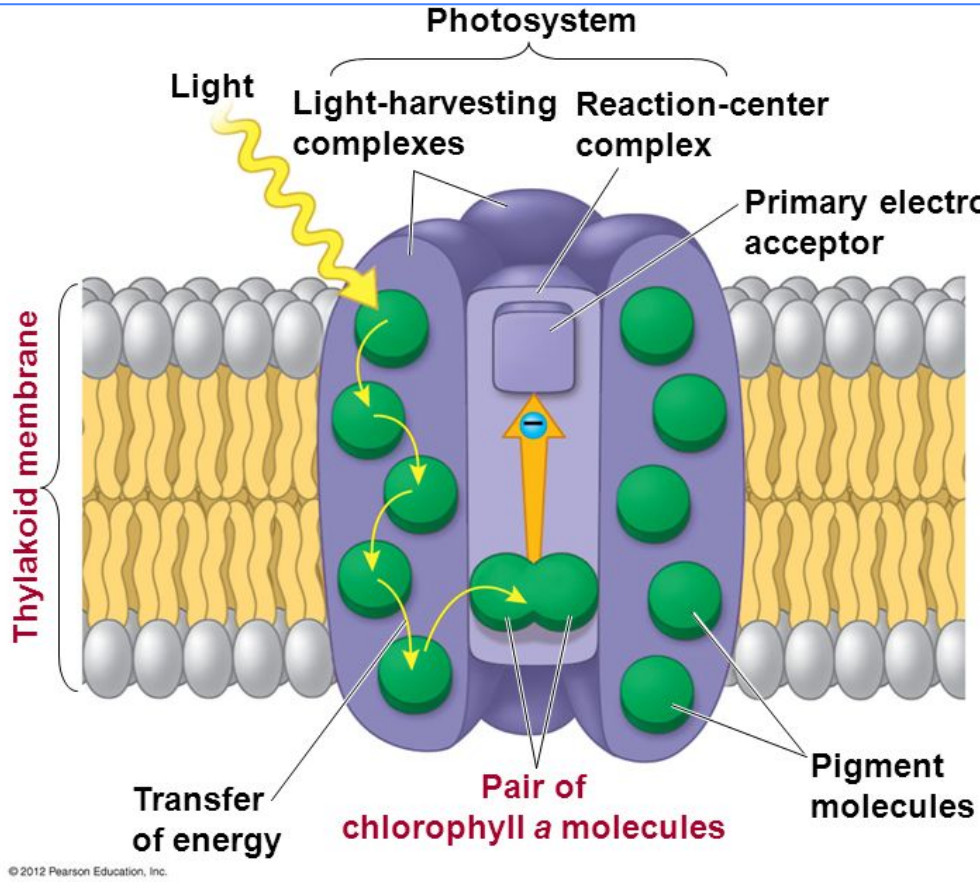




Photosynthetic Units & Reaction Centers

Photosystem = Pair of ***chlorophyll a*** molecules surrounded by pigments and various enzyme

Capture solar energy to excite electrons in chlorophyll a

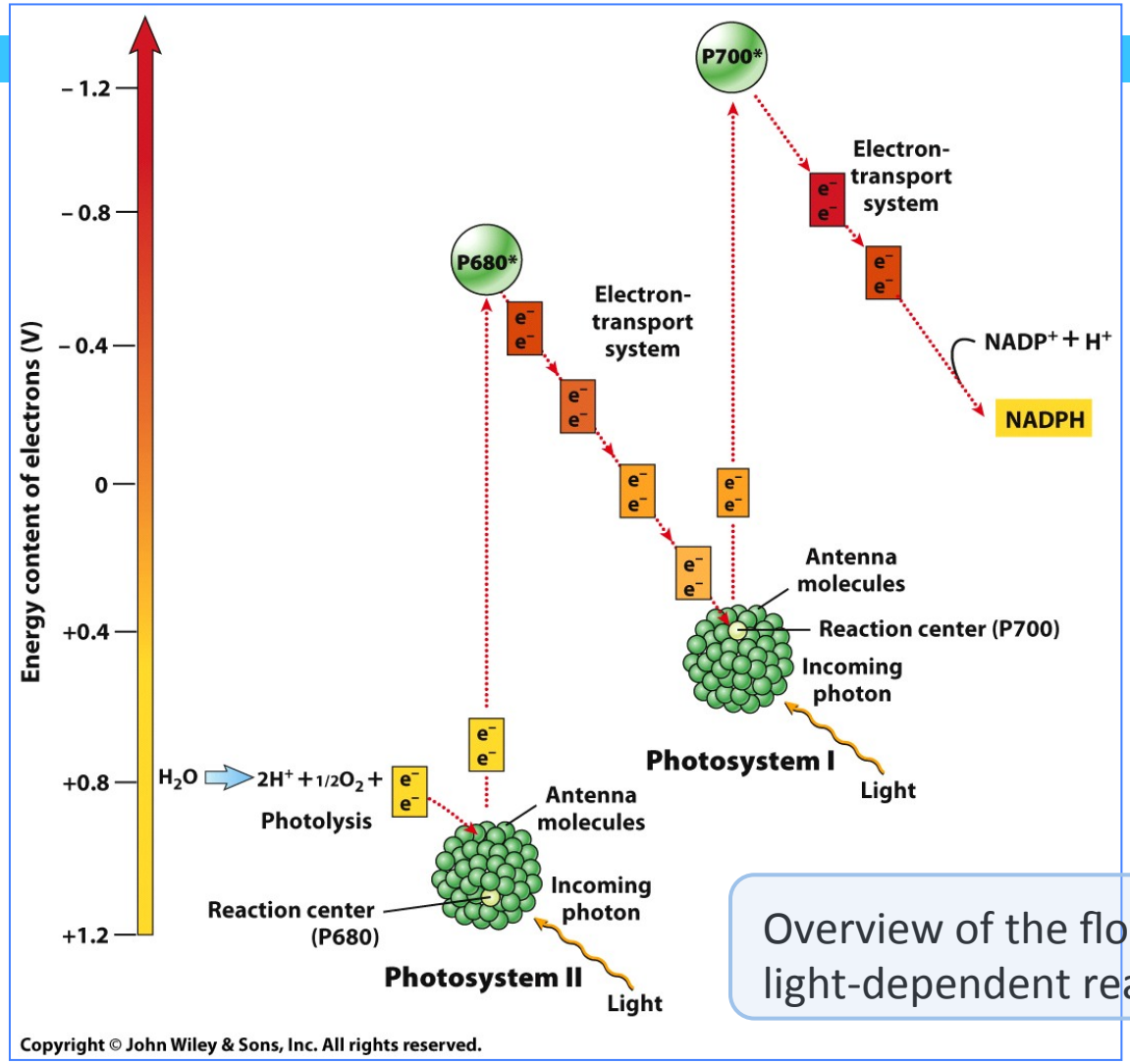


Photosynthetic Units & Reaction Centers

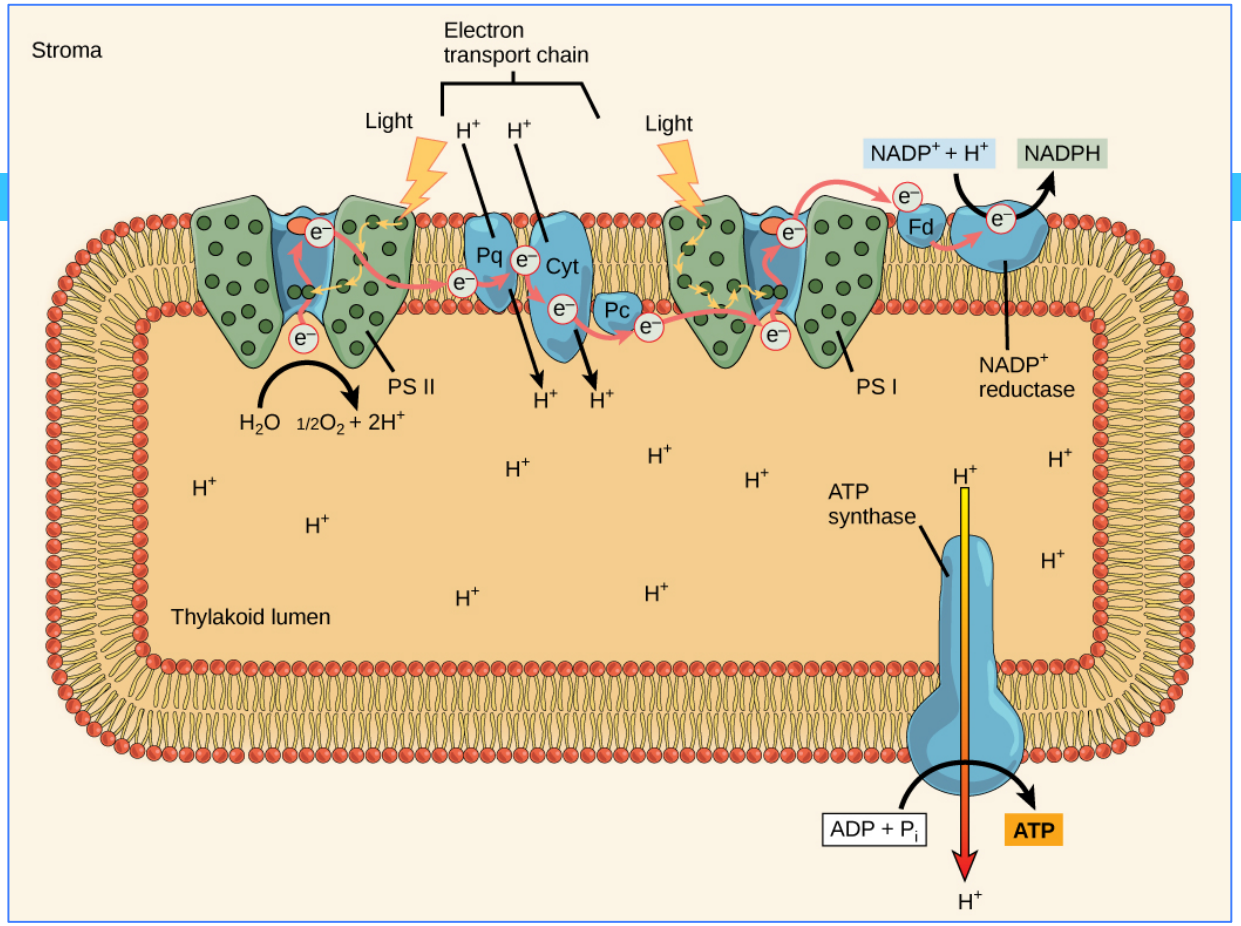
Coordination of the Action of Two Different Photosynthetic Systems

- Two large pigment-protein complexes called **photosystems** act in series to raise electrons from H_2O to $NADP^+$.
  - **Photosystem II** (PSII or **P680**)
    - Absorbs at the wavelength of 680 nm
    - Accepts electrons from water
  - **Photosystem I** (PSI or **P700**)
    - Absorbs at the wavelength of 700 nm
    - Accepts electrons given off from PSII

Photosynthetic Units & Reaction Centers



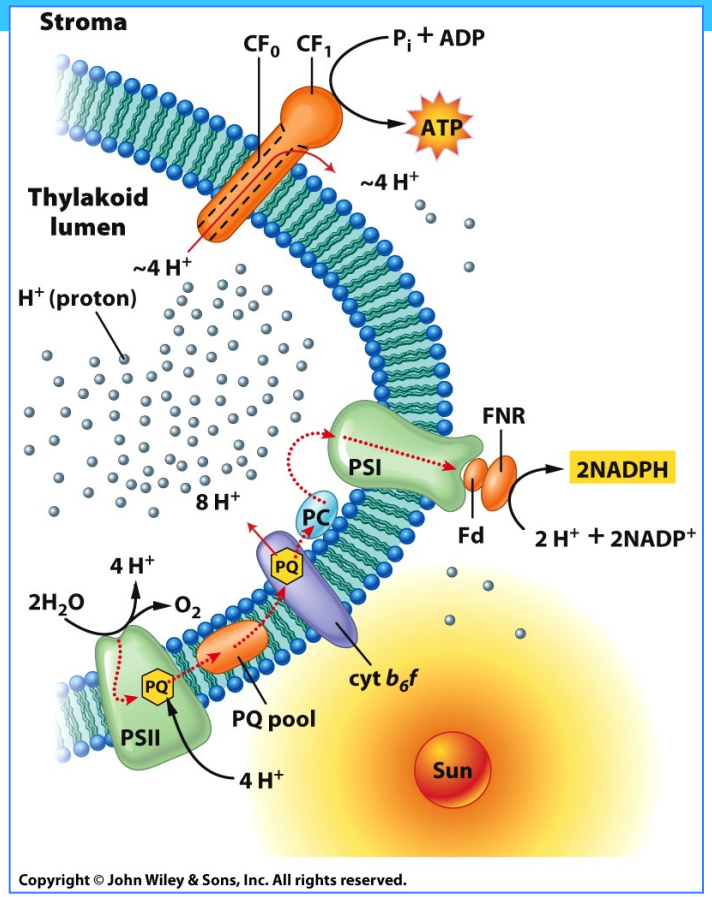
Overview of the flow of electrons during the light-dependent reactions of photosynthesis



- Protons are transferred from the stroma → thylakoid lumen as the electrons move from H_2O → PSII→ PSI → $NADP^+$
- Protons move back into the stroma through ATP synthase which turns the enzyme to synthesize ATP

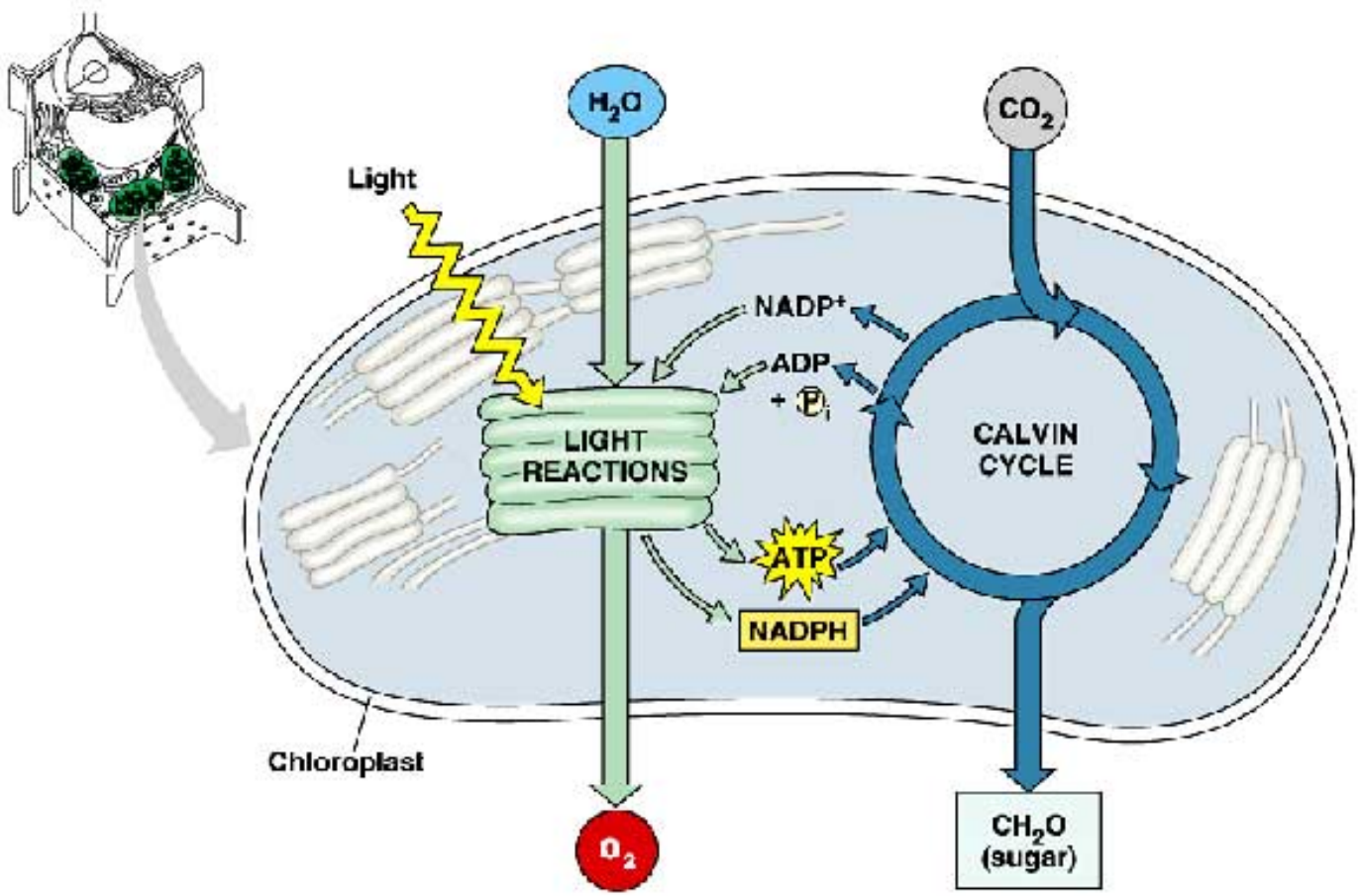
Photophosphorylation

- The machinery for ATP synthesis in a chloroplast is similar to that of mitochondrial enzymes.
- The ATP synthase consists of a head (CF_1), and a base (CF_0).
- The CF_1 heads project outward into the stroma, keeping with the orientation of the proton gradient.



Flow of electrons from H_2O to NADPH through the three transmembrane complexes

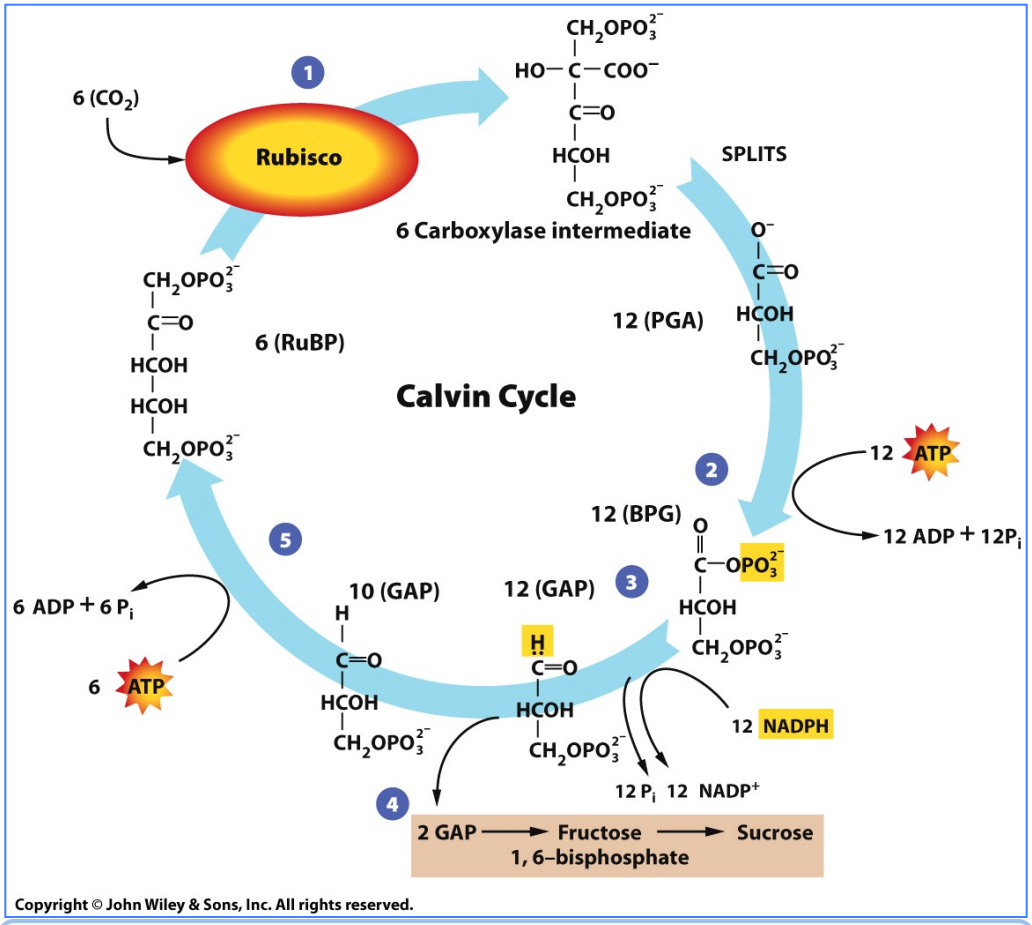
ATP and NADPH are used to make Sugar



Carbon Dioxide Fixation and the Synthesis of Carbohydrate (Dark Reactions)

Calvin cycle operates in the C_3 plants to fix carbohydrate:

- Carboxylation of ribulose bisphosphate (RuBP) to form 3-phosphoglycerate (PGA)
- Reduction of PGA to glyceraldehyde 3-phosphate (GAP) using NADPH and ATP from light reactions.
- Regeneration of RuBP

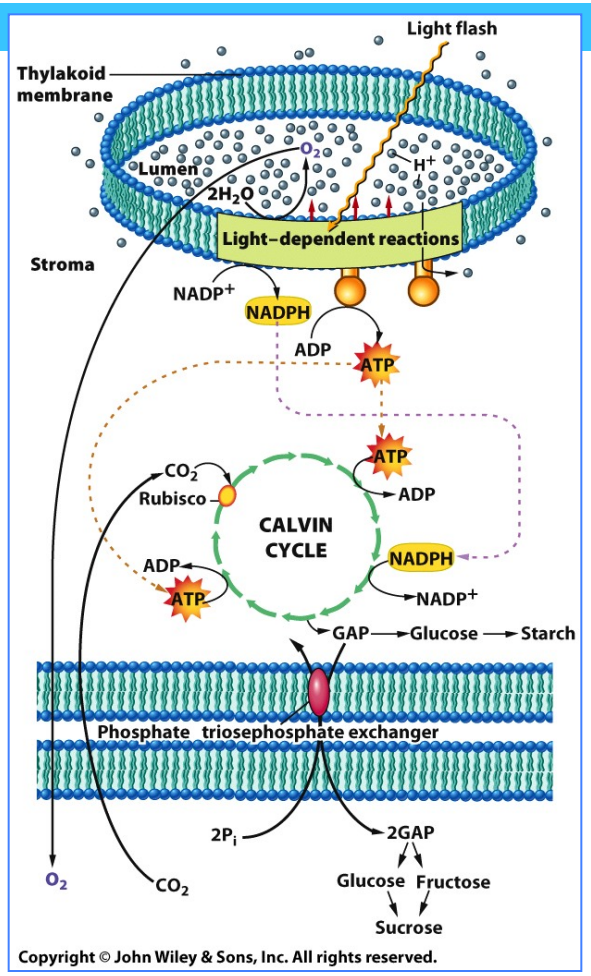


The Calvin cycle: Converting CO_2 into carbohydrate

Carbon Dioxide Fixation and the Synthesis of Carbohydrate

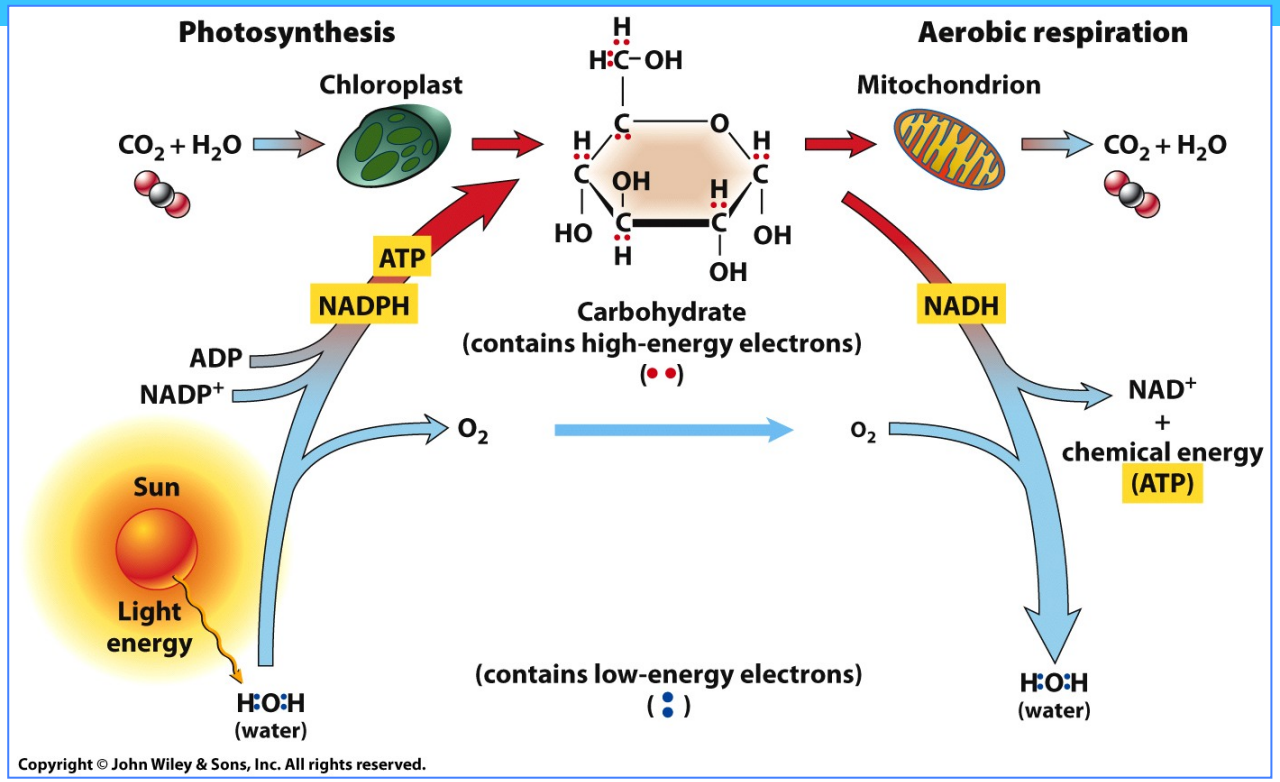
Carbohydrate Synthesis in C_3 Plants

- The GAP molecules can be exported into the cytosol in exchange for phosphate ions and used to synthesize sucrose.
- GAP can also remain in the chloroplast where it is converted to starch.
- It is an expensive process.
- Conversion of 6 molecules of CO_2 to 1 six-carbon sugar molecules requires 12 molecules of NADPH and 18 molecules of ATP.



Overview of various stages of photosynthesis

Photosynthesis & Aerobic Respiration



An overview of the energetics of photosynthesis and aerobic respiration

Some interesting links

- https://www.youtube.com/watch?v=5sGqbnQoyrI

Put your thinking cap on….

1. What is the direct effect on the pH of the inter-membrane space (mitochondrion) and stroma (chloroplast) if ATP synthase is inhibited?