Lecture Series 10

Photosynthesis: Energy from the Sun

Reading Assignments

- Review Chapter 3
  Energy, Catalysis, & Biosynthesis

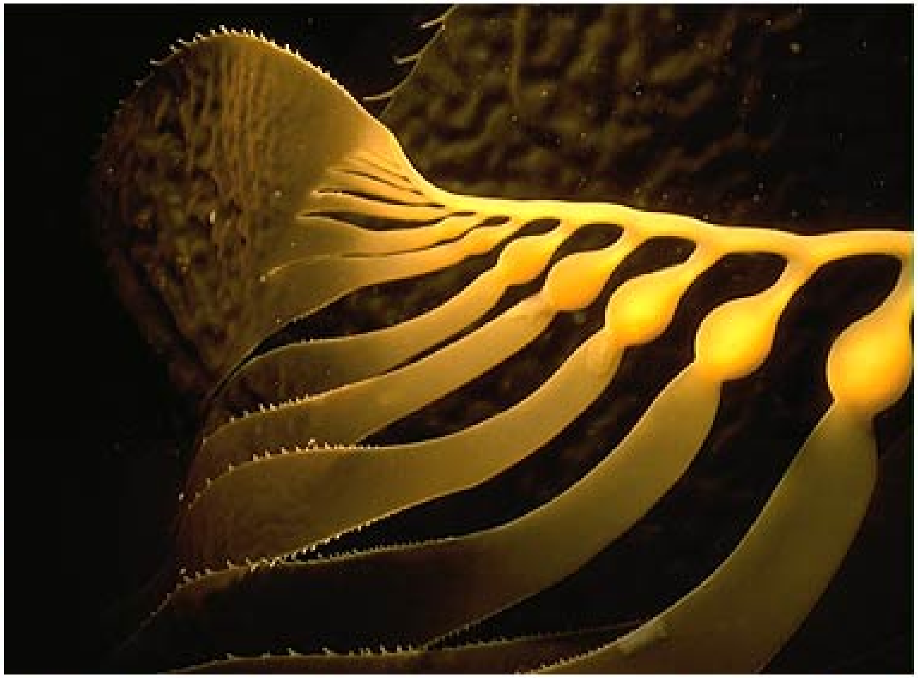
- Read Chapter 13
  How Cells obtain Energy from Food

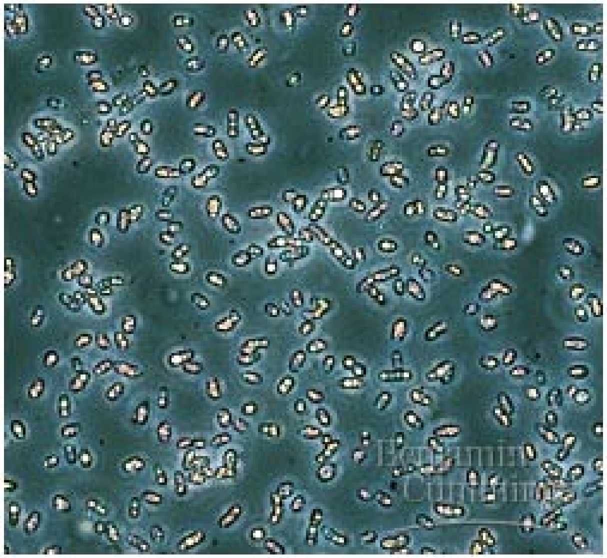
- Read Chapter 14
  Energy Generation in Mitochondria & Chloroplasts

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

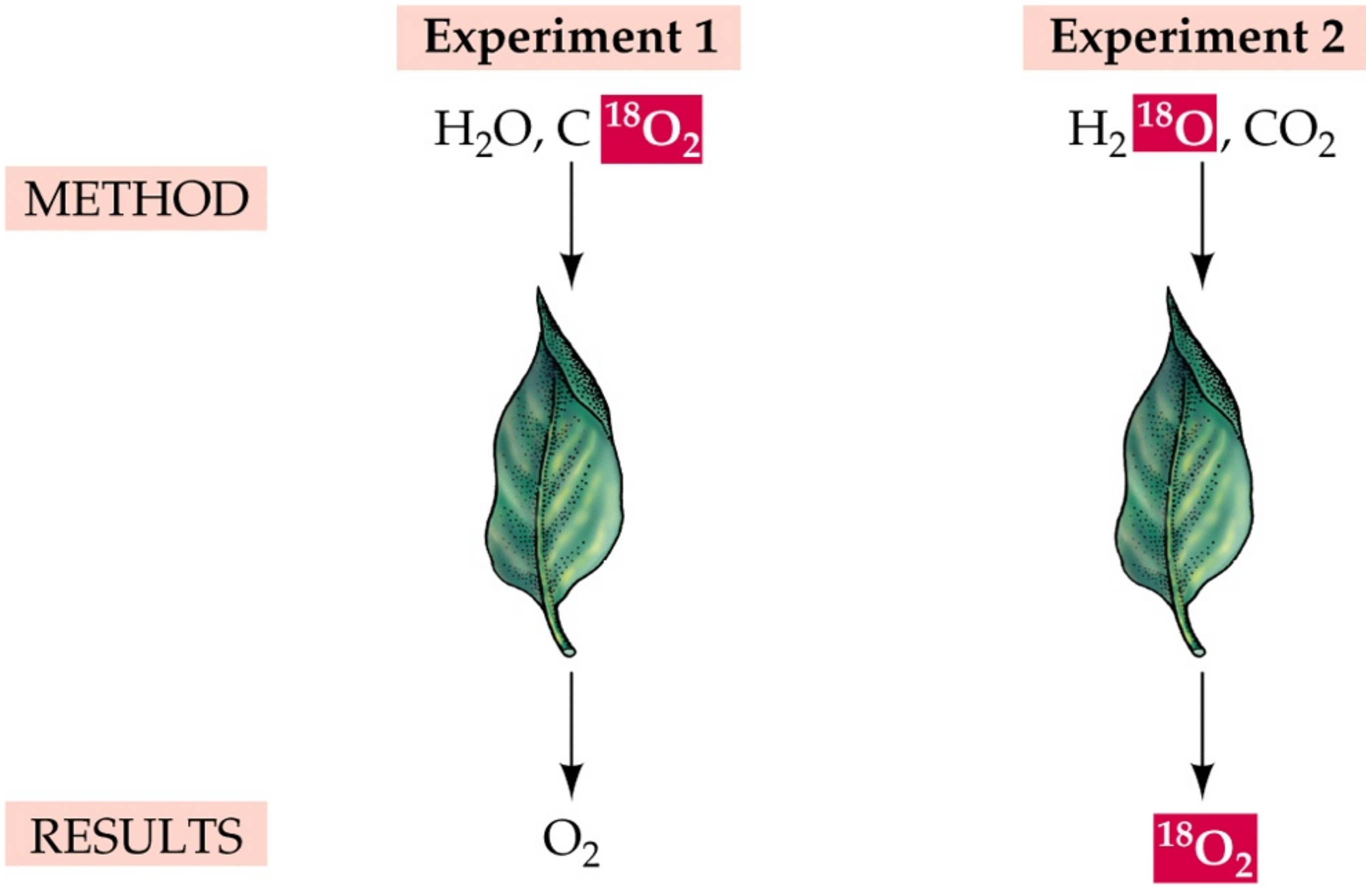
- Photosynthesizing plants take in CO_2, water, and light energy, producing O_2 and carbohydrate. The overall reaction is

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

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

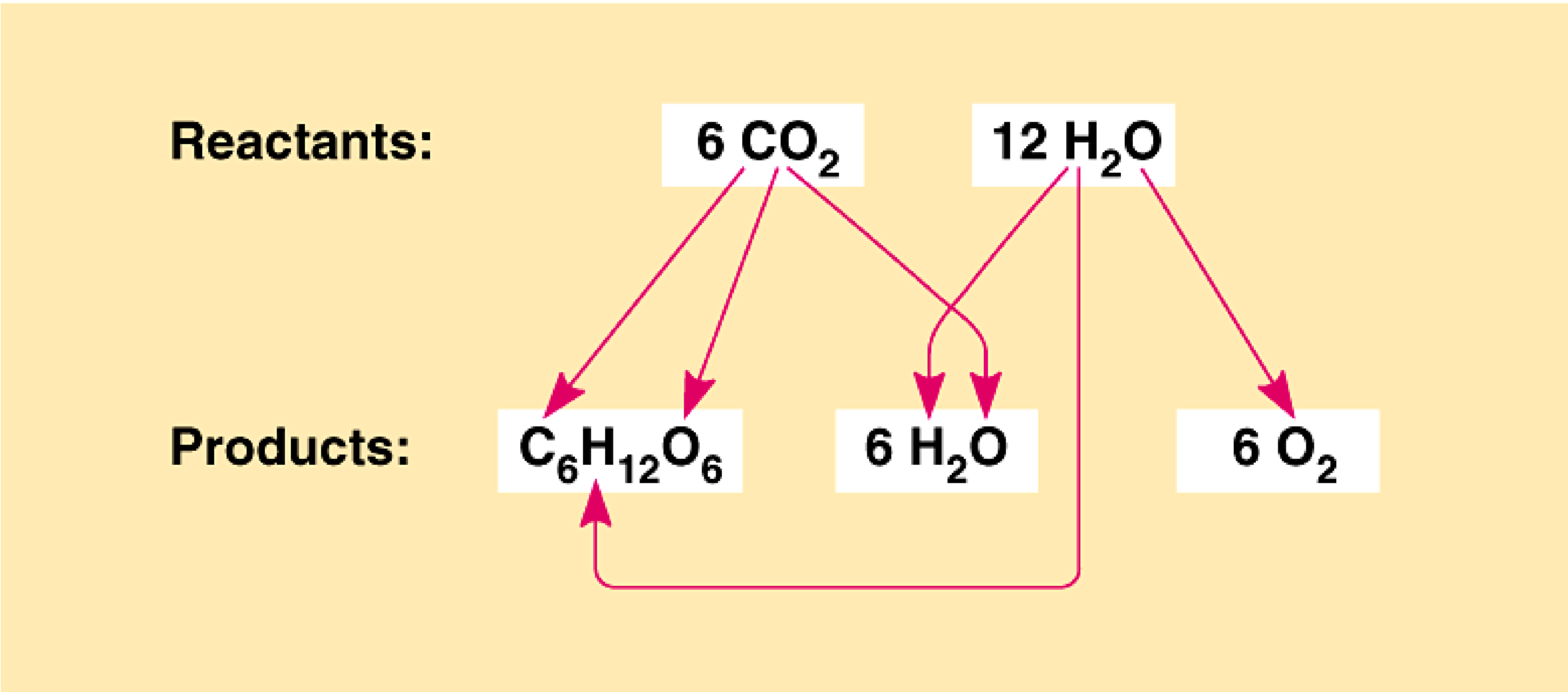
EXPERIMENT

Question: What is the source of the O_2 produced by photosynthesis?

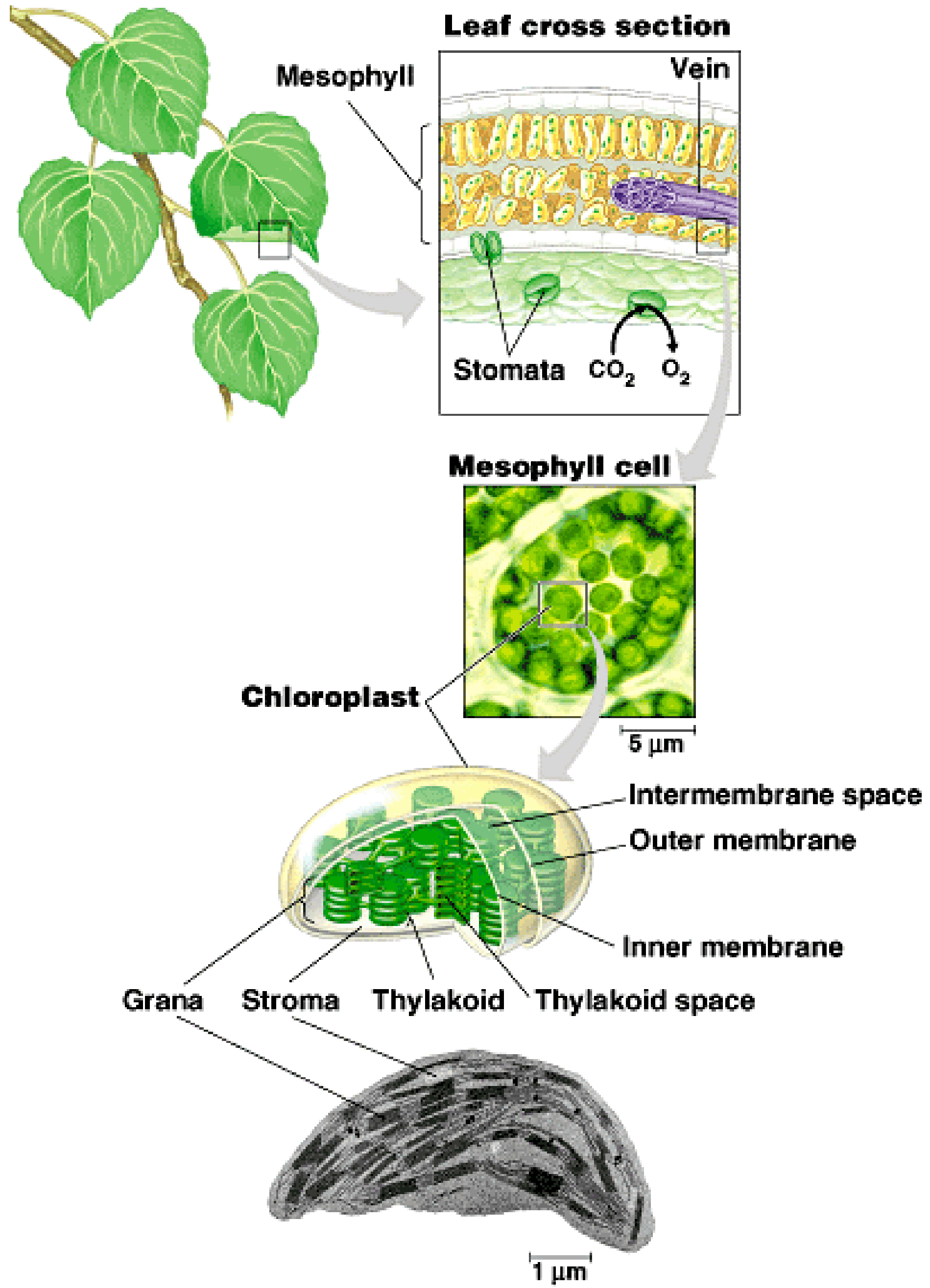


Conclusion: Water is the source of the O_2 produced by photosynthesis.

Tracking atoms through photosynthesis



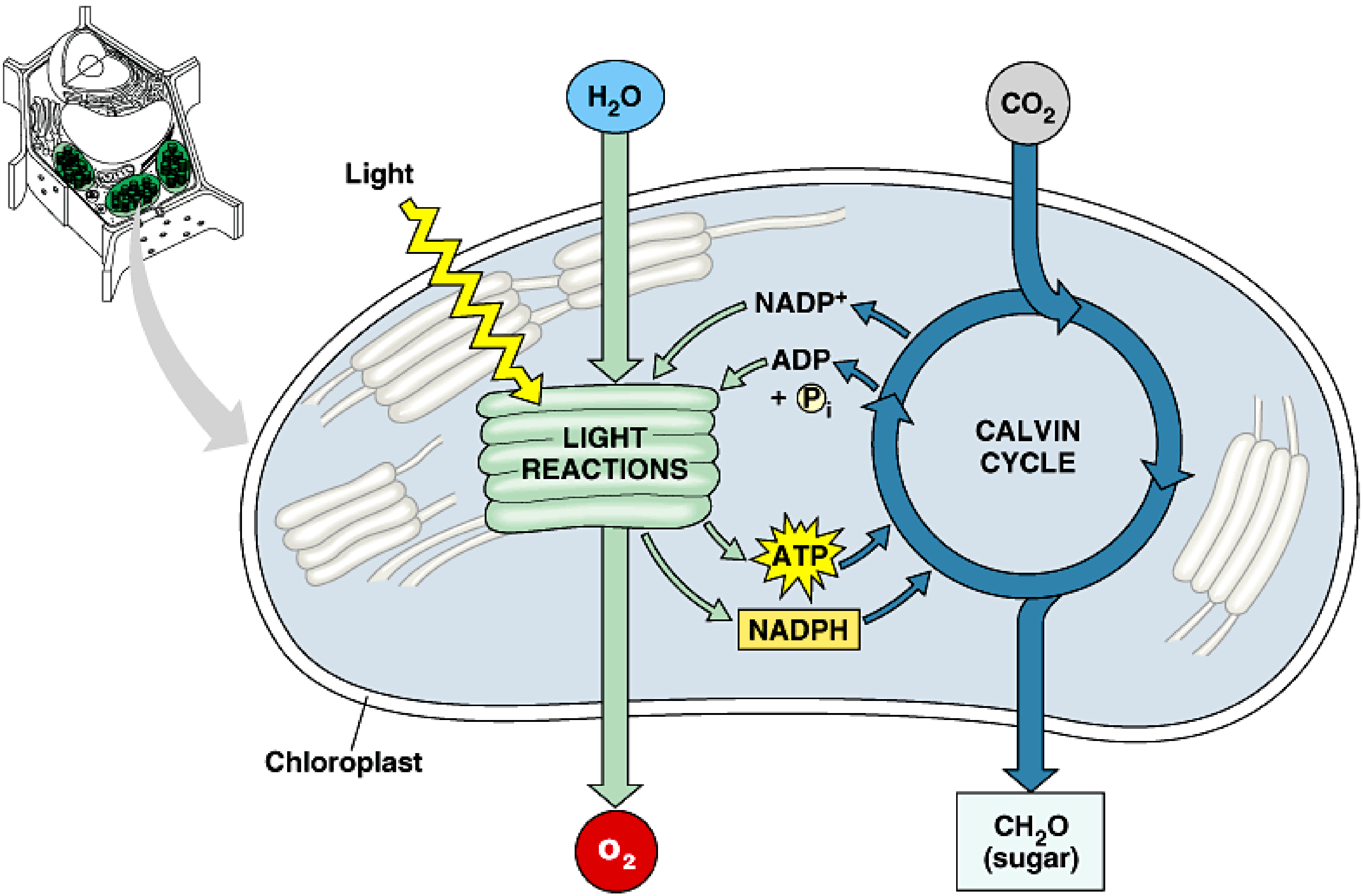
Focusing in on the location of photosynthesis in a plant



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.

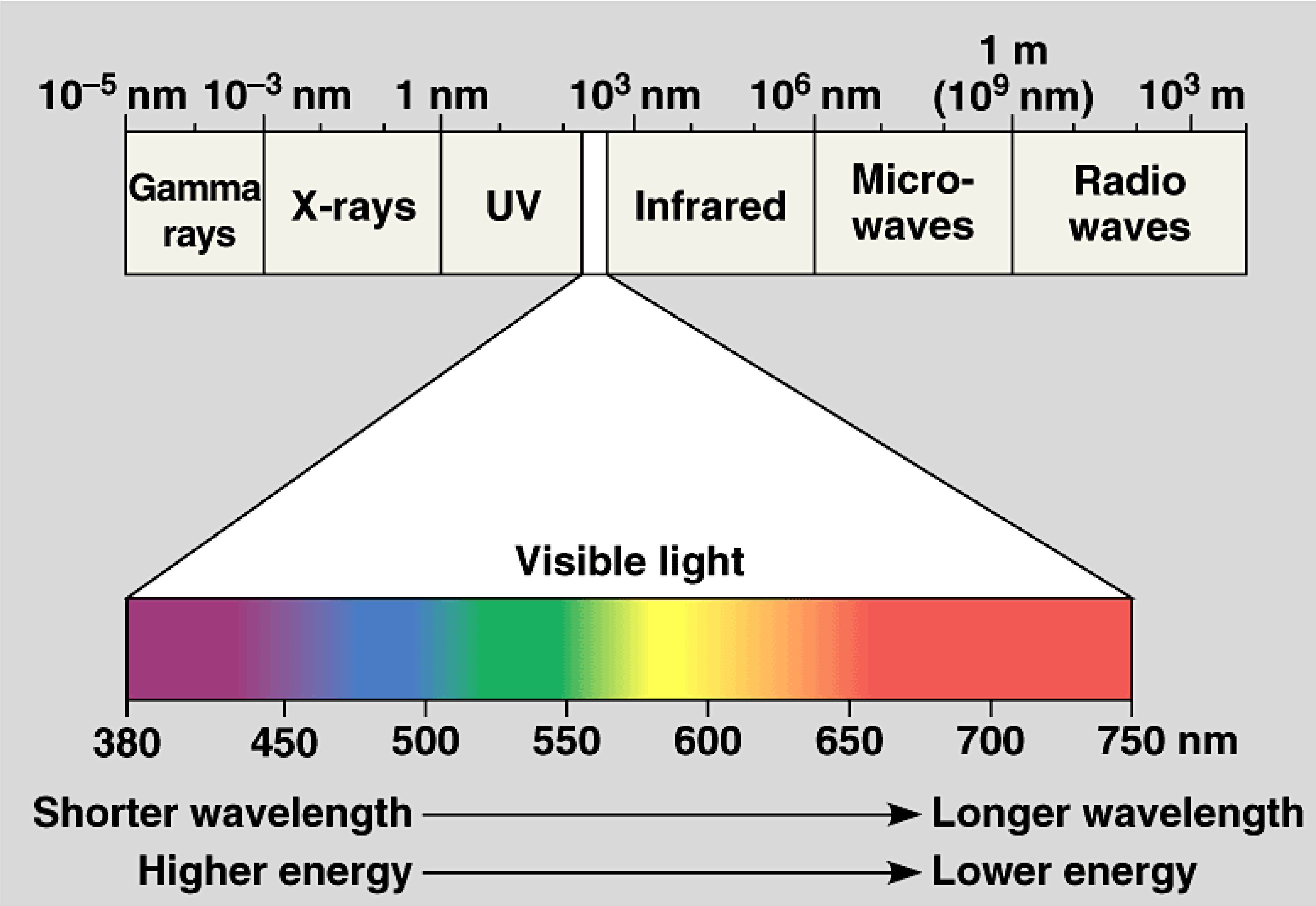
An overview of photosynthesis: cooperation of the light reactions and the Calvin cycle



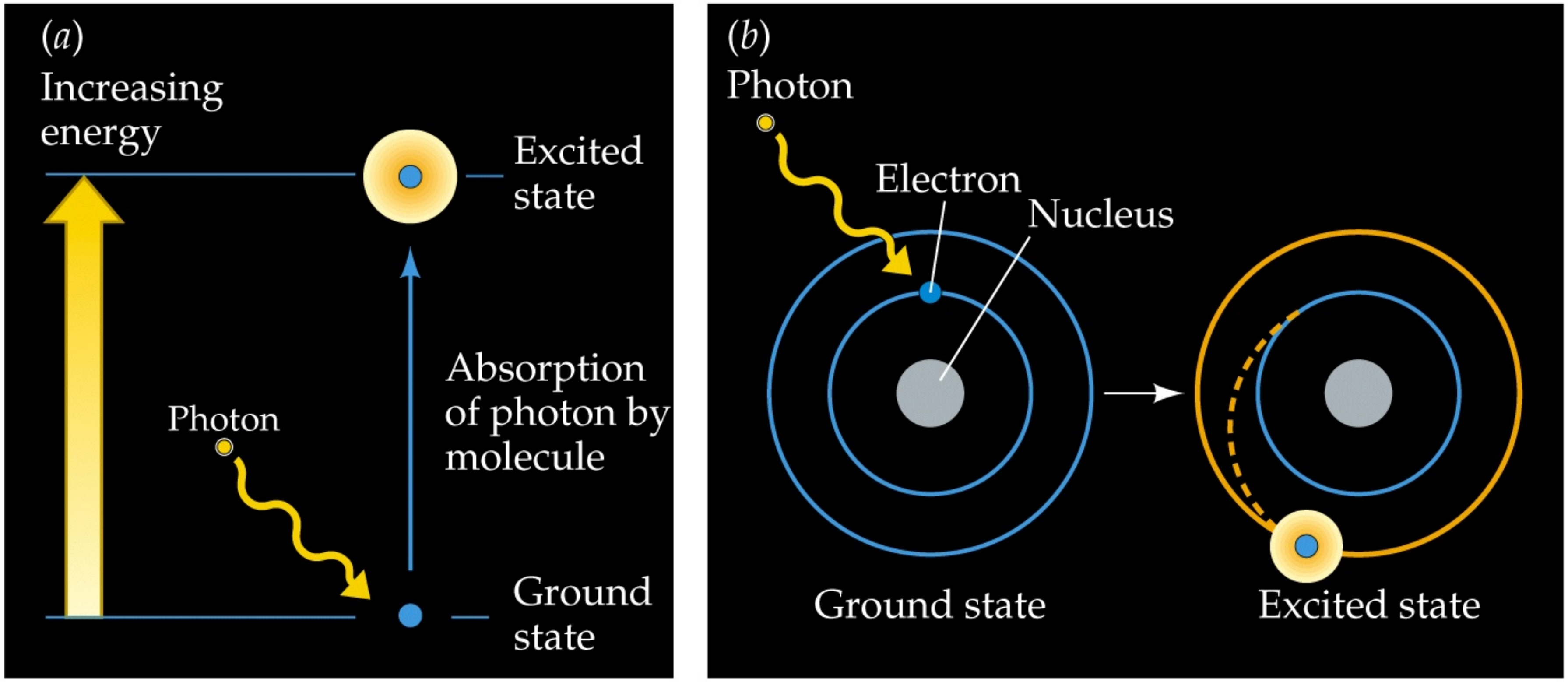
C. Properties of Light and Pigments

- 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



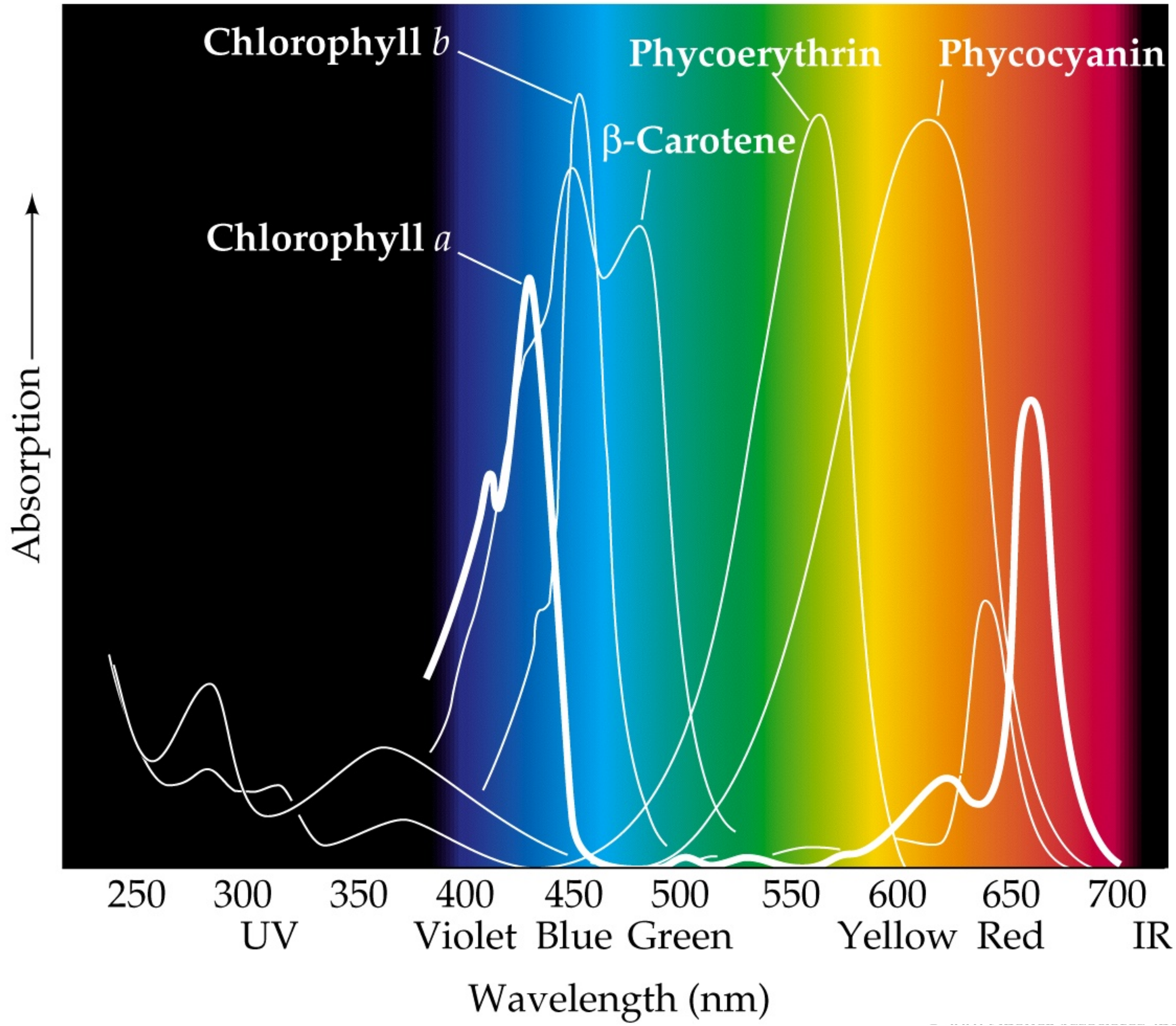
Exciting a Molecule



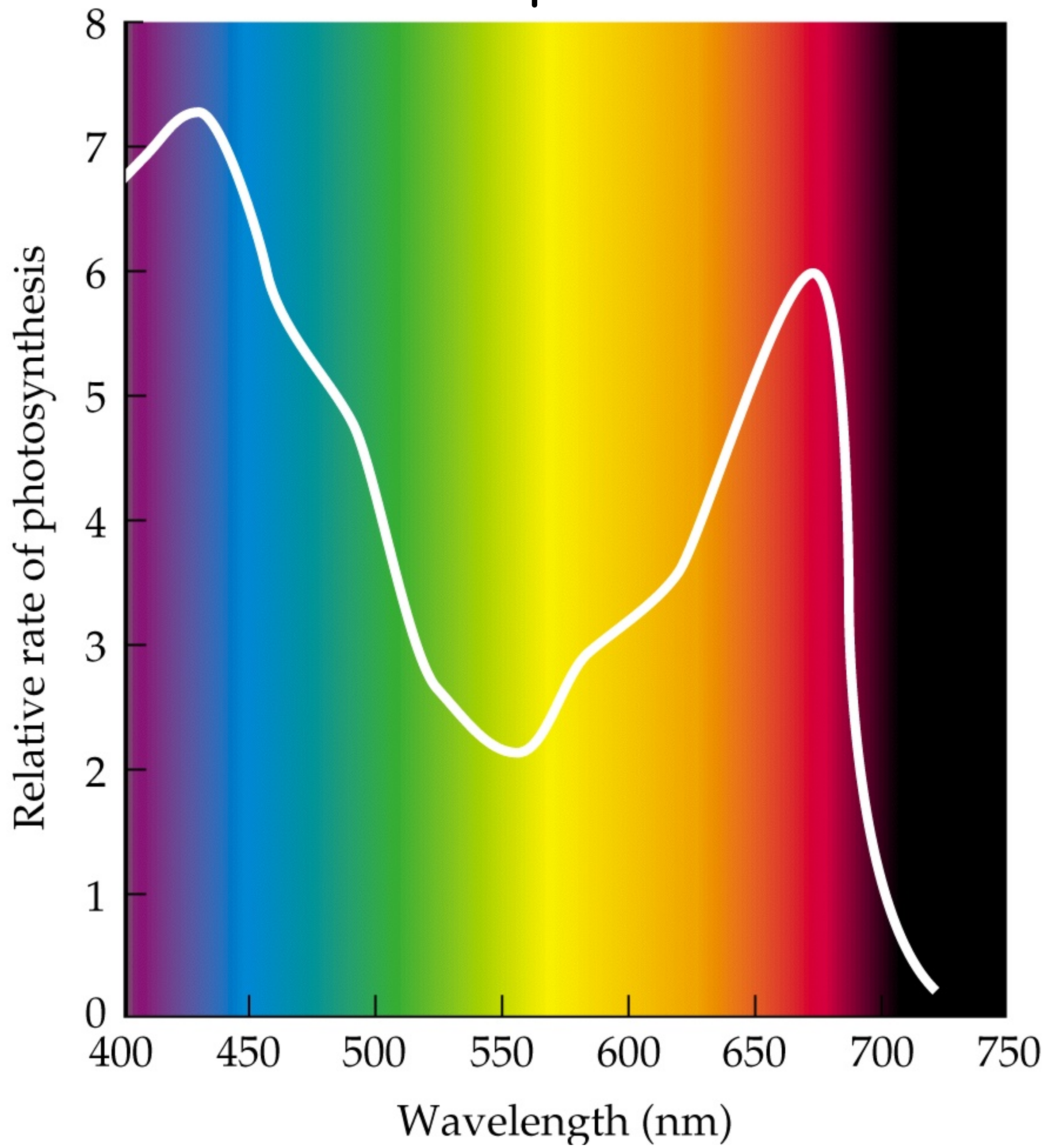
C. Properties of Light and Pigments

- 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.

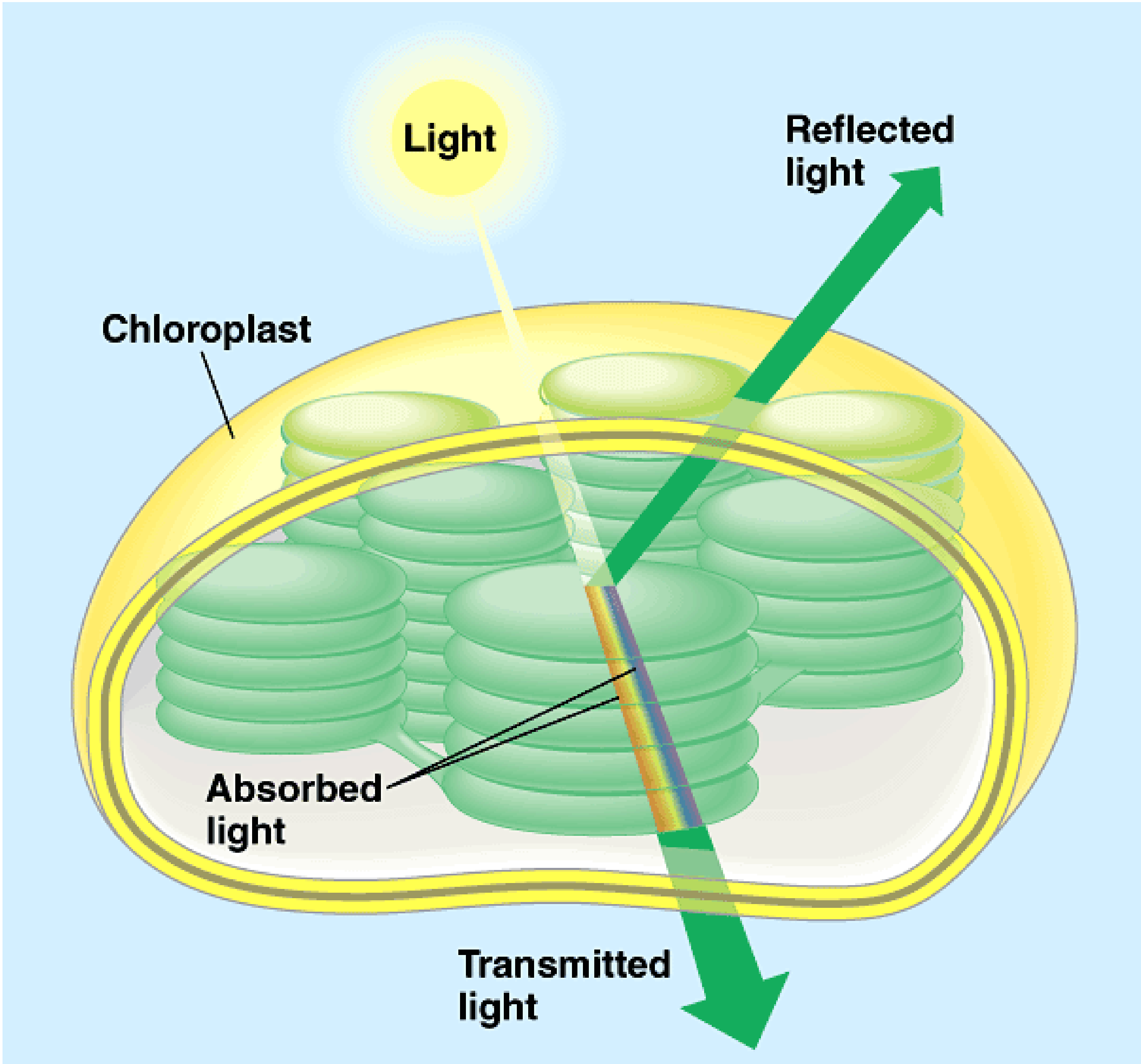
Absorption Spectra



Action Spectrum



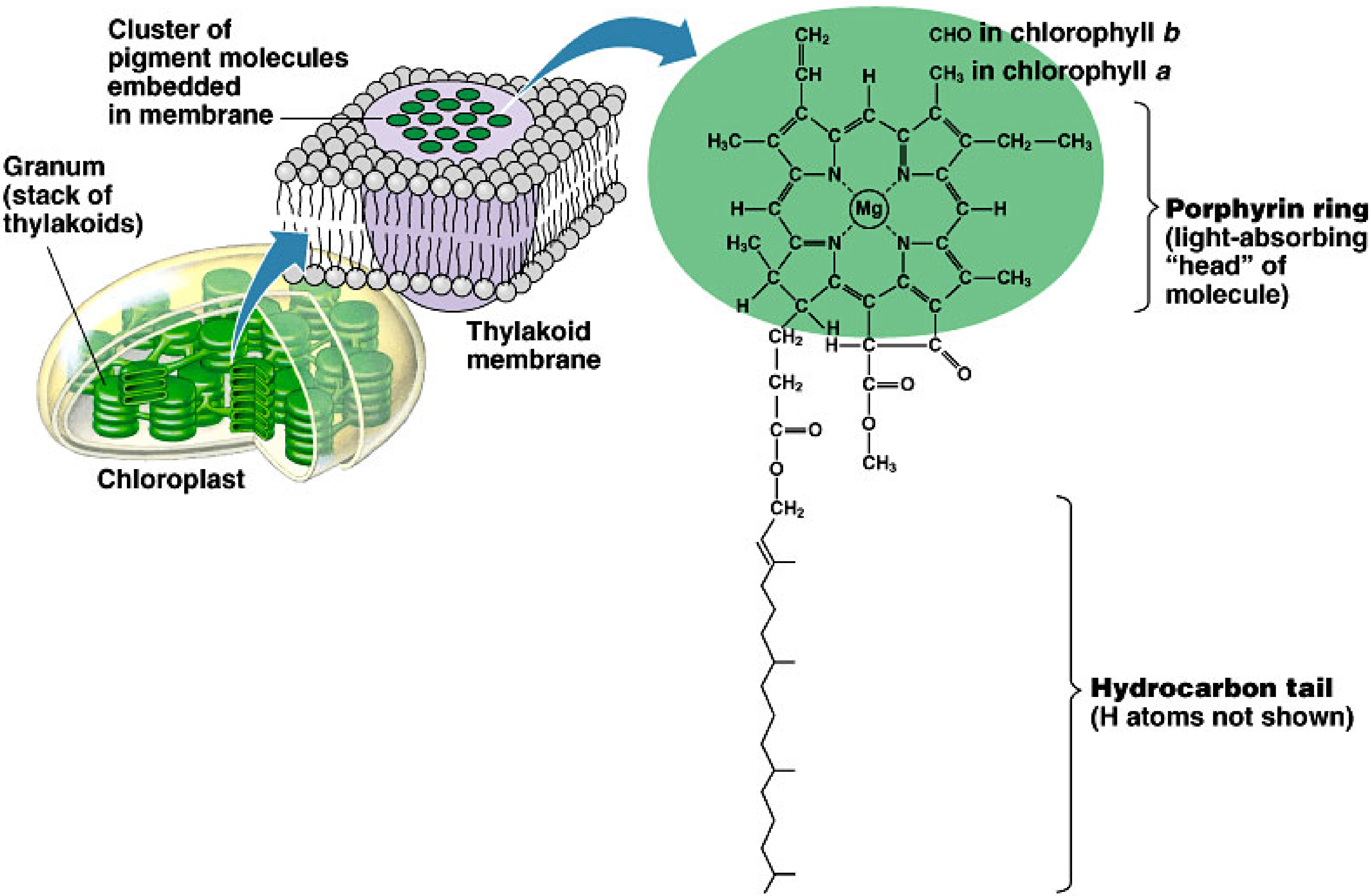
Why leaves are green: interaction of light with chloroplasts

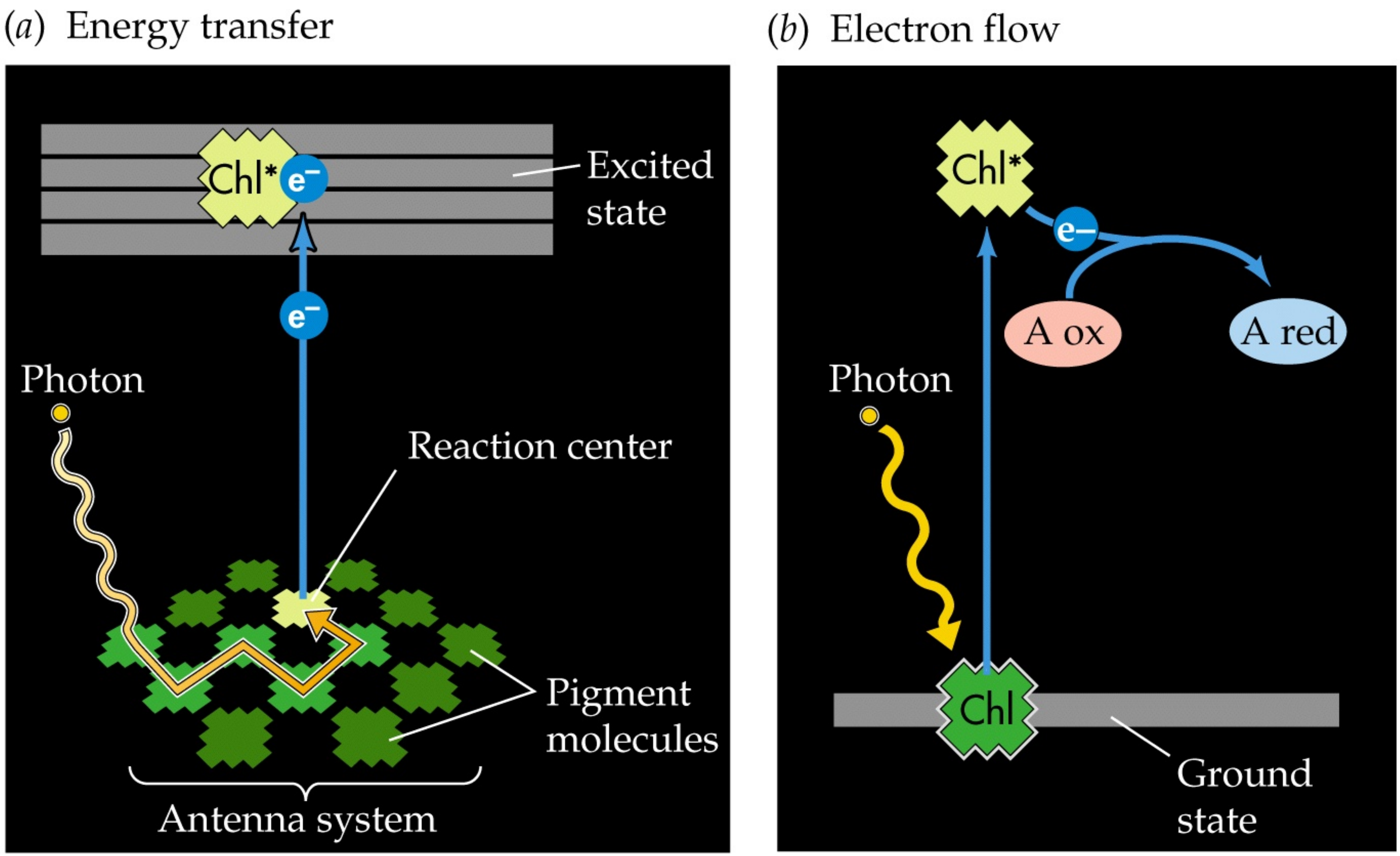


C. Properties of Light and Pigments

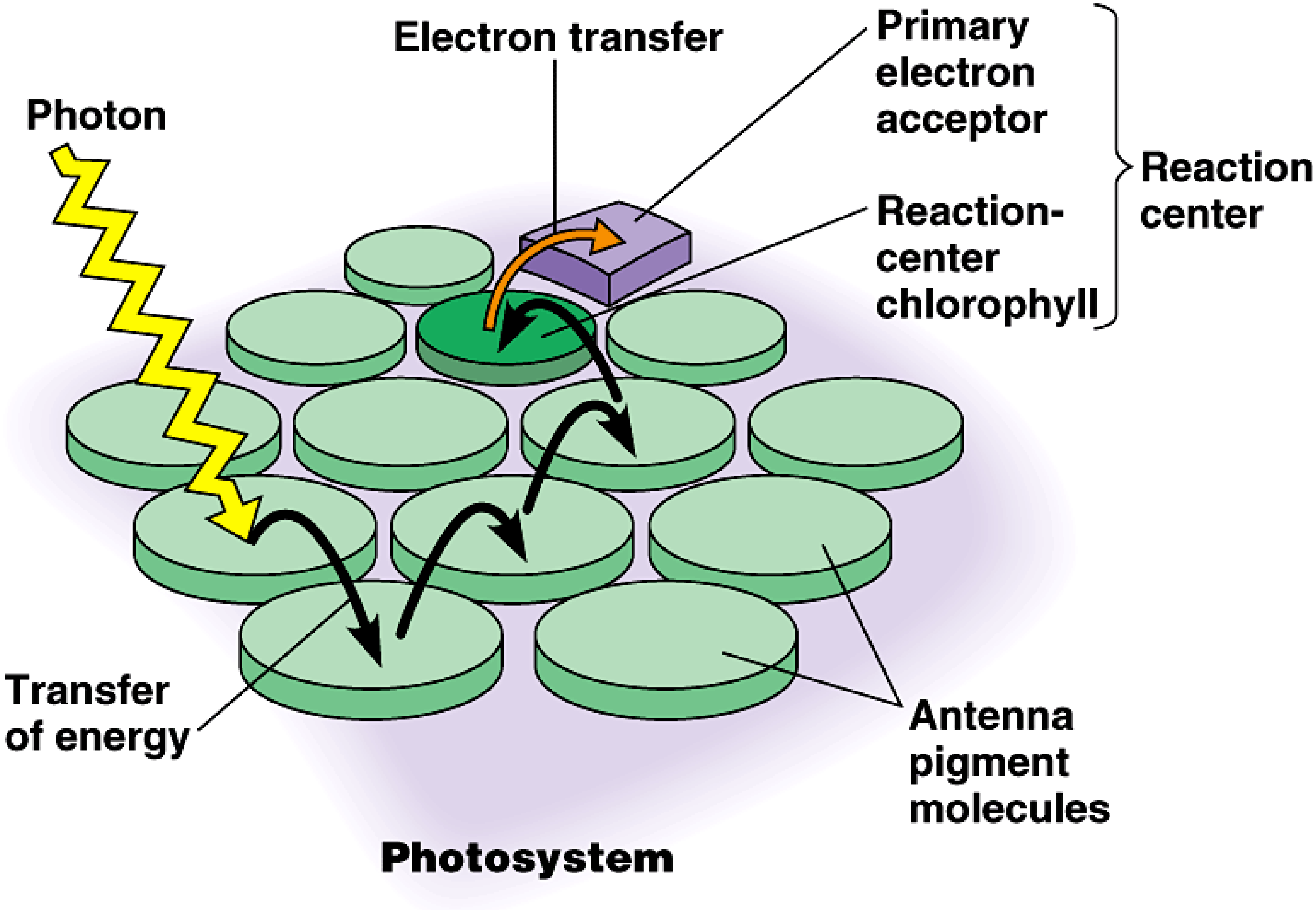
- Chlorophylls and accessory pigments form antenna systems for absorption of light energy.
- An excited pigment molecule may lose its energy by fluorescence, or by transferring it to another pigment molecule.

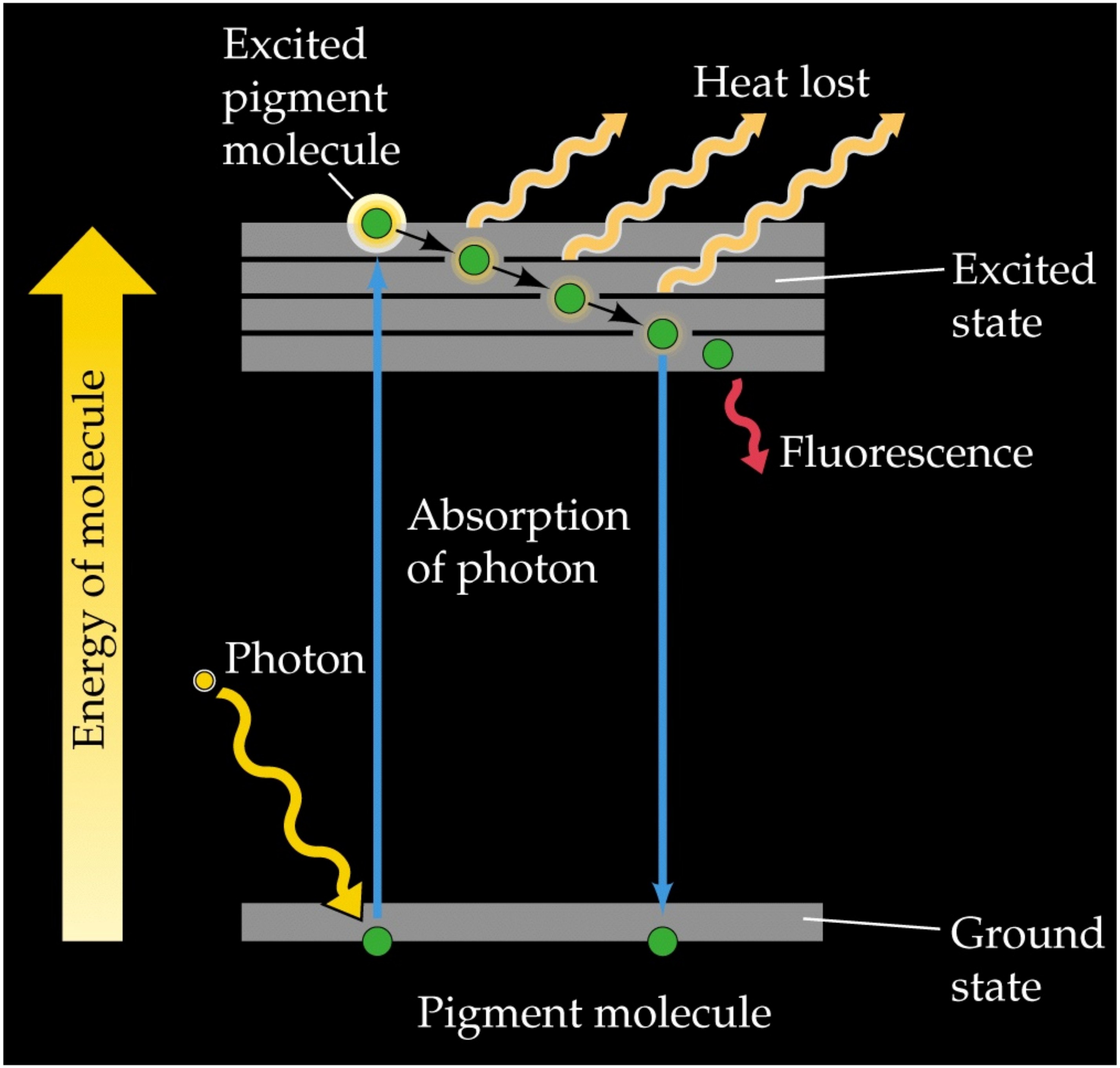
Location and structure of chlorophyll molecules in plants



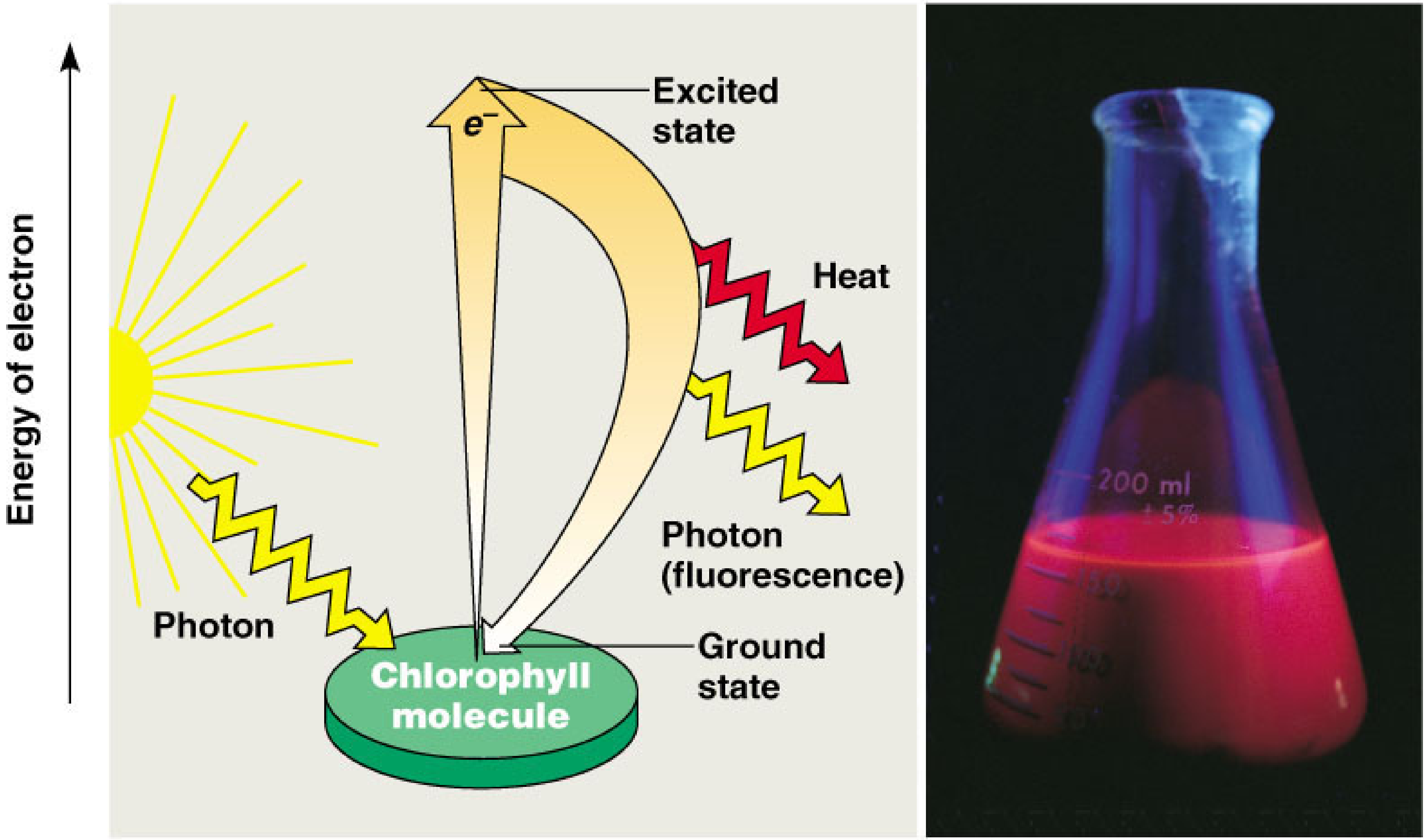

(a) Energy transfer
Chl*
e⁻
Excited state
e⁻
Photon
Reaction center
Pigment molecules
Antenna system
(b) Electron flow
Chl*
e–
A ox
A red
Photon
Chl
Ground state

How a photosystem harvests light




Excited pigment molecule
Heat lost
Excited state
Fluorescence
Absorption of photon
Energy of molecule
Photon
Ground state
Pigment molecule

Excitation of isolated chlorophyll by light



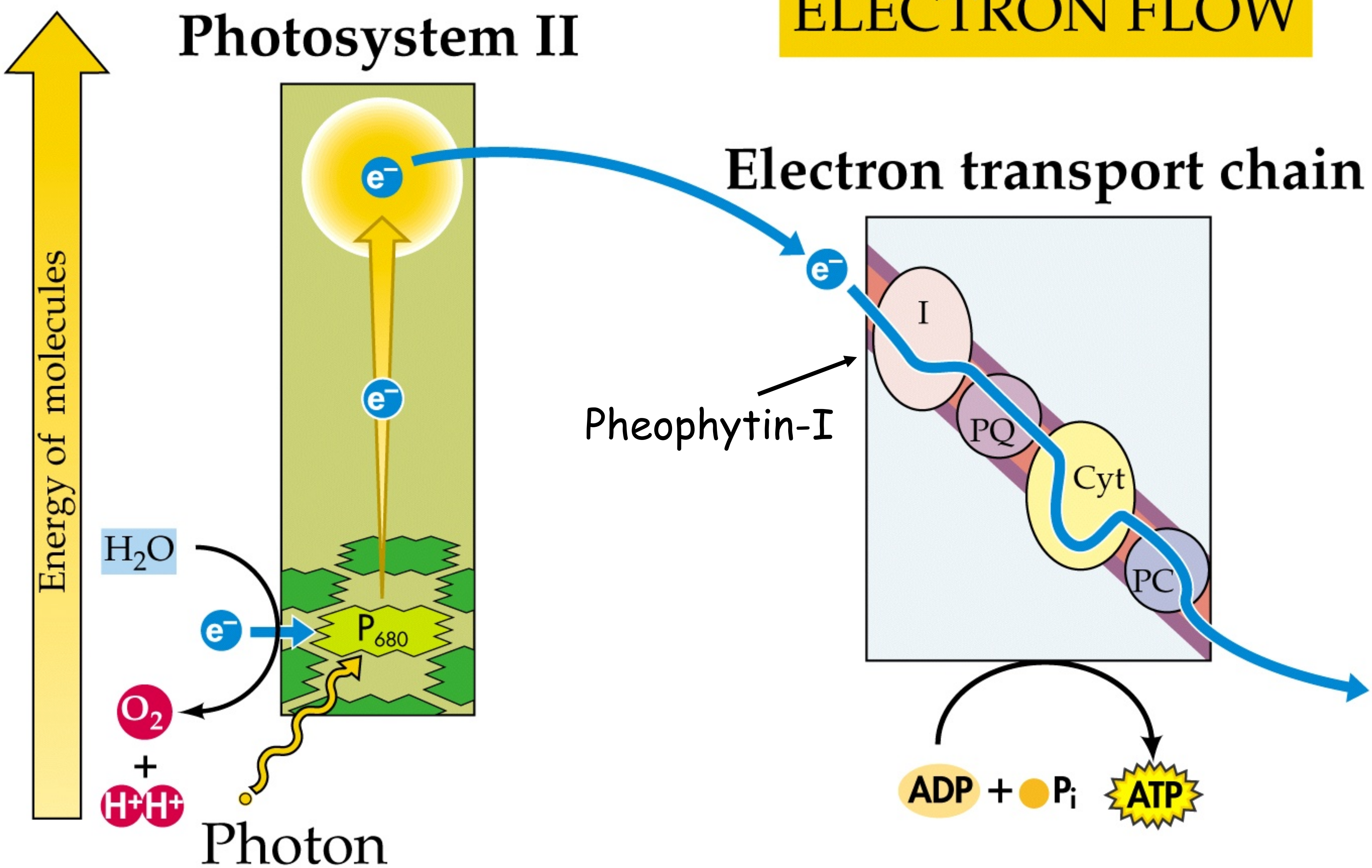
(a) Excitation of isolated chlorophyll molecule

(b) Fluorescence

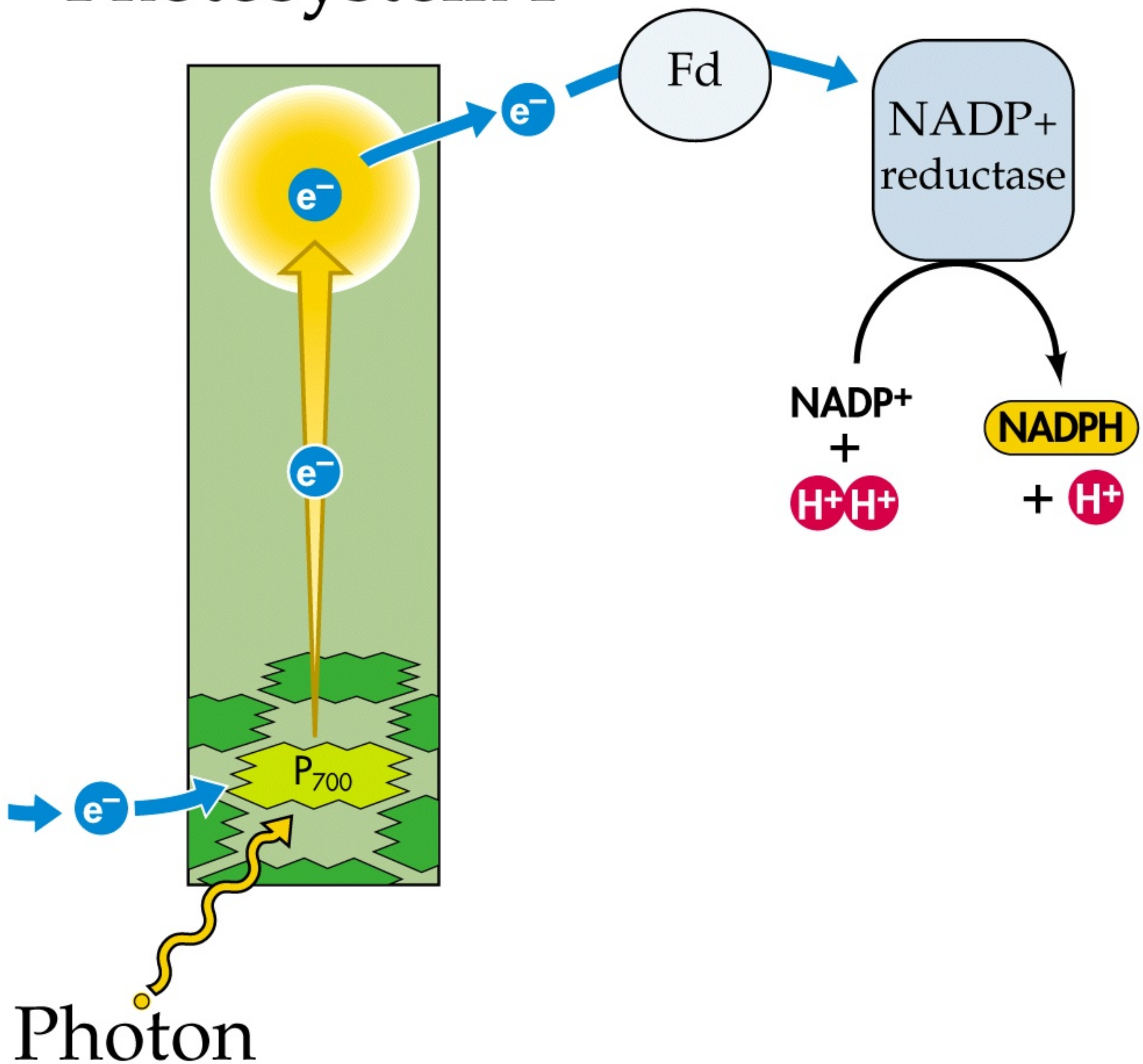
D. Electron Flow, Photophos-phorylation, and Reductions

- 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^+.

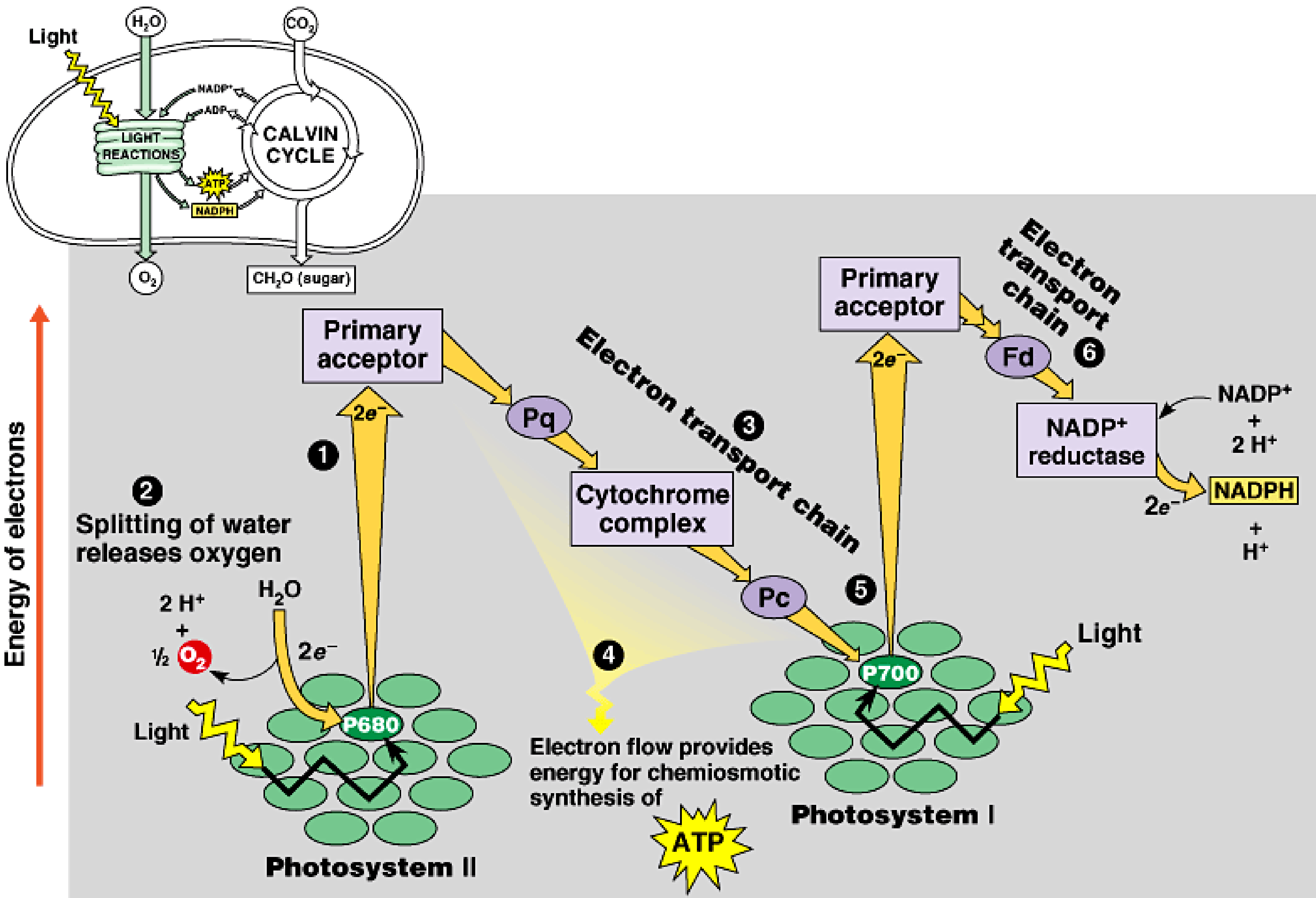
ELECTRON FLOW



Photosystem I

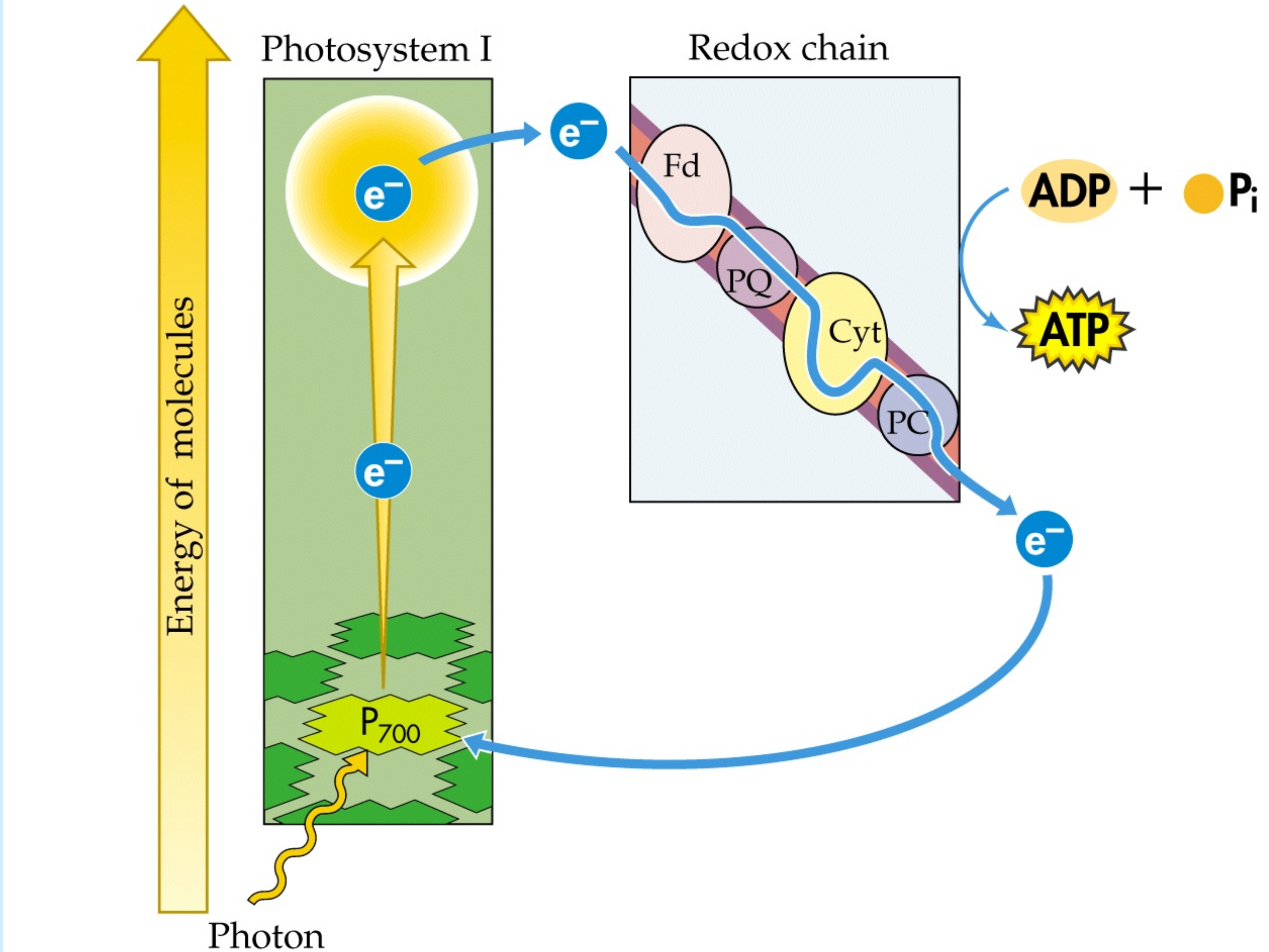


How noncyclic electron flow during the light reactions generates ATP and NADPH

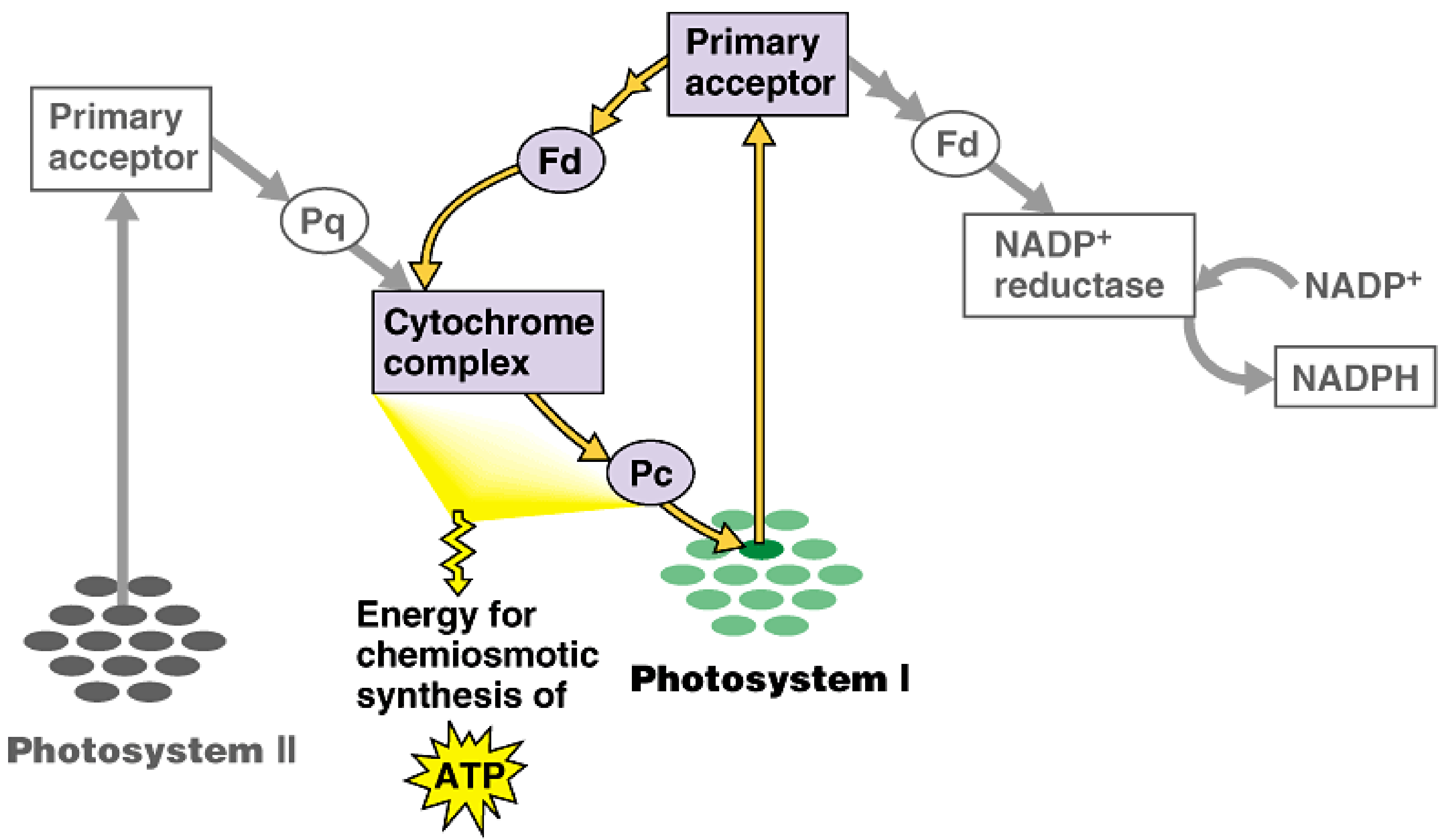


D. Electron Flow, Photophos-phorylation, and Reductions

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

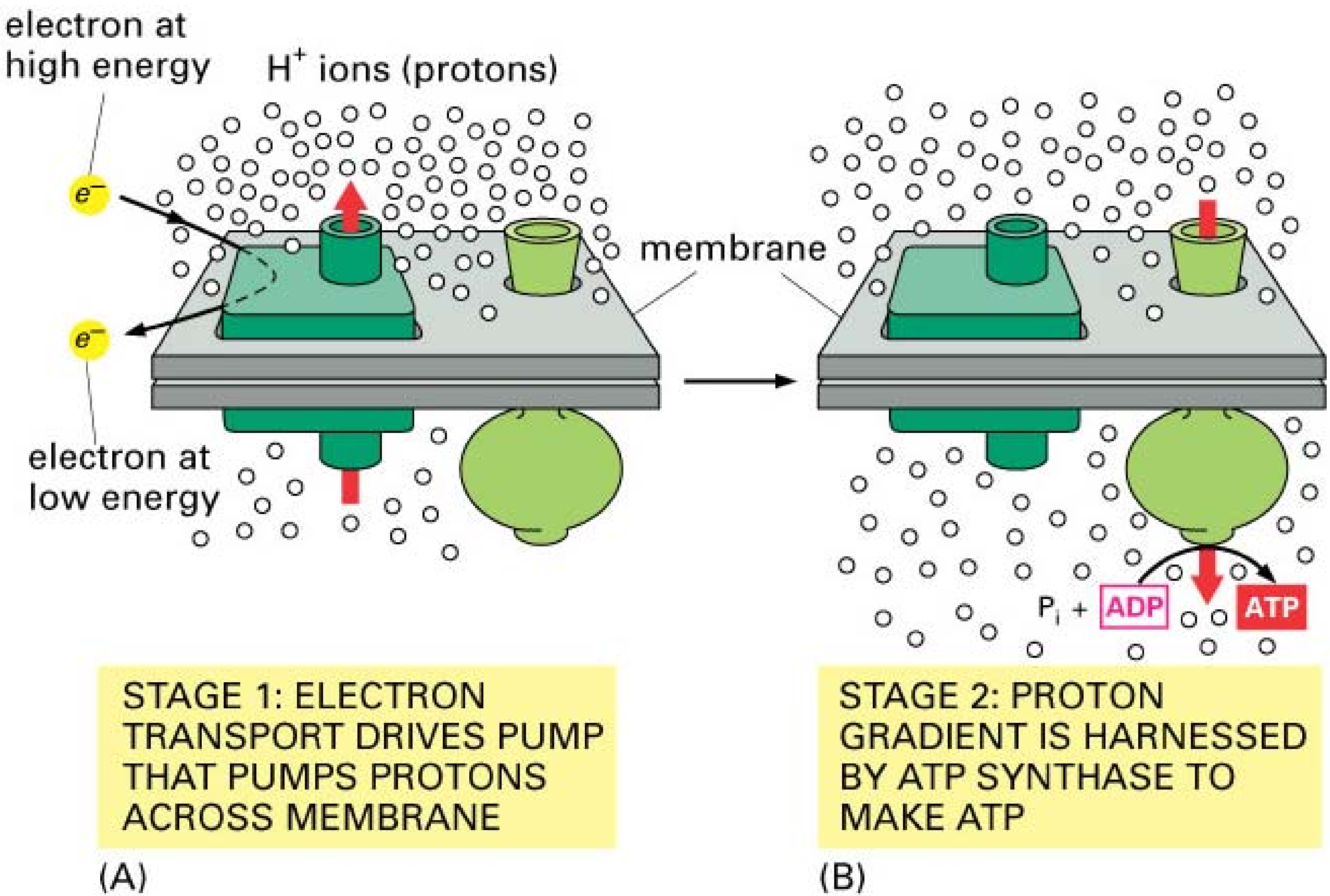

Photosystem I
Redox chain
Energy of molecules
e⁻
Fd
PQ
Cyt
PC
ADP + Pi
ATP
P700
Photon

Cyclic electron flow

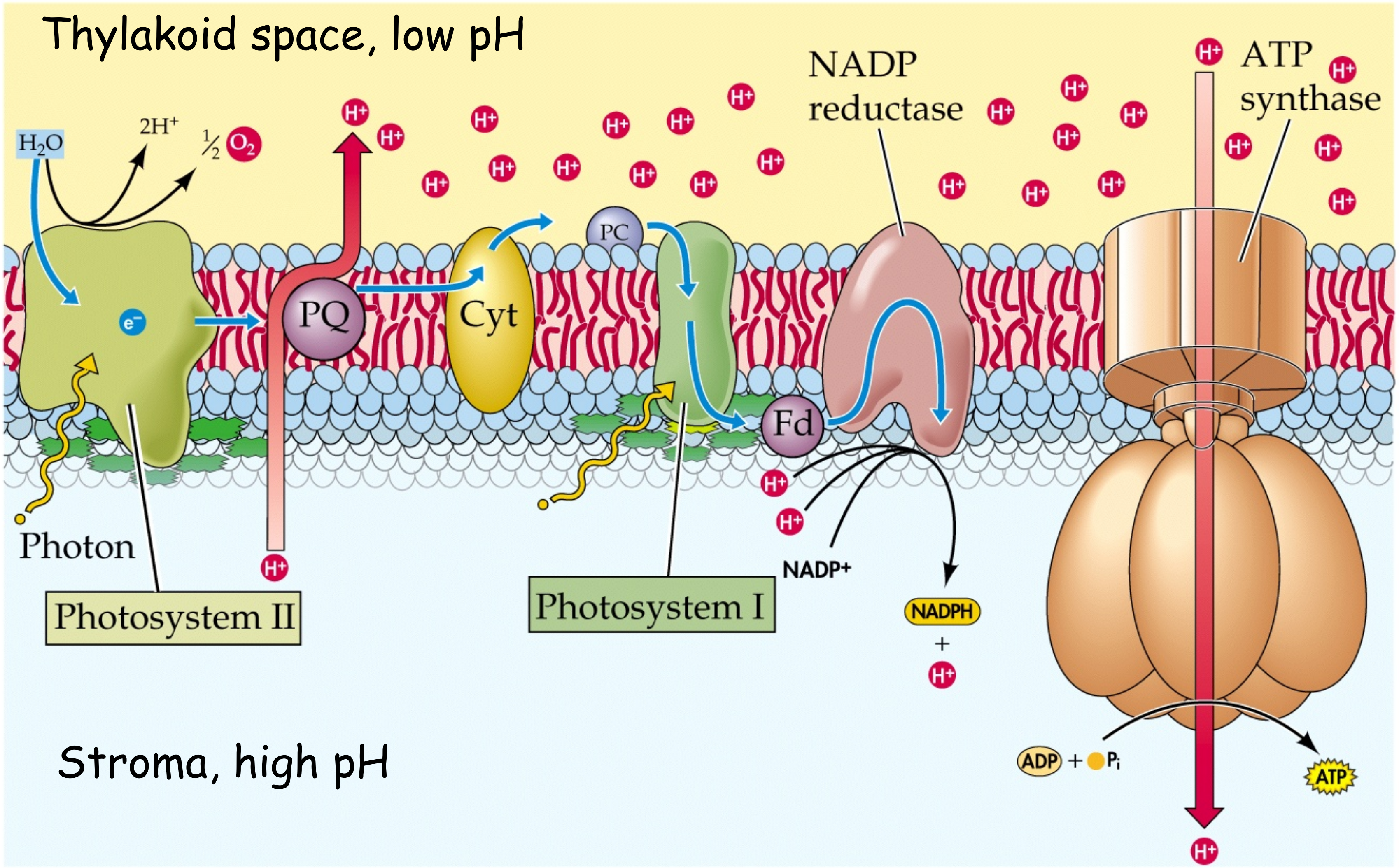


D. Electron Flow, Photophos-phorylation, and Reductions

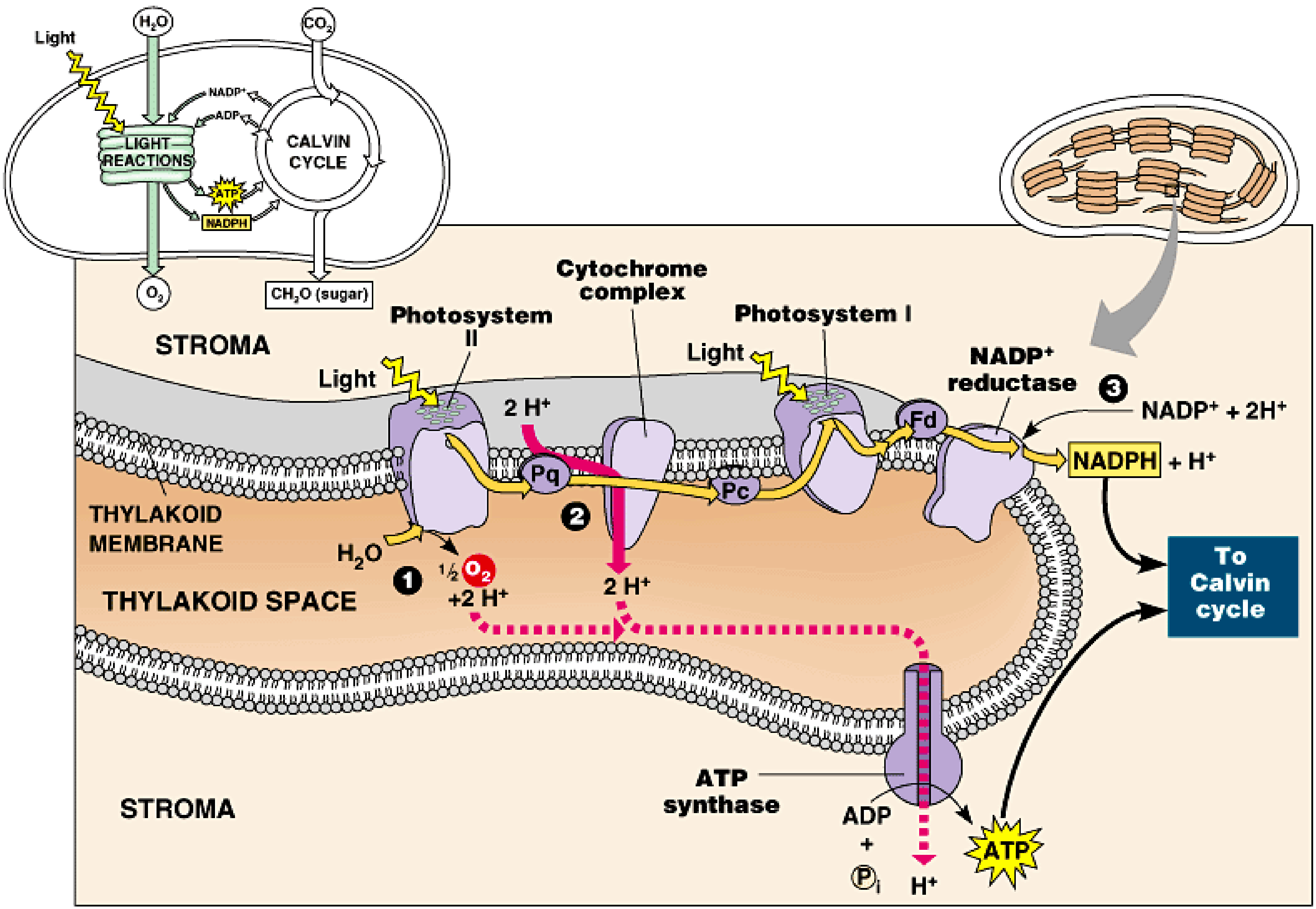
- Chemiosmosis is the source of ATP in photophosphorylation.
- Electron transport pumps protons from stroma into thylakoids, establishing a proton-motive force.
- Proton diffusion to stroma via ATP synthase channels drives ATP formation from ADP and P_i.


electron at
high energy
H+ ions (protons)
e−
e−
membrane
electron at
low energy
Pi + ADP
ATP
STAGE 1: ELECTRON TRANSPORT DRIVES PUMP THAT PUMPS PROTONS ACROSS MEMBRANE
(A)
STAGE 2: PROTON GRADIENT IS HARNESSED BY ATP SYNTHASE TO MAKE ATP
(B)

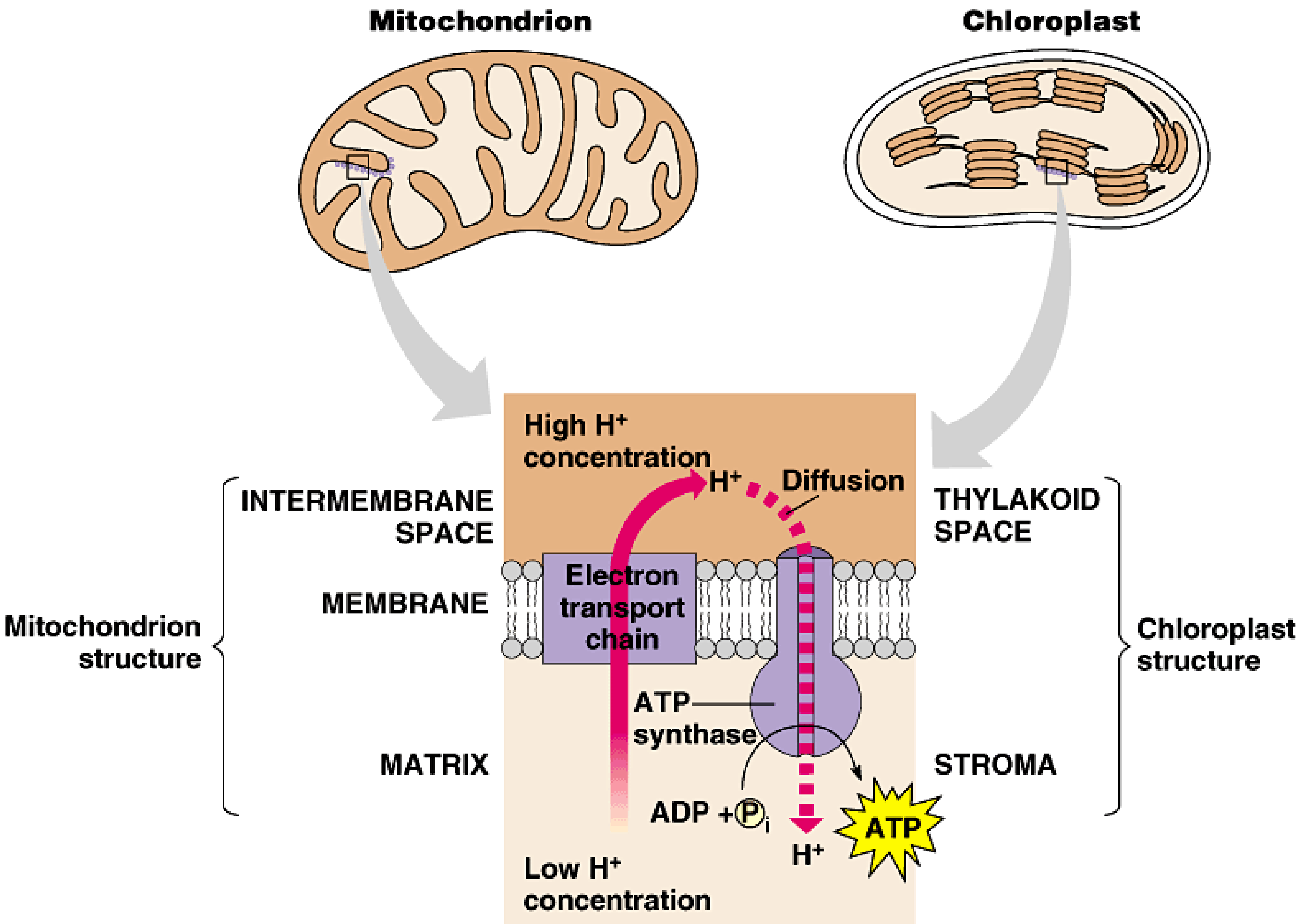
Chloroplast forms ATP Chemiosmotically



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.

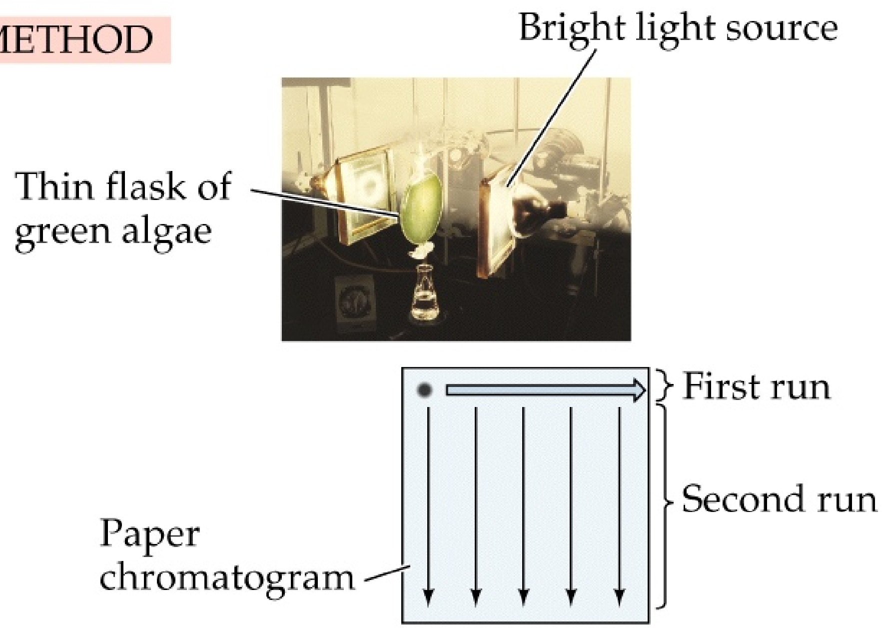
E. Making Sugar from CO_2: The Calvin-Benson Cycle

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

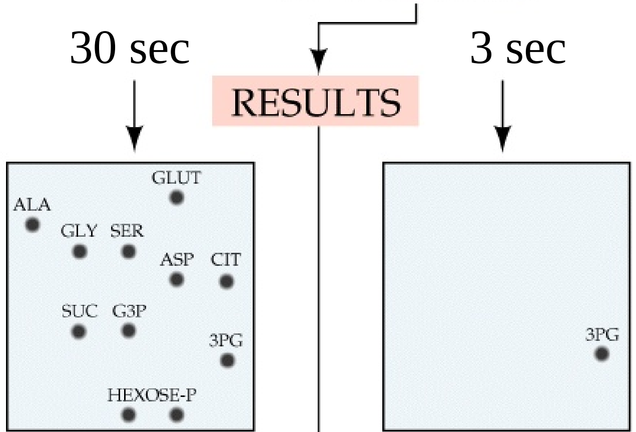
EXPERIMENT

Question: What is the pathway of CO_2 fixation in photosynthesis?

METHOD



RESULTS



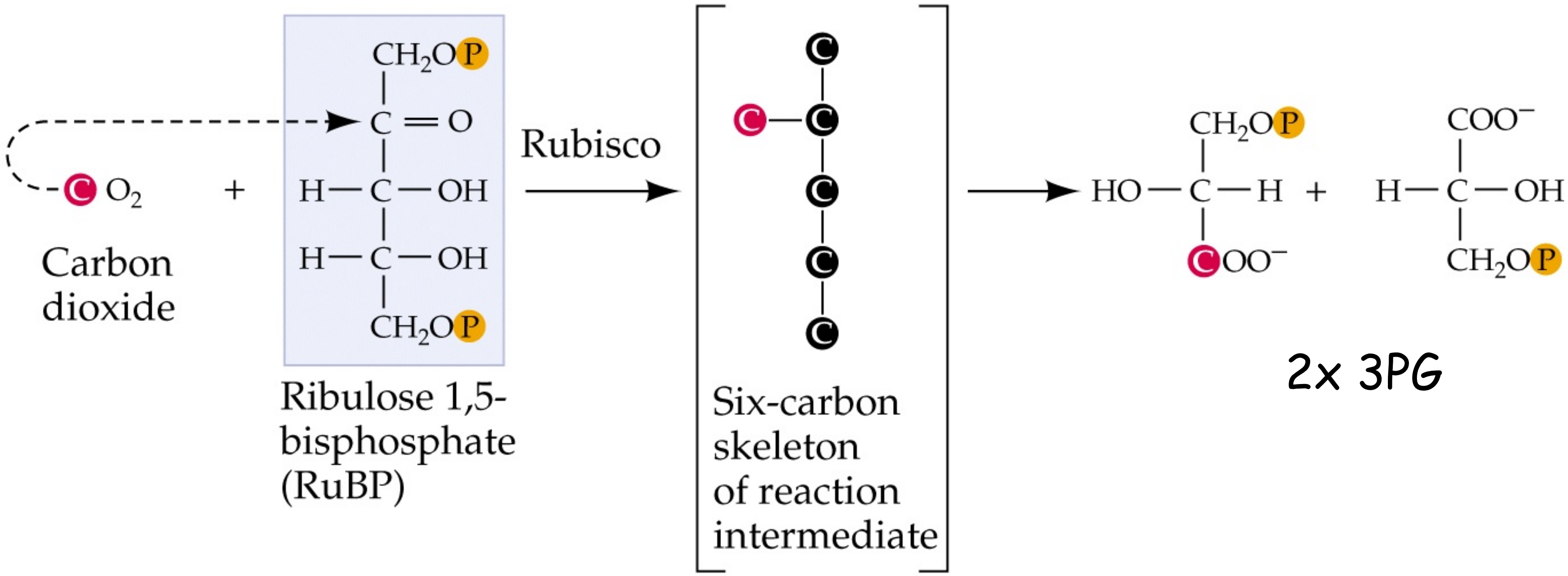
Conclusion: The carbon from CO_2 ends up in many molecules.

Conclusion: The initial product of CO_2 fixation is 3PG.

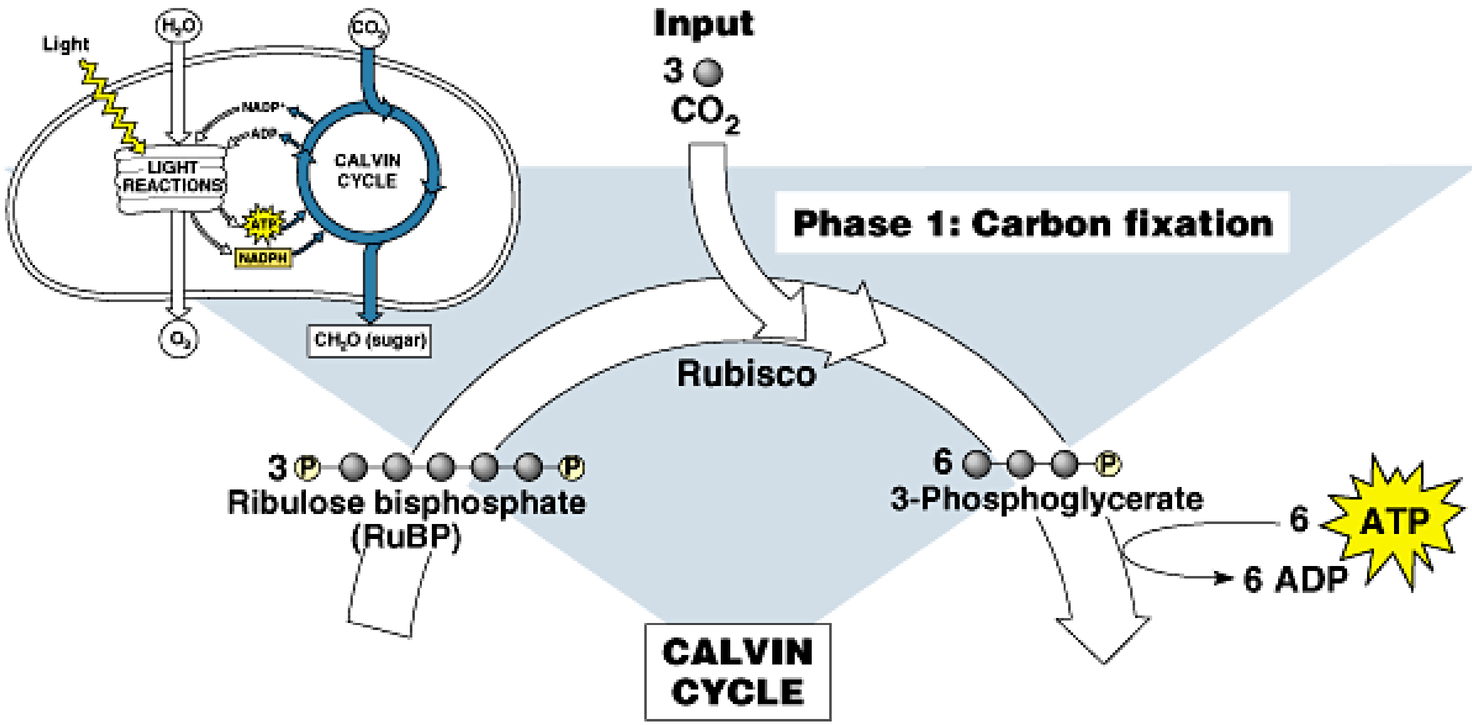
E. Making Sugar from CO_2: The Calvin-Benson Cycle

- 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.

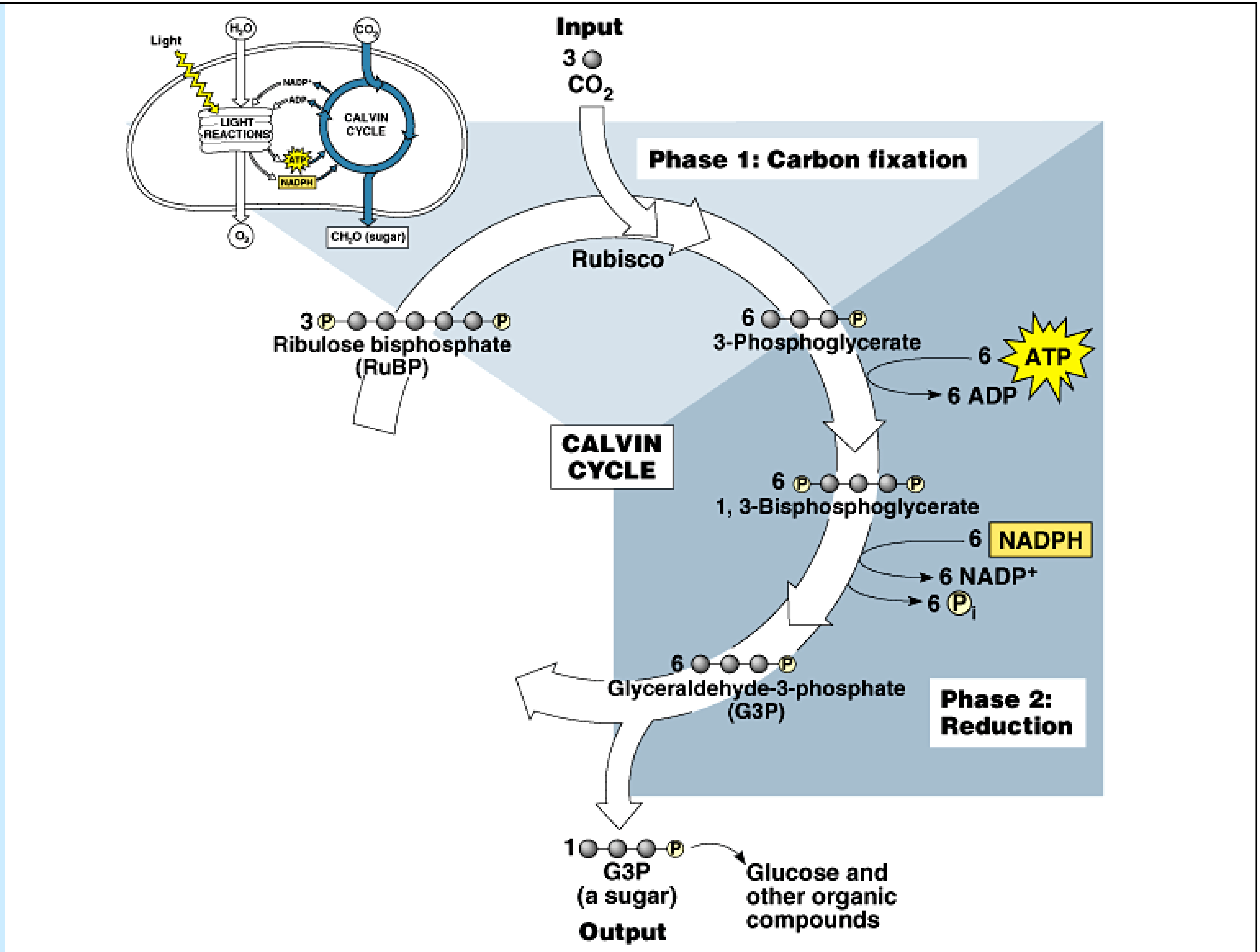
RuBP is the CO_2 Acceptor

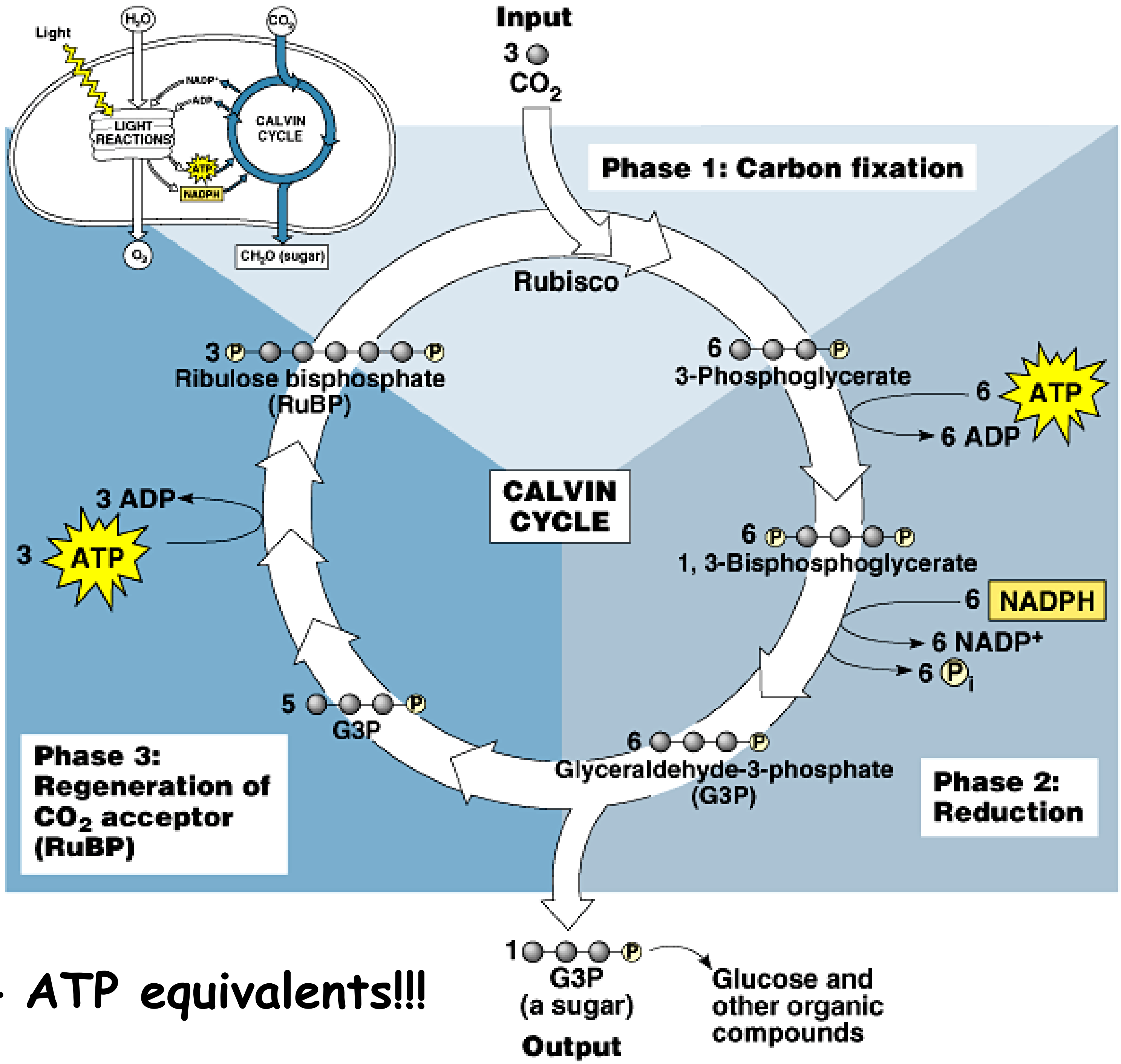


2x 3PG



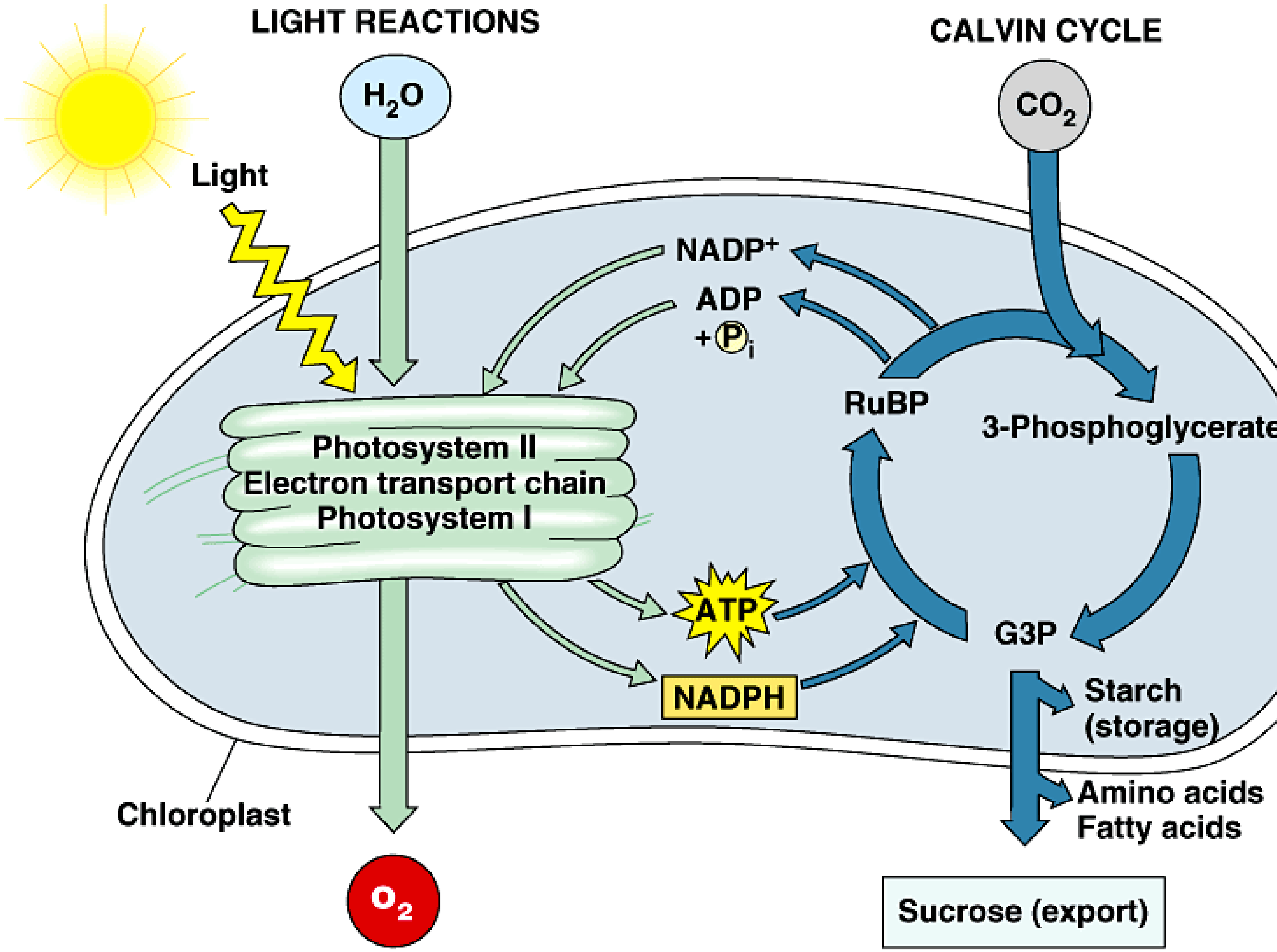
Light
H_2O
CO_2
LIGHT REACTIONS
CALVIN CYCLE
NADPH
O_2
CH_2O (sugar)
Input
3
CO_2
Phase 1: Carbon fixation
Rubisco
3
Ribulose bisphosphate (RuBP)
6
3-Phosphoglycerate
6 ATP
6 ADP
CALVIN CYCLE


Light
H_2O
CO_2
$NADP^+$
ADP
LIGHT REACTIONS
CALVIN CYCLE
ATP
NADPH
O_2
CH_2O (sugar)
Input
3
CO_2
Phase 1: Carbon fixation
Rubisco
3 P P
Ribulose bisphosphate (RuBP)
6 P
3-Phosphoglycerate
6 ATP
6 ADP
CALVIN CYCLE
6 P P
1, 3-Bisphosphoglycerate
6 NADPH
6 $NADP^+$
6 P_i
6 P
Glyceraldehyde-3-phosphate (G3P)
Phase 2: Reduction
1 P
G3P (a sugar)
Output
Glucose and other organic compounds



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 that of CO_2 and RuBP.
- Photorespiration byproducts are processed by chloroplasts, peroxisomes, and mitochondria.
- Photorespiration significantly reduces photosynthesis efficiency.
- Higher temperatures and dryer climates increase the effects of photorespiration.