Lecture Series 12

Photosynthesis: Energy from the Sun

Photosynthesis: Energy from the Sun

A. Identifying Photosynthetic Reactants and Products

B. The Two Pathways of Photosynthesis: An Overview

C. Properties of Light and Pigments

Photosynthesis: Energy from the Sun

D. Electron Flow, Photophosphorylations, and Reductions

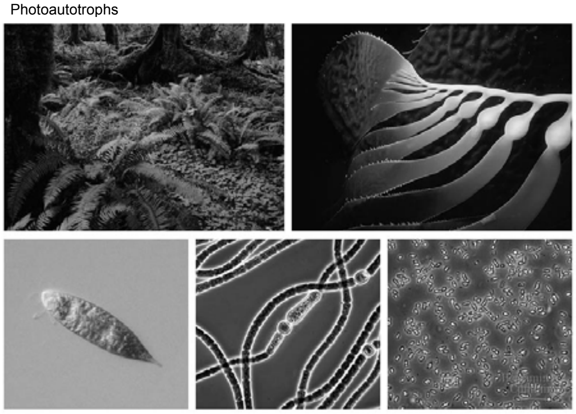
E. Making Sugar from CO_2: The Calvin–Benson Cycle

F. Photorespiration and Its Evolutionary Consequences

Photosynthesis In General

- Life on Earth depends on the absorption of light energy from the sun.
- In plants, photosynthesis takes place in chloroplasts.

Photoautotrophs



A. Identifying Photosynthetic Reactants and Products

- Photosynthesizing plants take in CO_2, water, and light energy, producing O_2 and carbohydrate. The overall reaction is

$$6\ CO_2 + 12\ H_2O + \text{light} \rightarrow C_6H_{12}O_6 + 6\ O_2 + 6\ H_2O$$

- The oxygen atoms in O_2 come from water, not from CO_2.

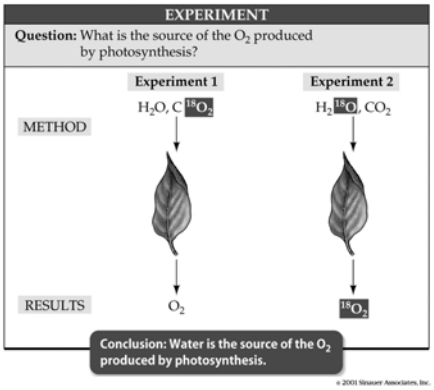
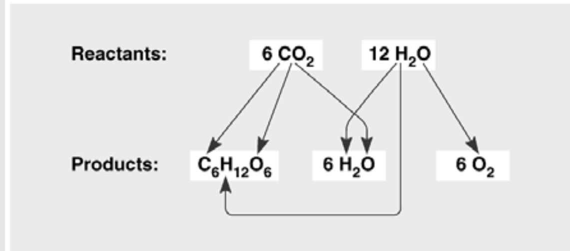


Figure 8.2

Tracking atoms through photosynthesis



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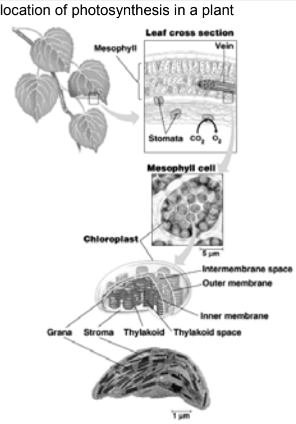
Focusing in on the location of photosynthesis in a plant



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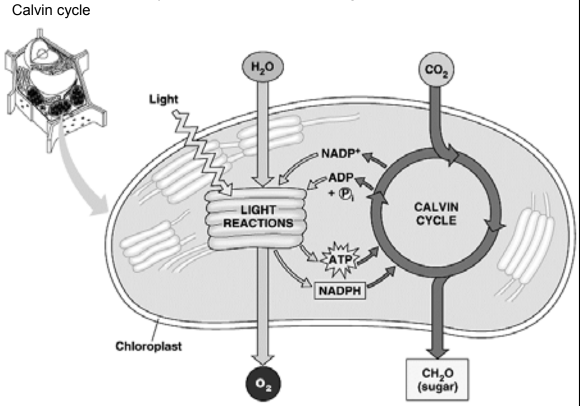
B. The Two Pathways of Photosynthesis: An Overview

- In the light reactions of photosynthesis, electron flow and photophosphorylation produce ATP and reduce $NADP^+$ to NADPH + H^+.
- ATP and NADPH + H^+ are needed for the reactions that fix and reduce CO_2 in the Calvin–Benson cycle, forming sugars. These are sometimes erroneously referred to as the dark reactions.

An overview of photosynthesis: cooperation of the light reactions and the Calvin cycle



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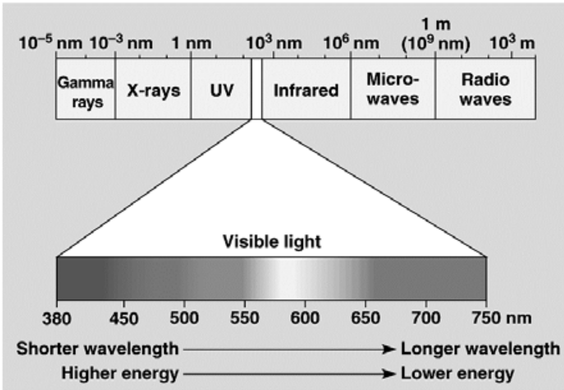
C. Properties of Light and Pigments

- Light energy comes in packets called photons, but it also has wavelike properties.
- Pigments absorb light in the visible spectrum.
- Absorption of a photon puts a pigment molecule in an excited state with more energy than its ground state.

The electromagnetic spectrum



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Exciting a Molecule

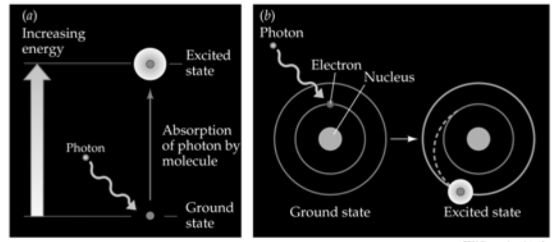

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Figure 8.6

C. Properties of Light and Pigments

- Each compound has a characteristic absorption spectrum which reveals the biological effectiveness of different wavelengths of light.
- An action spectrum plots the overall biological effectiveness of different wavelengths for an organism.

Absorption Spectra

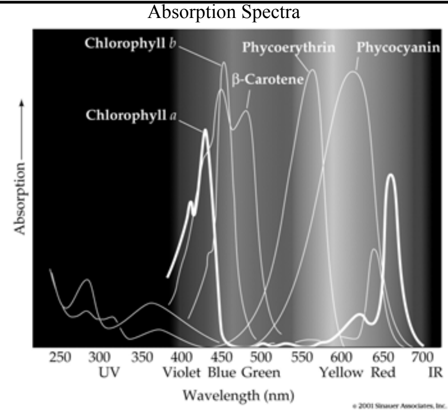

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Figure 8.7

Absorption Spectra

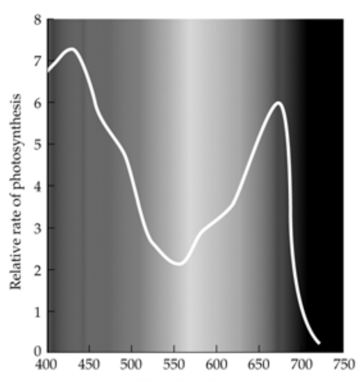

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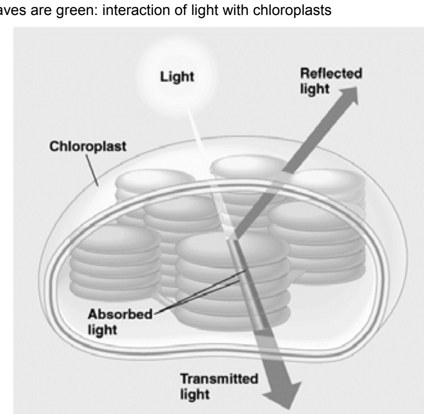
Figure 8.8

Why leaves are green: interaction of light with chloroplasts



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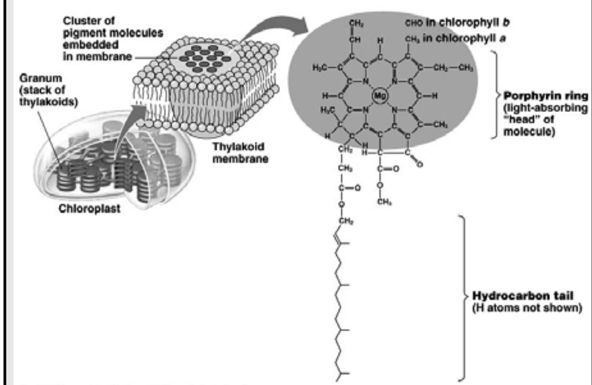
C. Properties of Light and Pigments

- Chlorophylls and accessory pigments form antenna systems for absorption of light energy.
- An excited pigment molecule may lose its energy by fluorescence, or by transferring it to another pigment molecule.

Location and structure of chlorophyll molecules in plants



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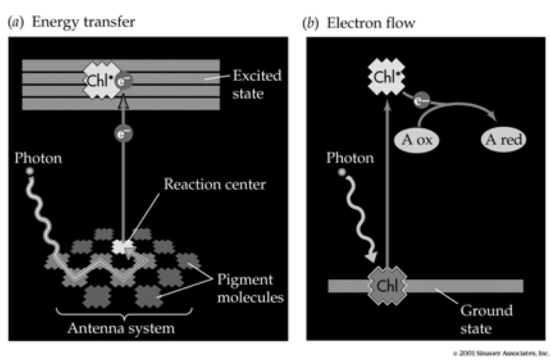
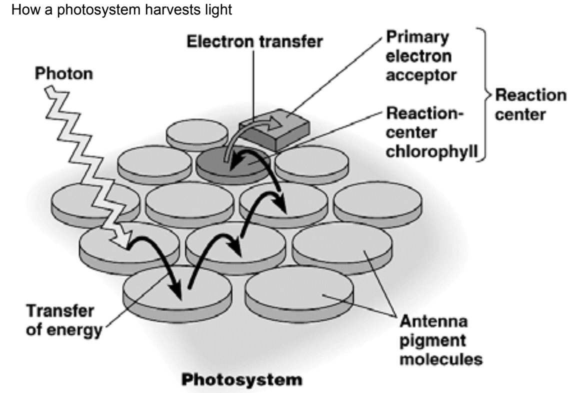


Figure 8.11

How a photosystem harvests light



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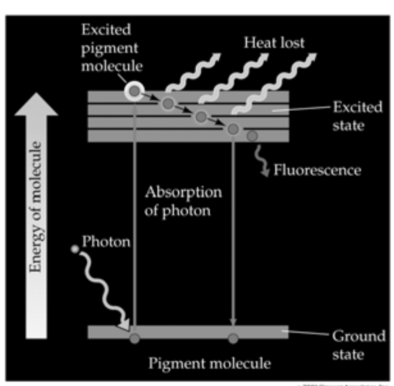
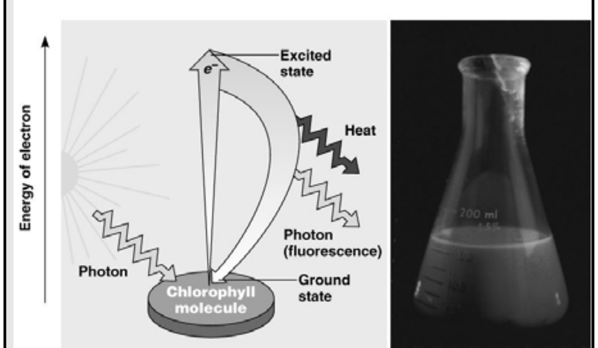


Figure 8.10

Excitation of isolated chlorophyll by light



(a) Excitation of isolated chlorophyll molecule (b) Fluorescence

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D. Electron Flow, Photophos-phorylation, and Reductions

- Noncyclic electron flow uses two photosystems.
- Photosystem II uses P_{680} chlorophyll, from which light-excited electrons pass to a redox chain that drives chemiosmotic ATP production. Light-driven water oxidation releases O_2, passing electrons to P_{680} chlorophyll.
- Photosystem I passes electrons from P_{700} chlorophyll to another redox chain and then to $NADP^+$, forming NADPH + H^+.

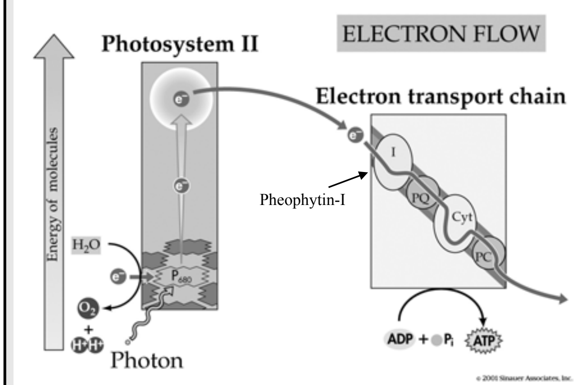


Figure 8.12 – Part 1

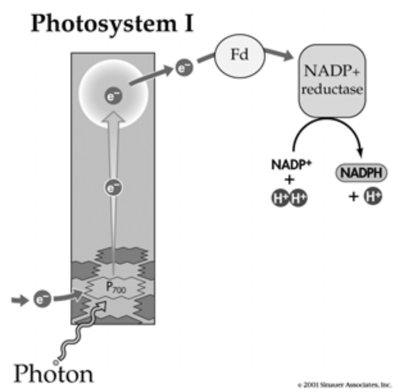
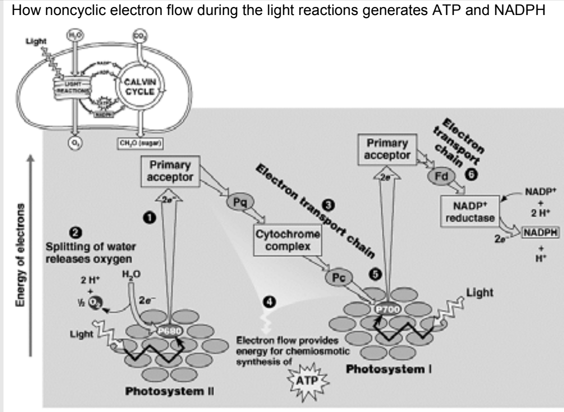


Figure 8.12 – Part 2

How noncyclic electron flow during the light reactions generates ATP and NADPH



D. Electron Flow, Photophos-phorylation, and Reductions

- Cyclic electron flow uses P_{700} chlorophyll producing **only** ATP. Its operation maintains the proper balance of ATP and NADPH + H^+ in the chloroplast.

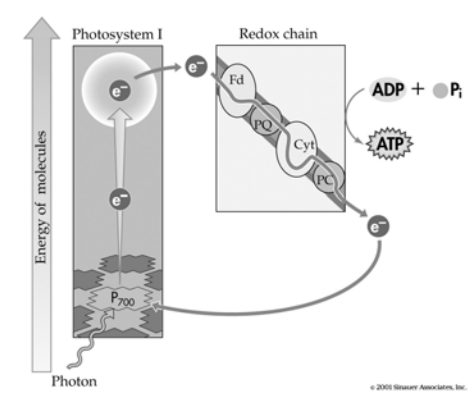
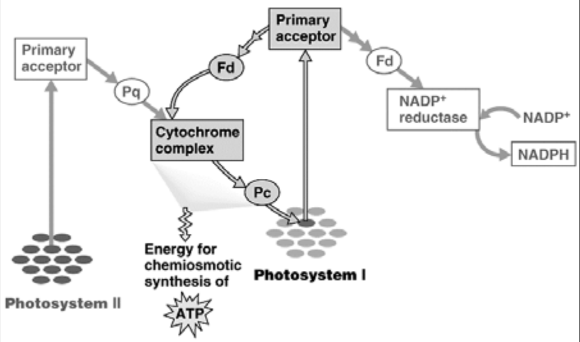


Figure 8.13

Cyclic electron flow



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D. Electron Flow, Photophos-phorylation, and Reductions

- Chemiosmosis is the source of ATP in photophosphorylation.
- Electron transport pumps protons from stroma into thylakoids, establishing a proton-motive force.
- Proton diffusion to stroma via ATP synthase channels drives ATP formation from ADP and P_i.

Chloroplast forms ATP Chemiosmotically

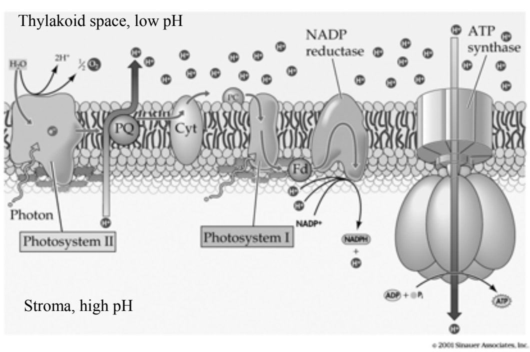
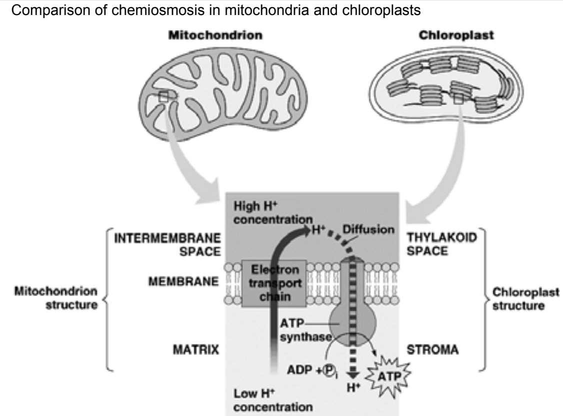


Figure 8.14

Comparison of chemiosmosis in mitochondria and chloroplasts



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D. Electron Flow, Photophos-phorylation, and Reductions

- Photosynthesis probably originated in anaerobic bacteria that used H_2S as a source of electrons instead of H_2O.
- Oxygen production by bacteria was important in eukaryote evolution.

E. Making Sugar from CO_2: The Calvin–Benson Cycle

- The Calvin–Benson cycle makes sugar from CO_2. This pathway was elucidated through use of radioactive tracers.

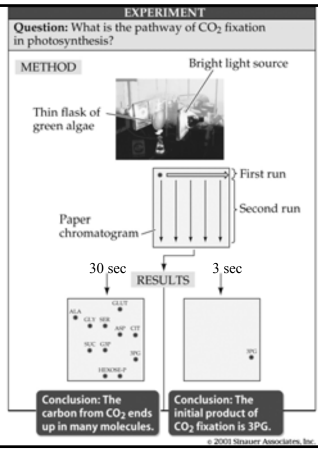


Figure 8.15

E. Making Sugar from CO_2: The Calvin–Benson Cycle

- The Calvin–Benson cycle has three phases:
- Fixation of CO_2
- Reduction (and carbohydrate production)
- Regeneration of RuBP.
- RuBP is the initial CO_2 acceptor, 3PG is the first stable product of CO_2 fixation. Rubisco catalyzes the reaction of CO_2 and RuBP to form 3PG.

RuBP is the CO_2 Acceptor

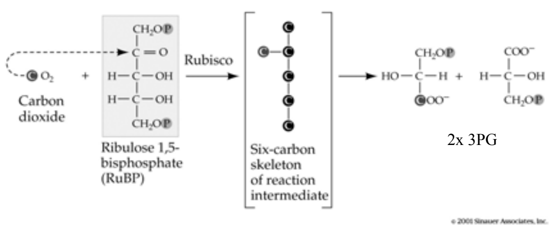


Figure 8.16

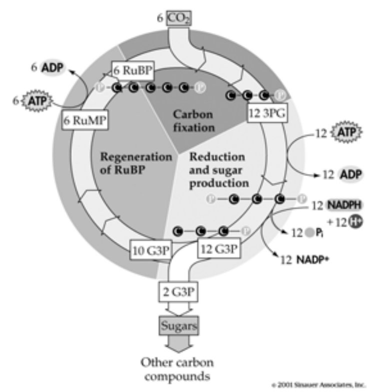
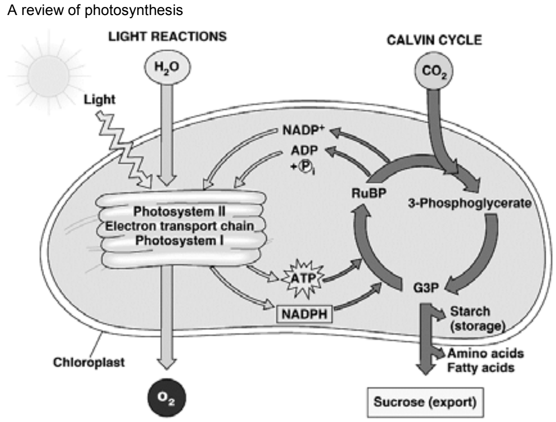


Figure 8.17

A review of photosynthesis



F. Photorespiration and Its Evolutionary Consequences

- Rubisco catalyzes a reaction between O_2 and RuBP in addition to that of CO_2 and RuBP.
- Photorespiration significantly reduces photosynthesis efficiency.
- Reactions that constitute photorespiration are distributed over chloroplast, peroxisome, and mitochondria organelles.

F. Photorespiration and Its Evolutionary Consequences

- At high temperatures and low CO_2 concentrations, the oxygenase function of rubisco is favored.
- C_4 plants bypass photorespiration. PEP carboxylase in mesophyll chloroplasts initially fixes CO_2 in four-carbon acids, which diffuse into bundle sheath cells, where their decarboxylation produces locally high concentrations of CO_2.

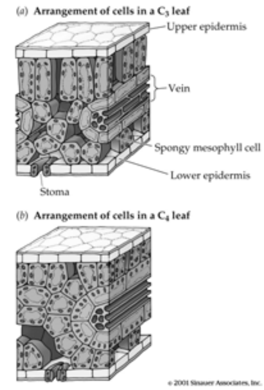
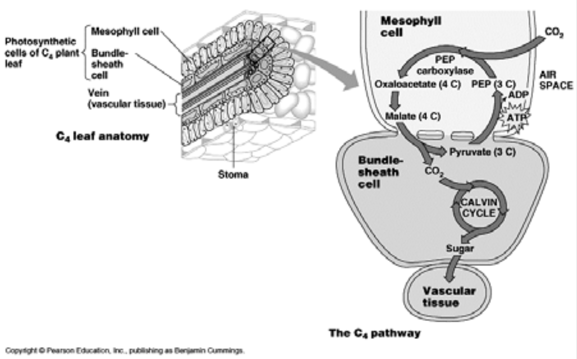


Figure 8.19

C_4 leaf anatomy and the C_4 pathway



F. Photorespiration and Its Evolutionary Consequences

- CAM (crassulacean acid metabolism) plants operate much like C_4 plants, but their initial CO_2 fixation by PEP carboxylase is temporally separated from the Calvin–Benson cycle, rather than spatially separated.

C_4 and CAM photosynthesis compared