Lecture Series 10

Photosynthesis: Energy from the Sun

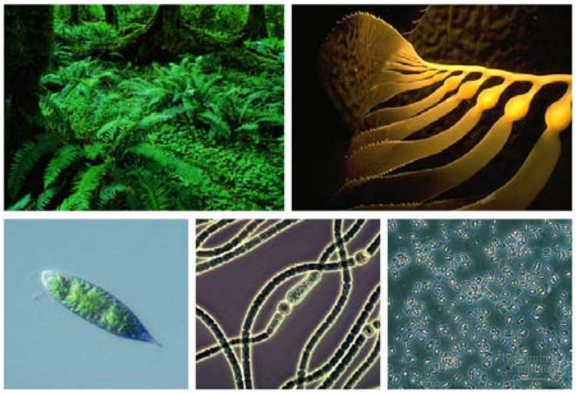
Reading Assignments

- 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

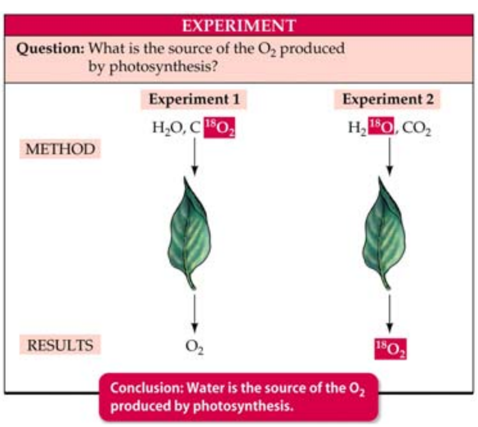


A. Identifying Photosynthetic Reactants and Products

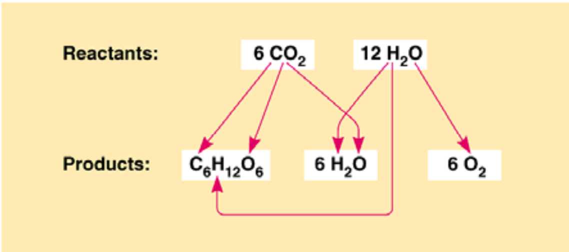
- Photosynthesizing plants take in CO_2, water, and light energy, producing O_2 and carbohydrate. The overall reaction is

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

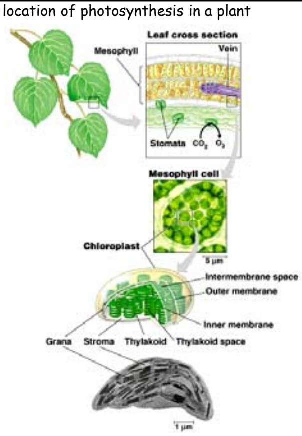
- The oxygen atoms in O_2 come from water, not from CO_2.



Tracking atoms through photosynthesis



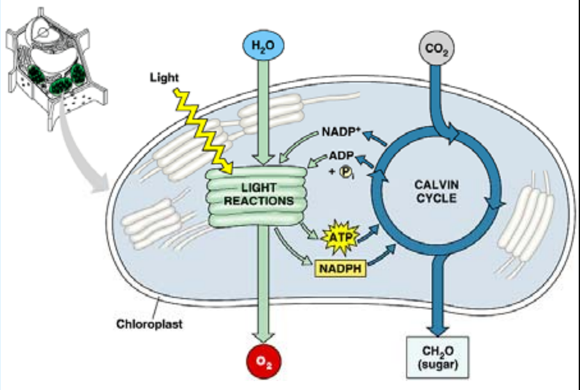
Focusing in on the location of photosynthesis in a plant



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.

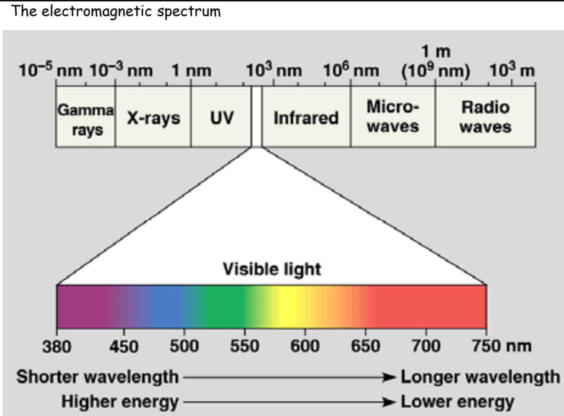
An overview of photosynthesis: cooperation of the light reactions and the Calvin cycle



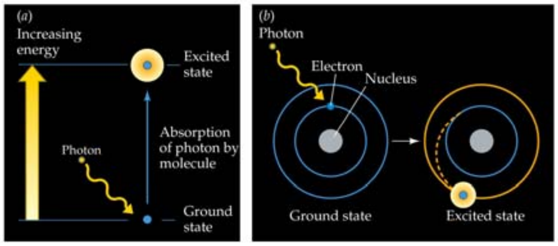
C. Properties of Light and Pigments

- 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



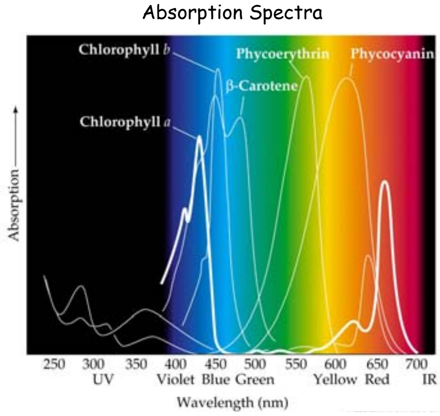
Exciting a Molecule



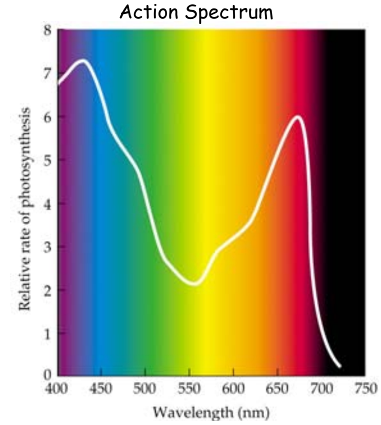
C. Properties of Light and Pigments

- 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.

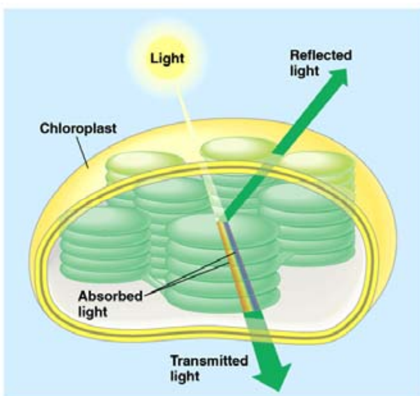
Absorption Spectra



Action Spectrum



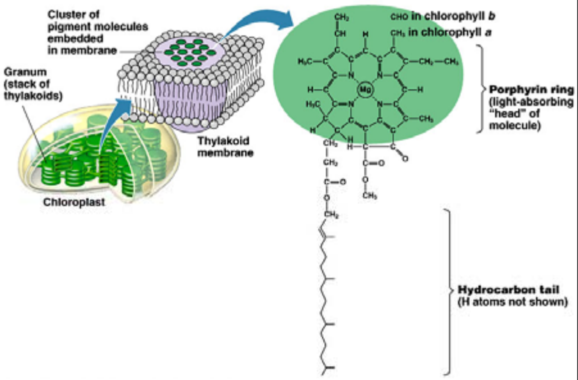
Why leaves are green: interaction of light with chloroplasts

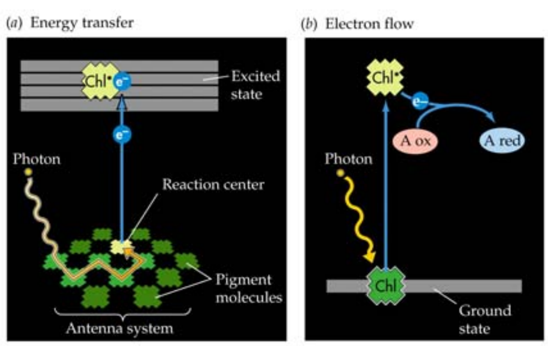


C. Properties of Light and Pigments

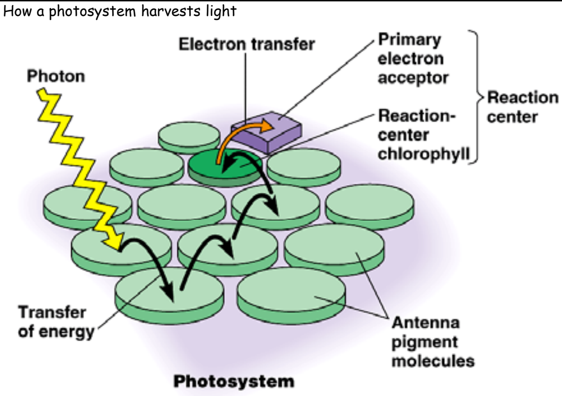
- Chlorophylls and accessory pigments form antenna systems for absorption of light energy.
- An excited pigment molecule may lose its energy by fluorescence, or by transferring it to another pigment molecule.

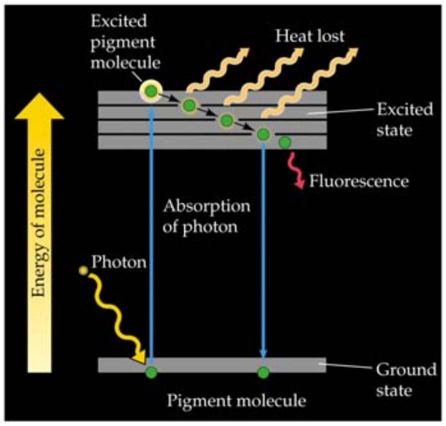
Location and structure of chlorophyll molecules in plants



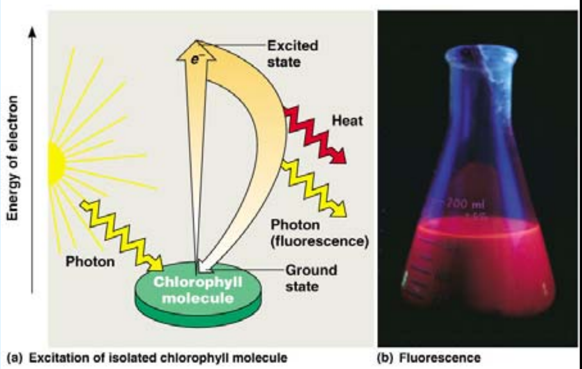


How a photosystem harvests light



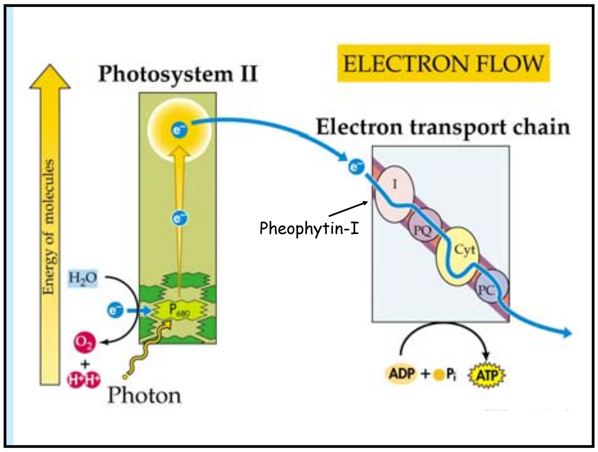


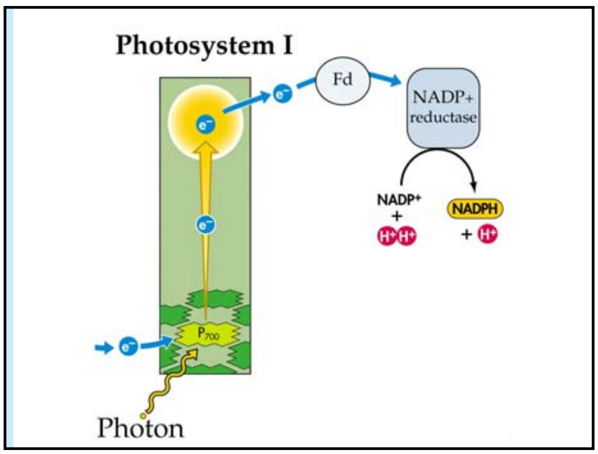
Excitation of isolated chlorophyll by light

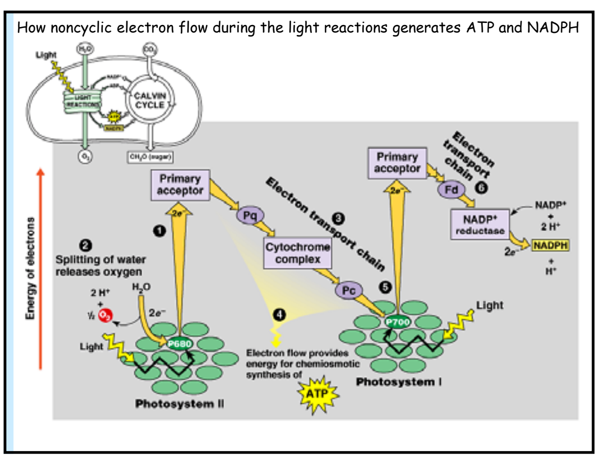


D. Electron Flow, Photophosphorylation, and Reductions

- 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^+.

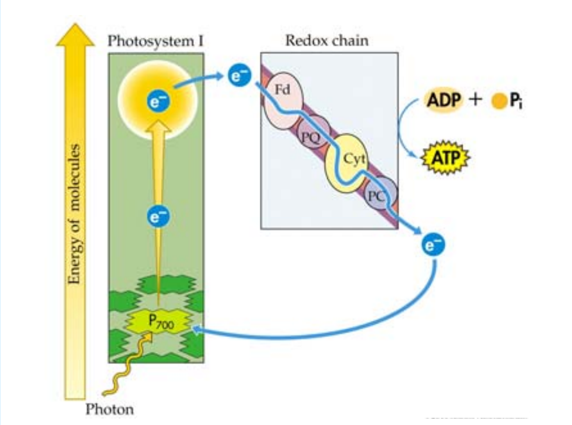

Photosystem II
ELECTRON FLOW
Electron transport chain
Energy of molecules
Pheophytin-I
I
PQ
Cyt
PC
H_2O
P_{680}
O_2
Photon
ADP + P_i
ATP


Photosystem I
Fd
NADP+ reductase
P_{700}
NADP+
NADPH
Photon

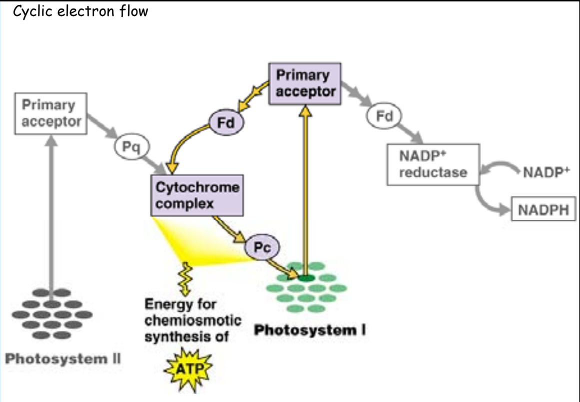

How noncyclic electron flow during the light reactions generates ATP and NADPH
Light
CALVIN CYCLE
Energy of electrons
Primary acceptor
Pq
Electron transport chain
Cytochrome complex
Pc
Primary acceptor
Electron transport chain
Fd
NADP+ reductase
NADPH
Splitting of water releases oxygen
P680
P700
Electron flow provides energy for chemiosmotic synthesis of
ATP
Photosystem II
Photosystem I

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.

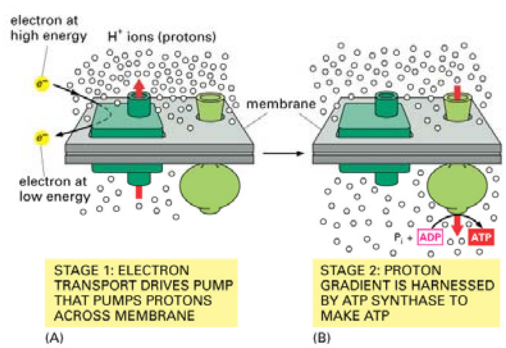


Cyclic electron flow

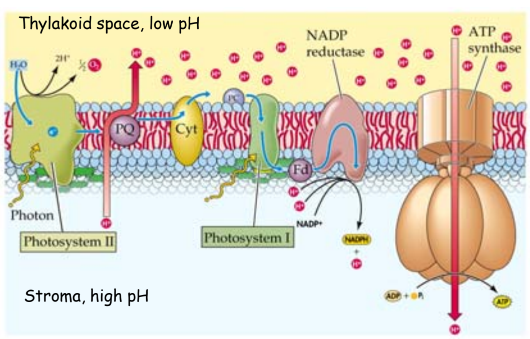


D. Electron Flow, Photophosphorylation, and Reductions

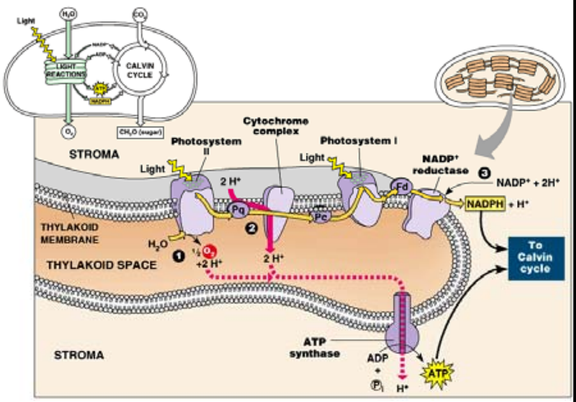
- Chemiosmosis is the source of ATP in photophosphorylation.
- Electron transport pumps protons from stroma into thylakoids, establishing a proton-motive force.
- Proton diffusion to stroma via ATP synthase channels drives ATP formation from ADP and P_i.



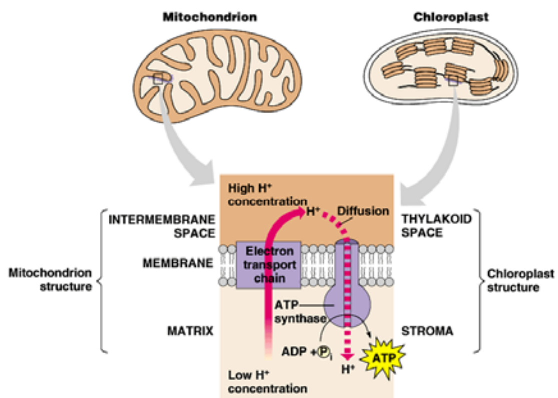
Chloroplast forms ATP Chemiosmotically



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



Comparison of chemiosmosis in mitochondria and chloroplasts

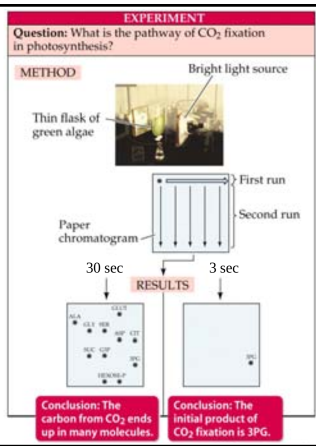


D. Electron Flow, Photophosphorylation, and Reductions

- 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

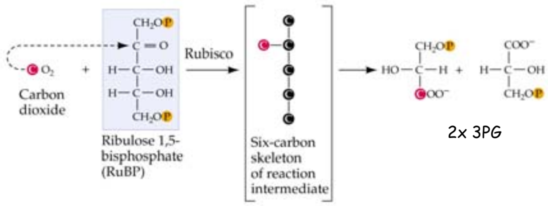
- The Calvin–Benson cycle makes sugar from CO_2. This pathway was elucidated through use of radioactive tracers.

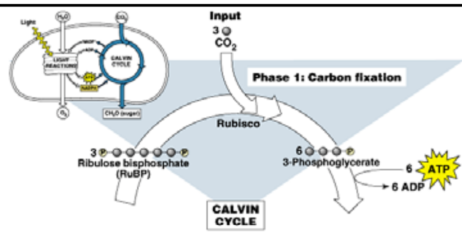


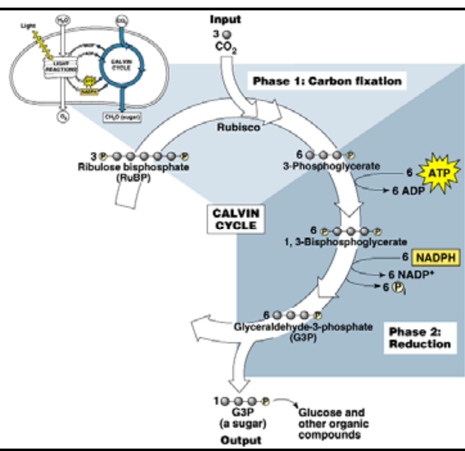
E. Making Sugar from CO_2: The Calvin–Benson Cycle

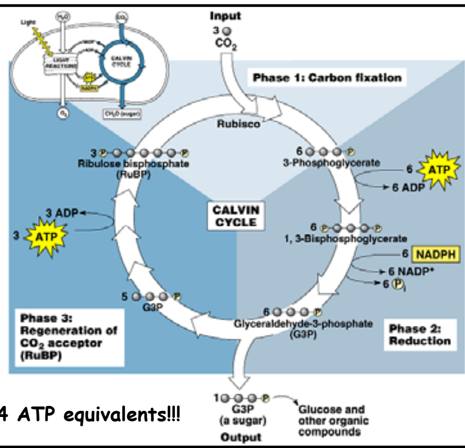
- The Calvin–Benson cycle has three phases:
- Fixation of CO_2
- Reduction (and carbohydrate production)
- Regeneration of RuBP.
- RuBP is the initial CO_2 acceptor, 3PG is the first stable product of CO_2 fixation. Rubisco catalyzes the reaction of CO_2 and RuBP to form 3PG.

RuBP is the CO_2 Acceptor



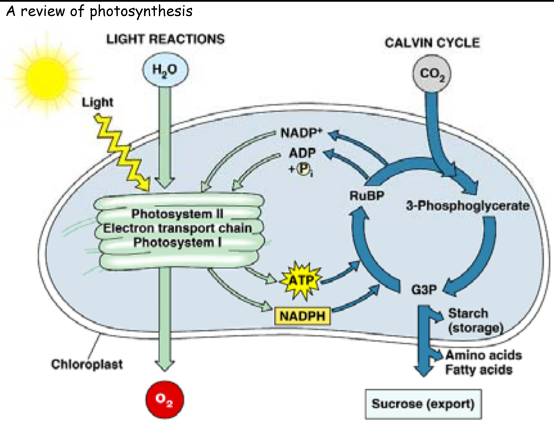






54 ATP equivalents!!!

A review of photosynthesis

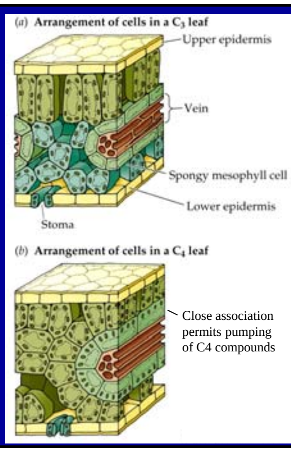


F. Photorespiration and Its Consequences

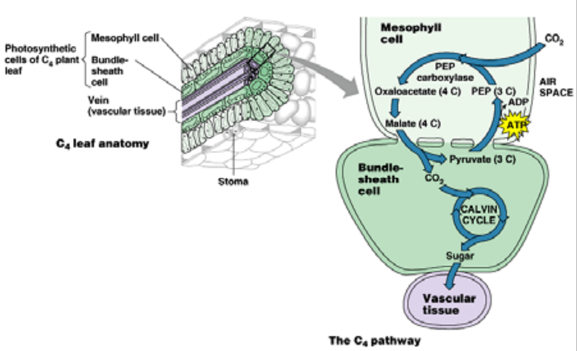
- Rubisco catalyzes a reaction between O_2 and RuBP (forming phosphoglycolate + 3PG) in addition to the usual route of CO_2 and RuBP.
- Photorespiration byproducts are processed by chloroplasts, peroxisomes, and mitochondria.
- Photorespiration significantly reduces photosynthesis efficiency.

F. Photoresspiration 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