Lecture Series 10

Photosynthesis: Energy from the Sun

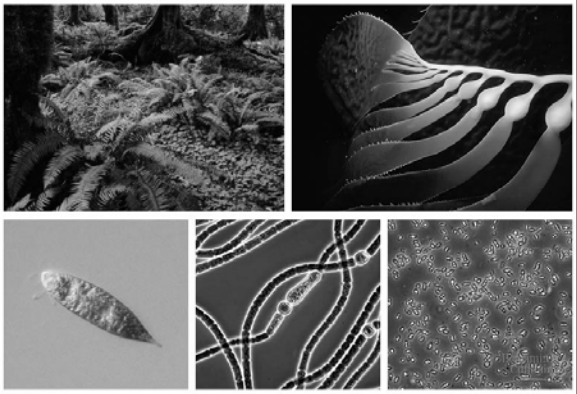
Reading Assignments

- Review Chapter 3
  Energy, Catalysis, & Biosynthesis
- Read Chapter 13
  How Cells obtain Energy from Food
- Read Chapter 14
  Energy Generation in Mitochondria & Chloroplasts

Photosynthesis In General

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

Photoautotrophs

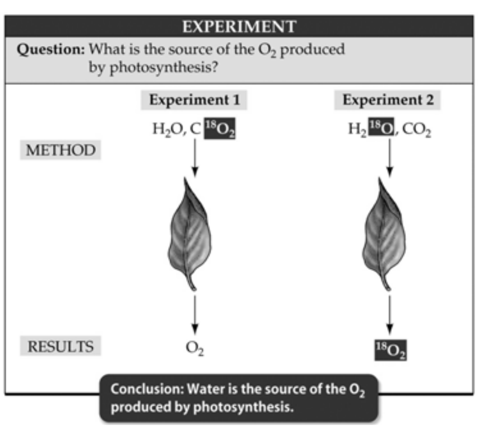


A. Identifying Photosynthetic Reactants and Products

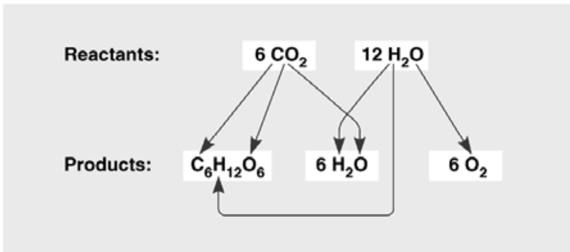
- Photosynthesizing plants take in CO_2, water, and light energy, producing O_2 and carbohydrate. The overall reaction is

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

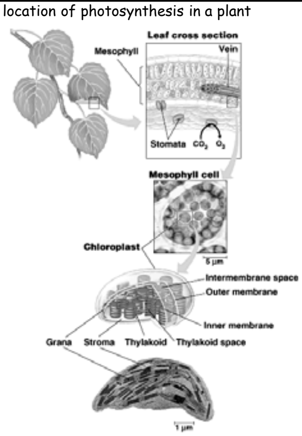
- The oxygen atoms in O_2 come from water, not from CO_2.



Tracking atoms through photosynthesis



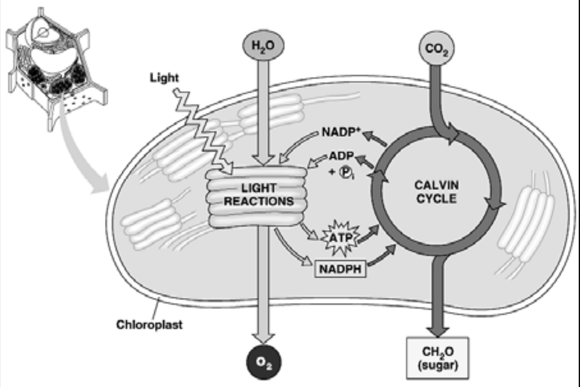
Focusing in on the location of photosynthesis in a plant



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.

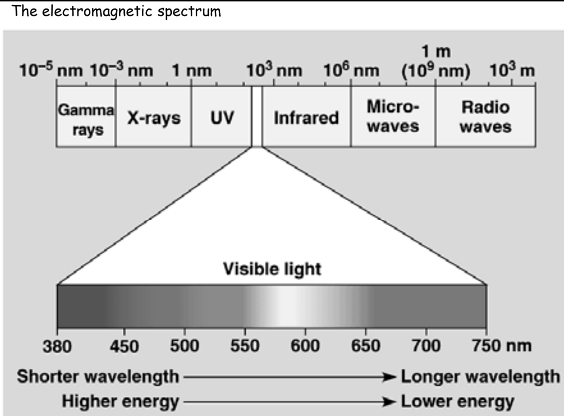
An overview of photosynthesis: cooperation of the light reactions and the Calvin cycle



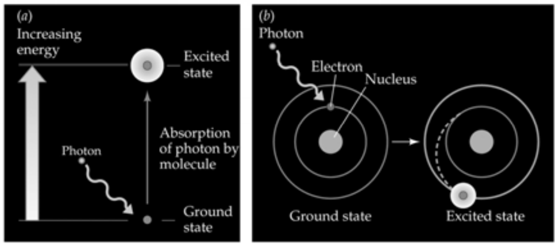
C. Properties of Light and Pigments

- 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



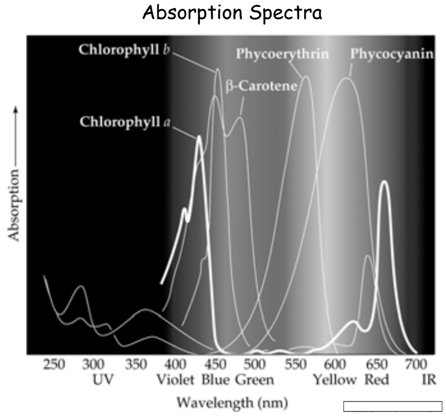
Exciting a Molecule



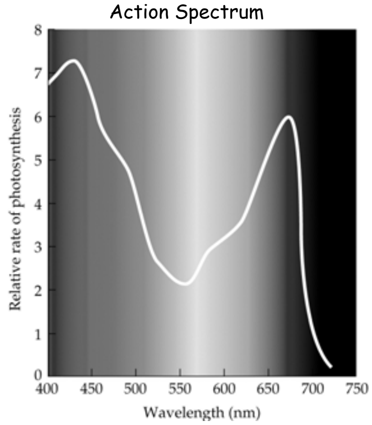
C. Properties of Light and Pigments

- 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.

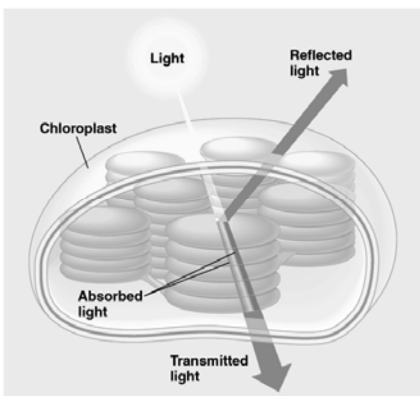
Absorption Spectra



Action Spectrum



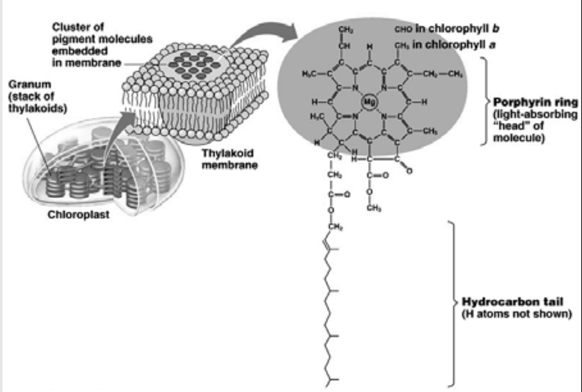
Why leaves are green: interaction of light with chloroplasts

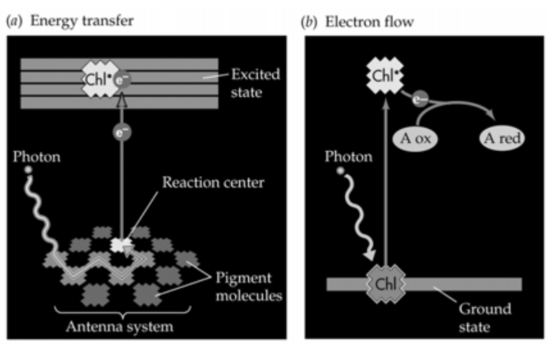


C. Properties of Light and Pigments

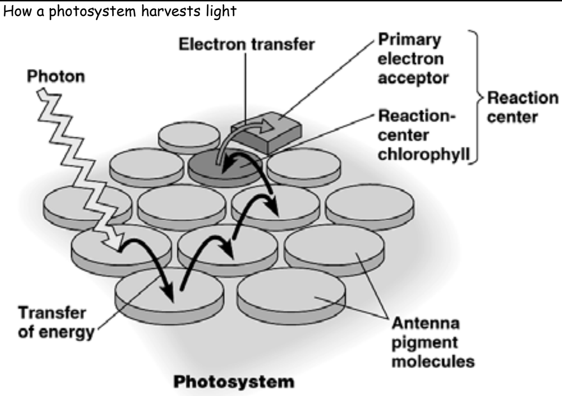
- Chlorophylls and accessory pigments form antenna systems for absorption of light energy.
- An excited pigment molecule may lose its energy by fluorescence, or by transferring it to another pigment molecule.

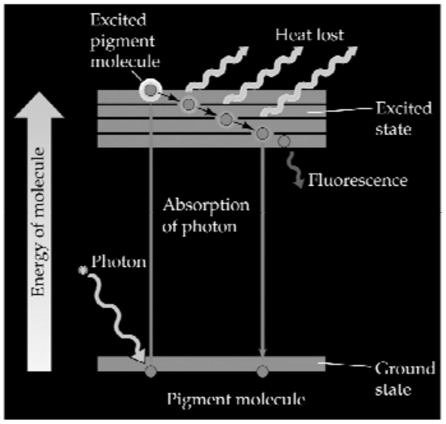
Location and structure of chlorophyll molecules in plants



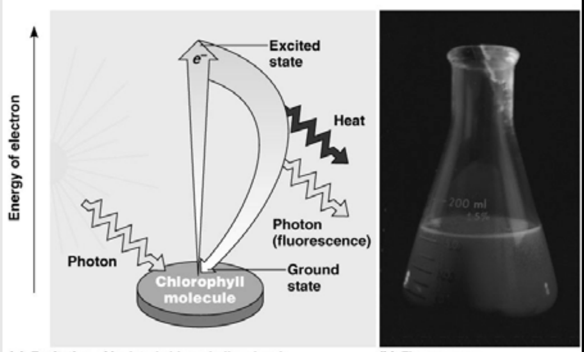


How a photosystem harvests light





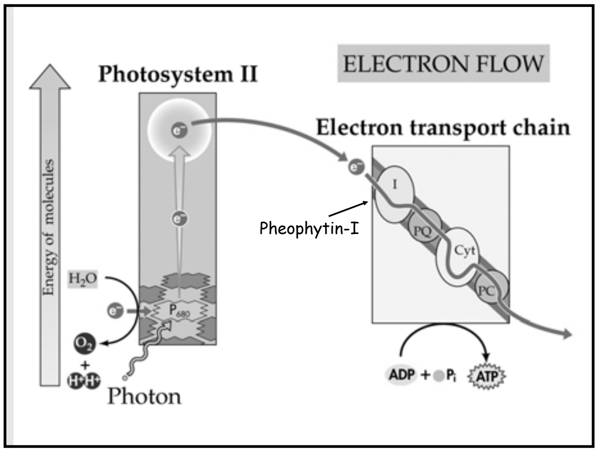
Excitation of isolated chlorophyll by light

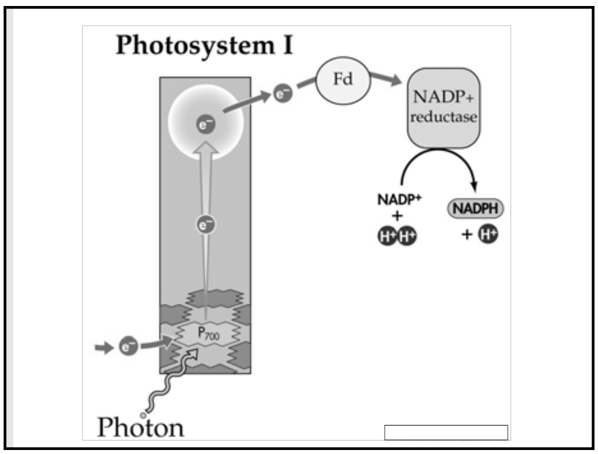


(a) Excitation of isolated chlorophyll molecule (b) Fluorescence

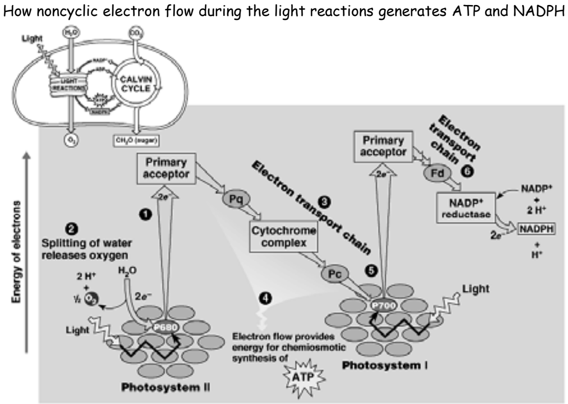
D. Electron Flow, Photophosphorylation, and Reductions

- 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^+.



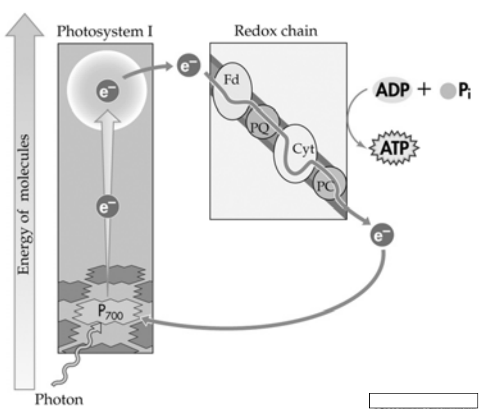


How noncyclic electron flow during the light reactions generates ATP and NADPH

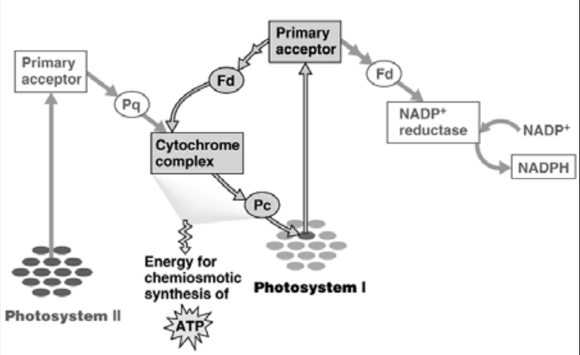


D. Electron Flow, Photophosphorylation, and Reductions

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

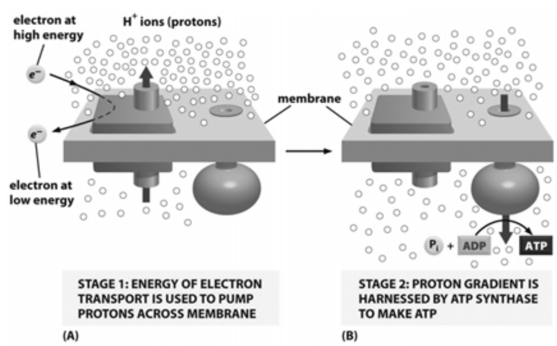


Cyclic electron flow

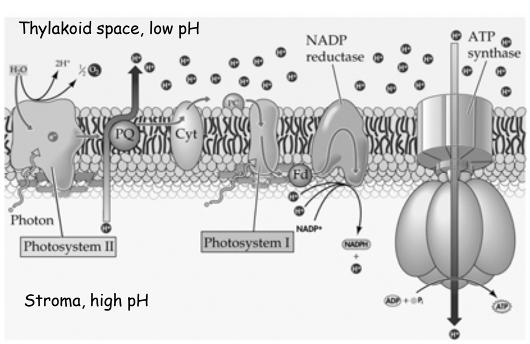


D. Electron Flow, Photophos-phorylation, and Reductions

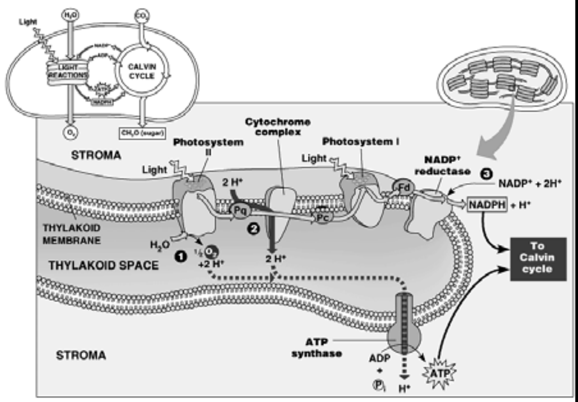
- Chemiosmosis is the source of ATP in photophosphorylation.
- Electron transport pumps protons from stroma into thylakoids, establishing a proton-motive force.
- Proton diffusion to stroma via ATP synthase channels drives ATP formation from ADP and P_i.



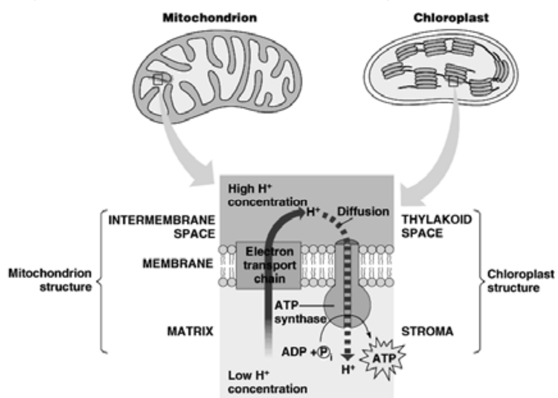
Chloroplast forms ATP Chemiosmotically



The light reactions and chemiosmosis: the organization of the thylakoid membrane



Comparison of chemiosmosis in mitochondria and chloroplasts

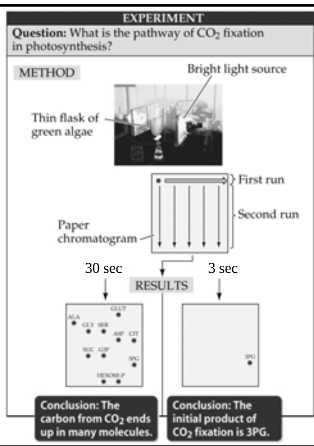


D. Electron Flow, Photophos-phorylation, and Reductions

- 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

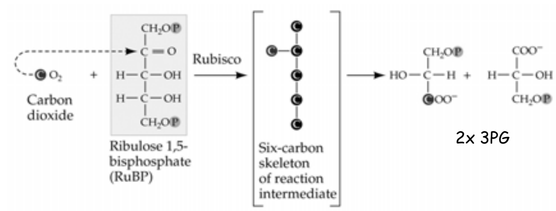
- The Calvin–Benson cycle makes sugar from CO_2. This pathway was elucidated through use of radioactive tracers.

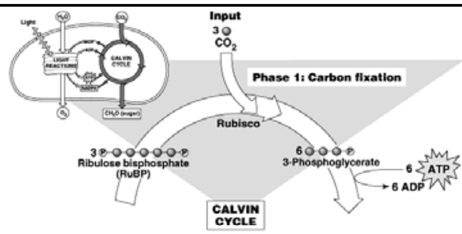


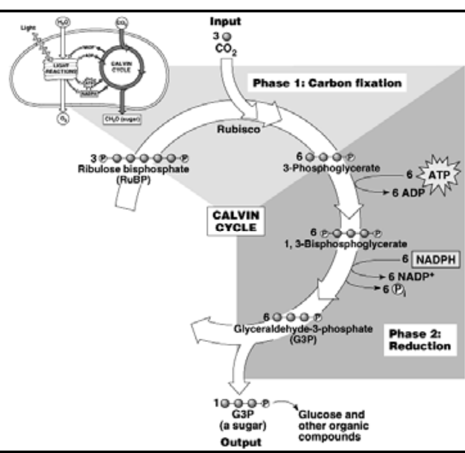
E. Making Sugar from CO_2: The Calvin–Benson Cycle

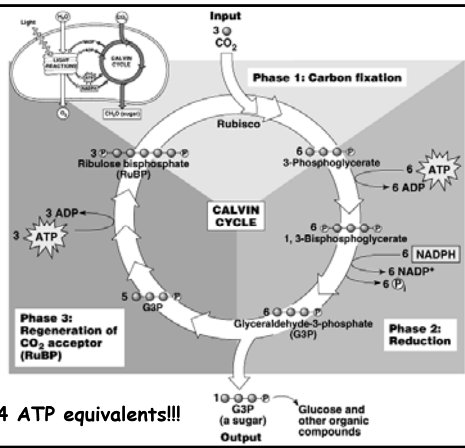
- The Calvin–Benson cycle has three phases:
- Fixation of CO_2
- Reduction (and carbohydrate production)
- Regeneration of RuBP.
- RuBP is the initial CO_2 acceptor, 3PG is the first stable product of CO_2 fixation. Rubisco catalyzes the reaction of CO_2 and RuBP to form 3PG.

RuBP is the CO_2 Acceptor



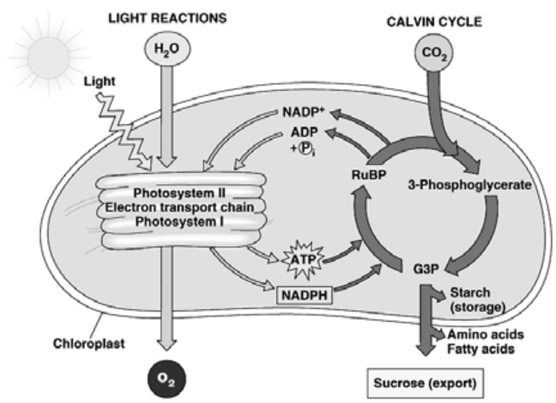






54 ATP equivalents!!!

A review of photosynthesis

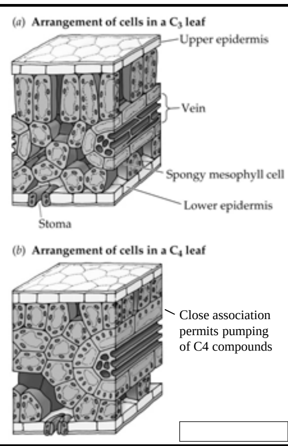


F. Photorespiration and Its Consequences

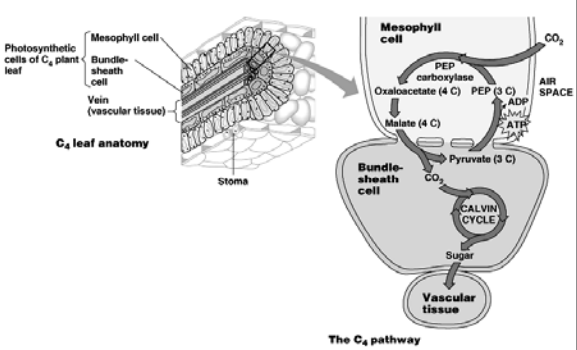
- Rubisco catalyzes a reaction between O_2 and RuBP (forming phosphoglycolate + 3PG) in addition to the usual route of CO_2 and RuBP.
- Photorespiration byproducts are processed by chloroplasts, peroxisomes, and mitochondria.
- Photorespiration significantly reduces photosynthesis efficiency.

F. Photorespiration and Its Consequences

- Higher temperatures and dryer climates increase the effects of photorespiration; the oxygenase function of rubisco is then 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.



C_4 leaf anatomy and the C_4 pathway



F. Photorespiration and Its Consequences

- Higher temperatures and dryer climates increase the effects of photorespiration; the oxygenase function of rubisco is then favored.
- 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