Chapter 8 Photosynthesis


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You need to know:

- The summary equation of photosynthesis, including the source and fate of the reactants and products.
- How leaf and chloroplast anatomy relate to photosynthesis.
- How photosystems convert solar energy to chemical energy.
- How linear electron flow in light reactions results in the formation of ATP, NADPH, and O_2.
- How the formation of a proton gradient in light reactions is used to form ATP from ADP plus inorganic phosphate by ATP synthase.
- How the Calvin cycle uses energy molecules of the light reactions (ATP and NADPH) to produce carbohydrates (G3P) from CO_2.

Photosynthesis in Nature

- Plants and other autotrophs are producers of biosphere
- Photoautotrophs: use light E to make organic molecules
- Heterotrophs: consume organic molecules from other organisms for E and carbon

Photoautotrophs

(a) Plants

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(b) Multicellular alga

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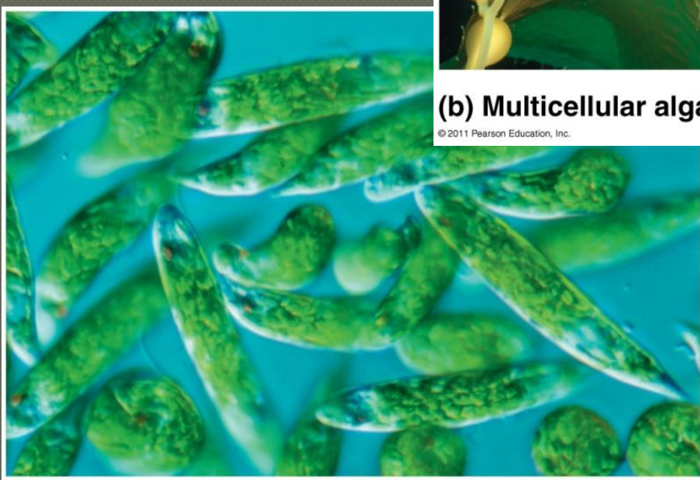

(c) Unicellular protists 10 μm

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(d) Cyanobacteria 40 μm

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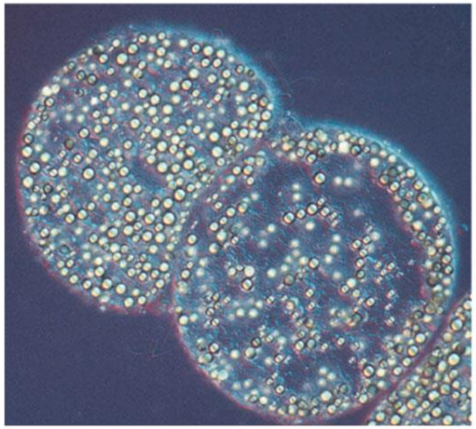

(e) Purple sulfur bacteria 1 μm

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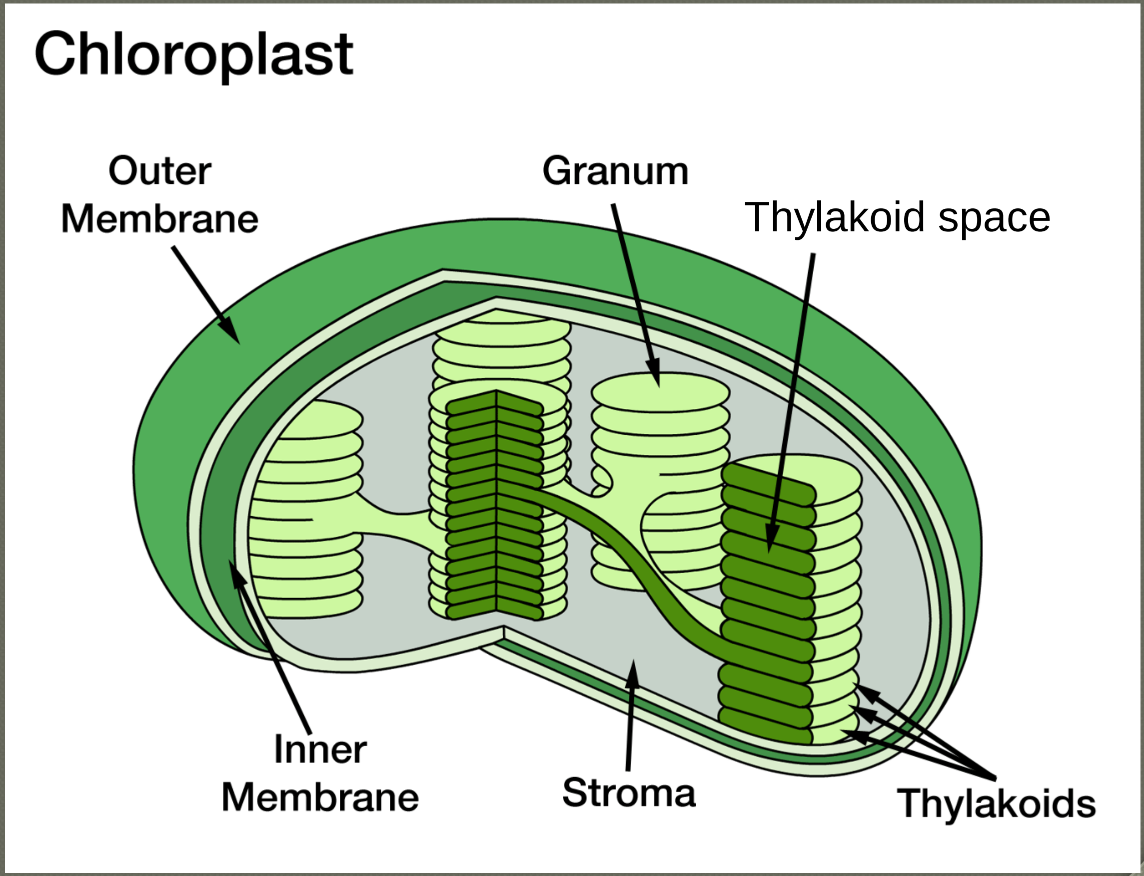
Photosynthesis: Converts light energy to chemical energy of food

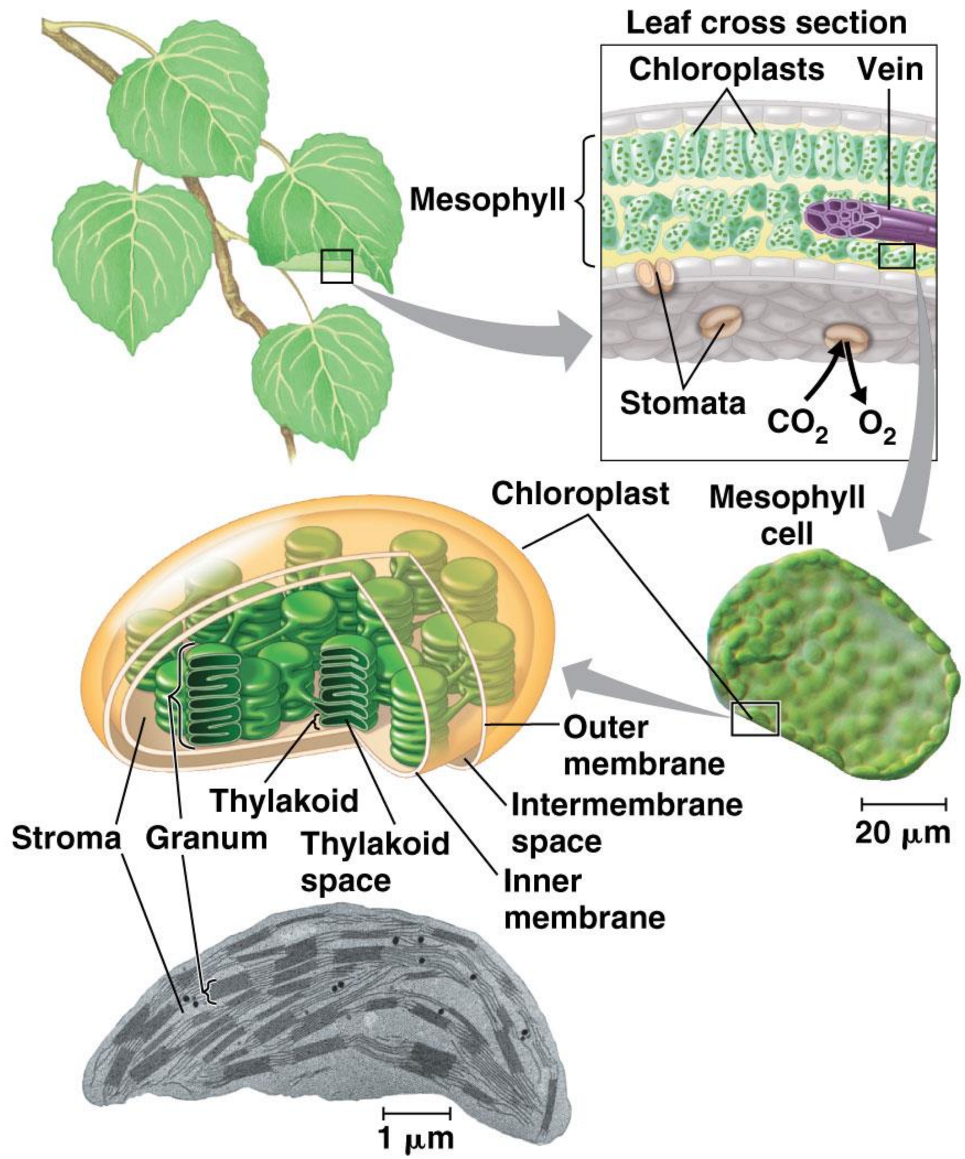
- Chloroplasts: sites of photosynthesis in plants




the chloroplast
genomics digital lab

Sites of Photosynthesis

- **mesophyll**: chloroplasts mainly found in these cells of leaf
- **stomata**: pores in leaf (CO_2 enter/O_2 exits)
- **chlorophyll**: green pigment in thylakoid membranes of chloroplasts



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Photosynthesis

$6CO_2 + 6H_2O$ + Light Energy → $C_6H_{12}O_6 + 6O_2$

Redox Reaction:

water is split → e^- transferred with H^+ to CO_2 → sugar

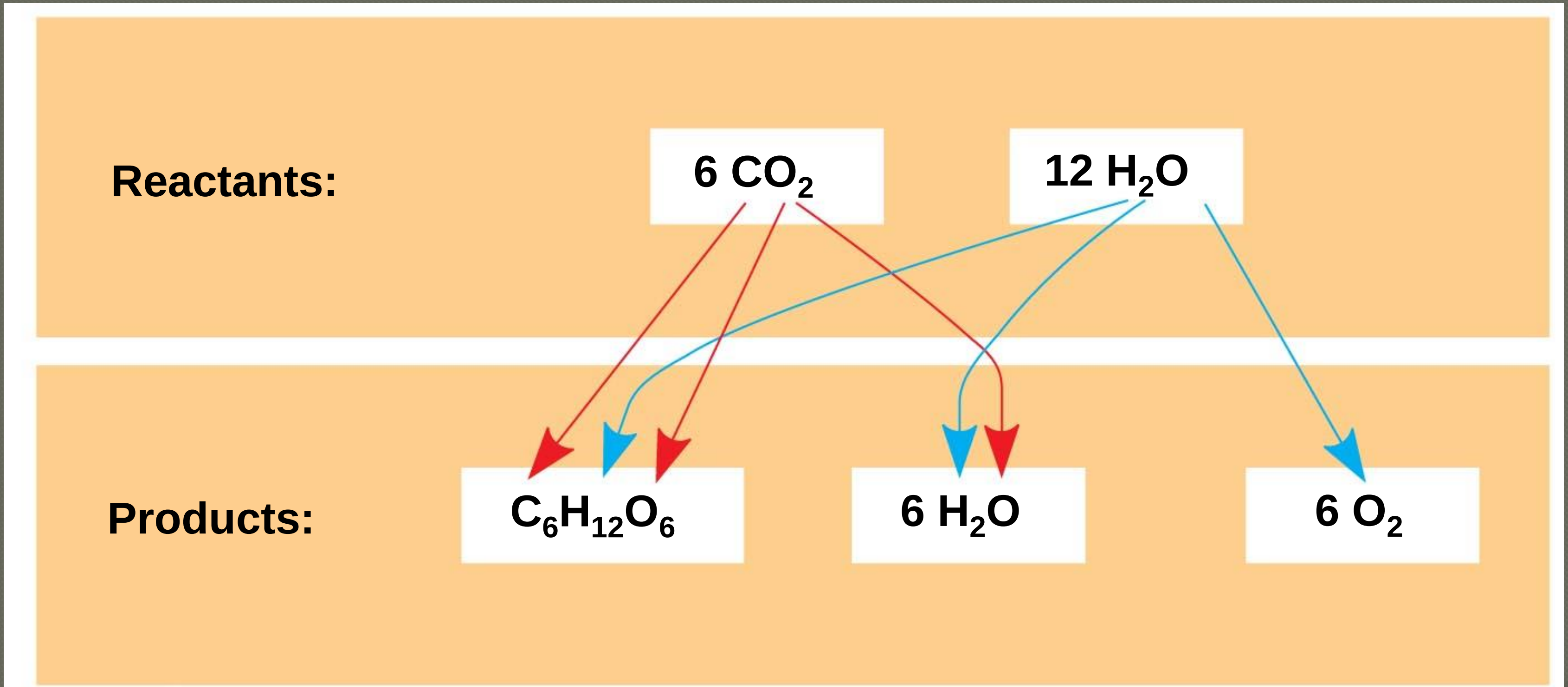
Remember: OILRIG

Oxidation: lose e^-

Reduction: gain e^-

Tracking atoms through photosynthesis

- Evidence that chloroplasts split water molecules enabled researchers to track atoms through photosynthesis (C.B. van Niel)



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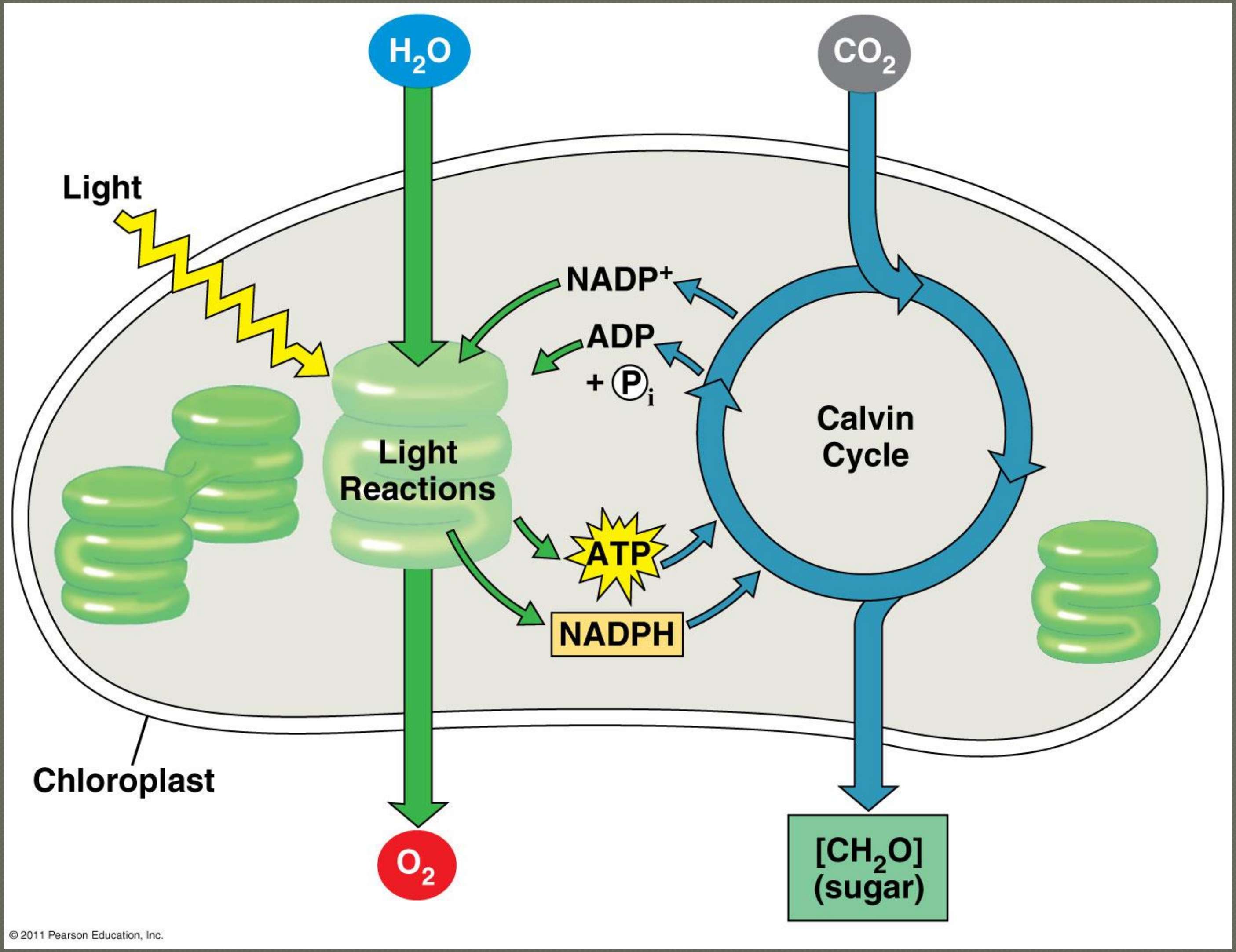
Photosynthesis = Light Reactions + Calvin Cycle

"photo" *"synthesis"*

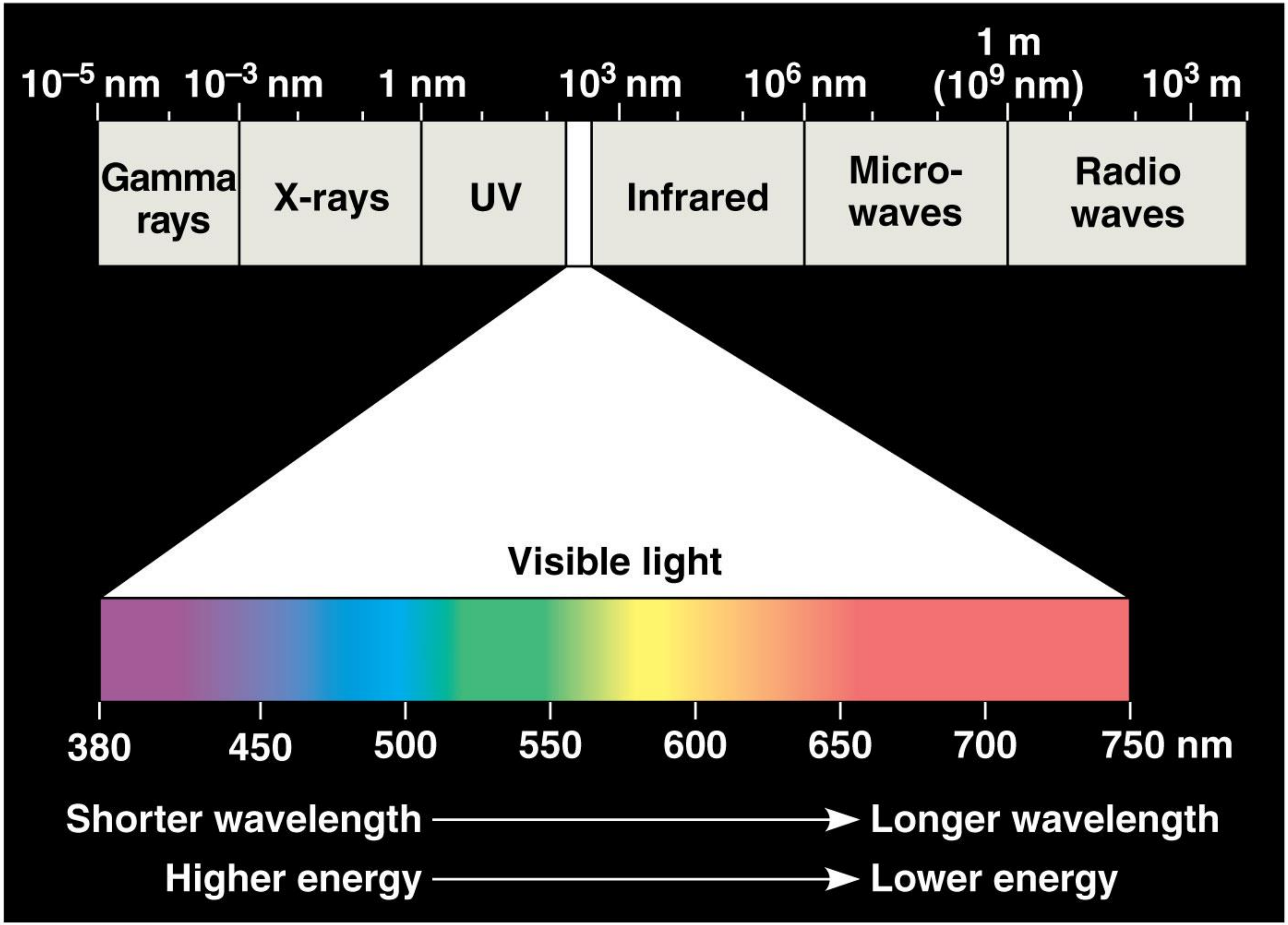


<u>Light Reactions</u>: Convert solar E to chemical E of ATP and NADPH

<u>Nature of sunlight</u>

- Light = Energy = electromagnetic radiation
- Shorter wavelength (λ): higher E
- Visible light - detected by human eye
- Light: reflected, transmitted or absorbed

Electromagnetic Spectrum



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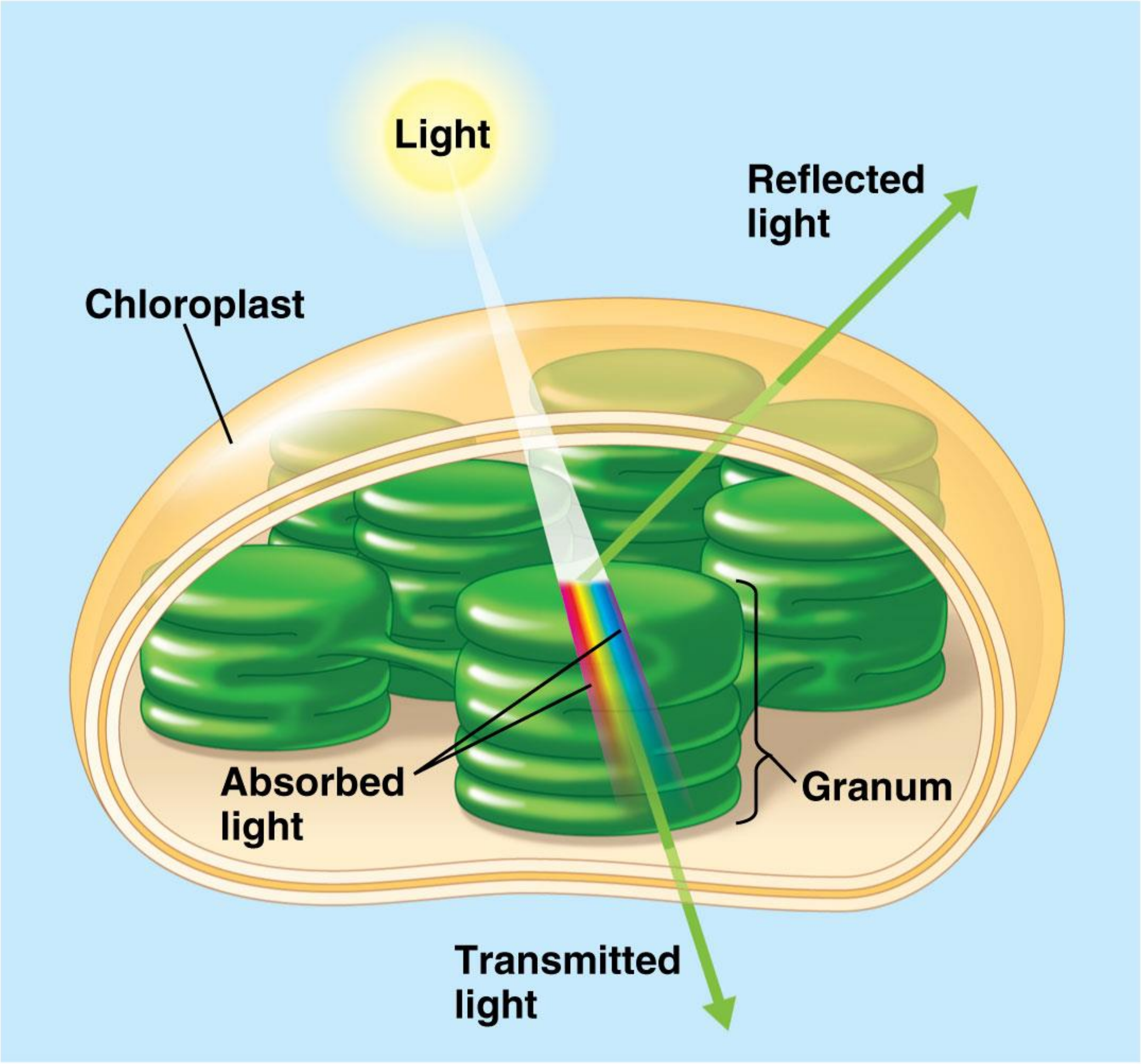
Interaction of light with chloroplasts



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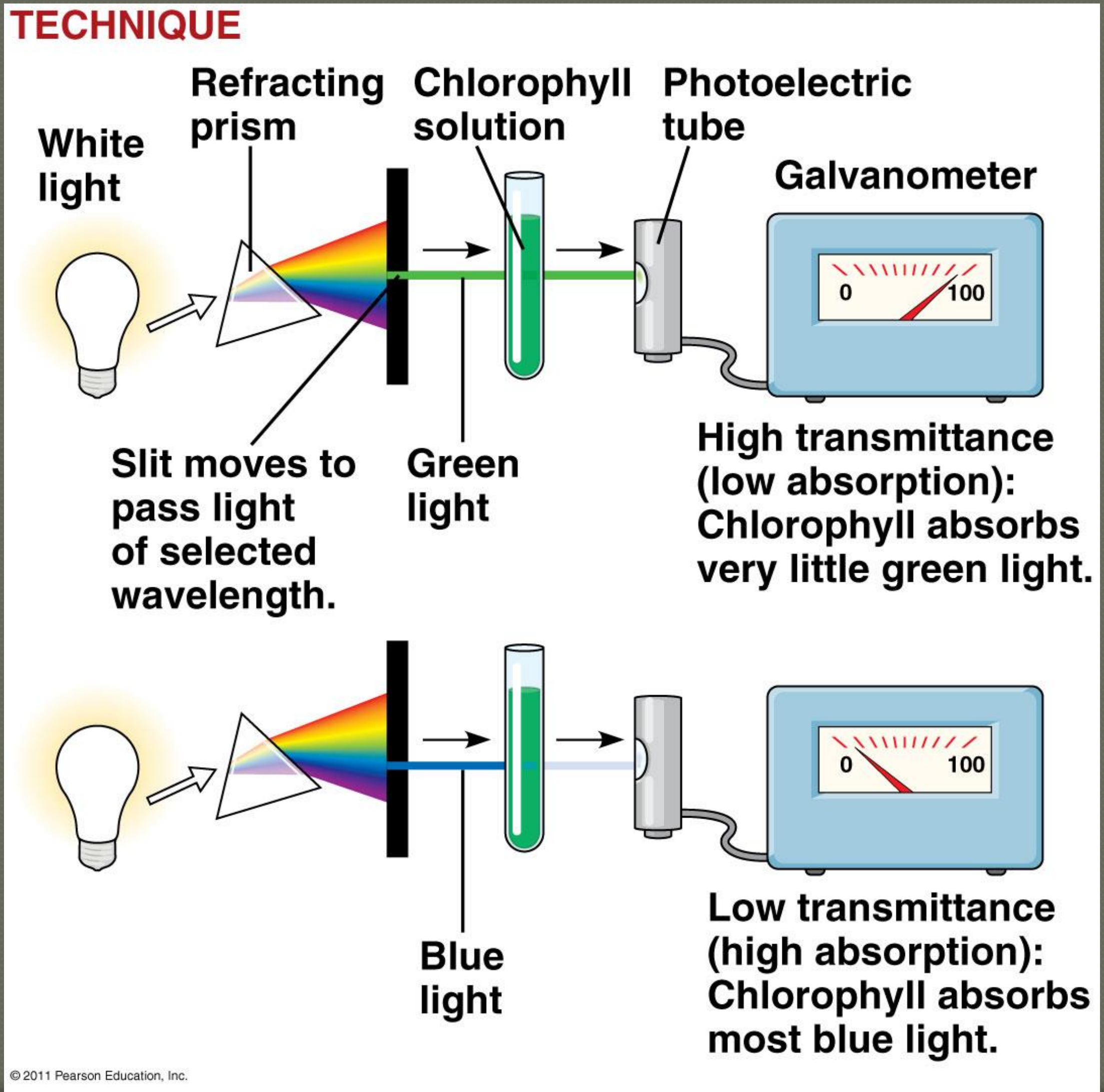
Photosynthetic pigments

- Pigments absorb different λ of light
- chlorophyll – absorb violet-blue/red light, reflect green
  - **chlorophyll a** (blue-green): light reaction, converts solar to chemical E
  - **chlorophyll b** (yellow-green): conveys E to chlorophyll a
  - **carotenoids** (yellow, orange): photoprotection, broaden color spectrum for photosynthesis

Absorption Spectrum: determines effectiveness of different wavelengths for photosynthesis



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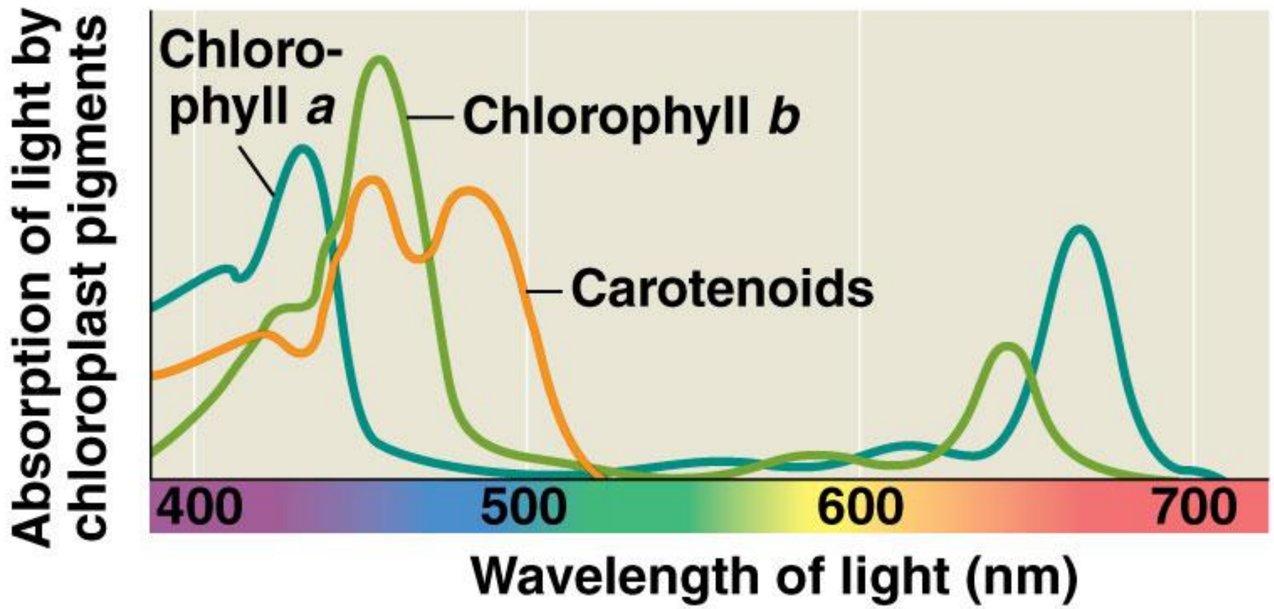


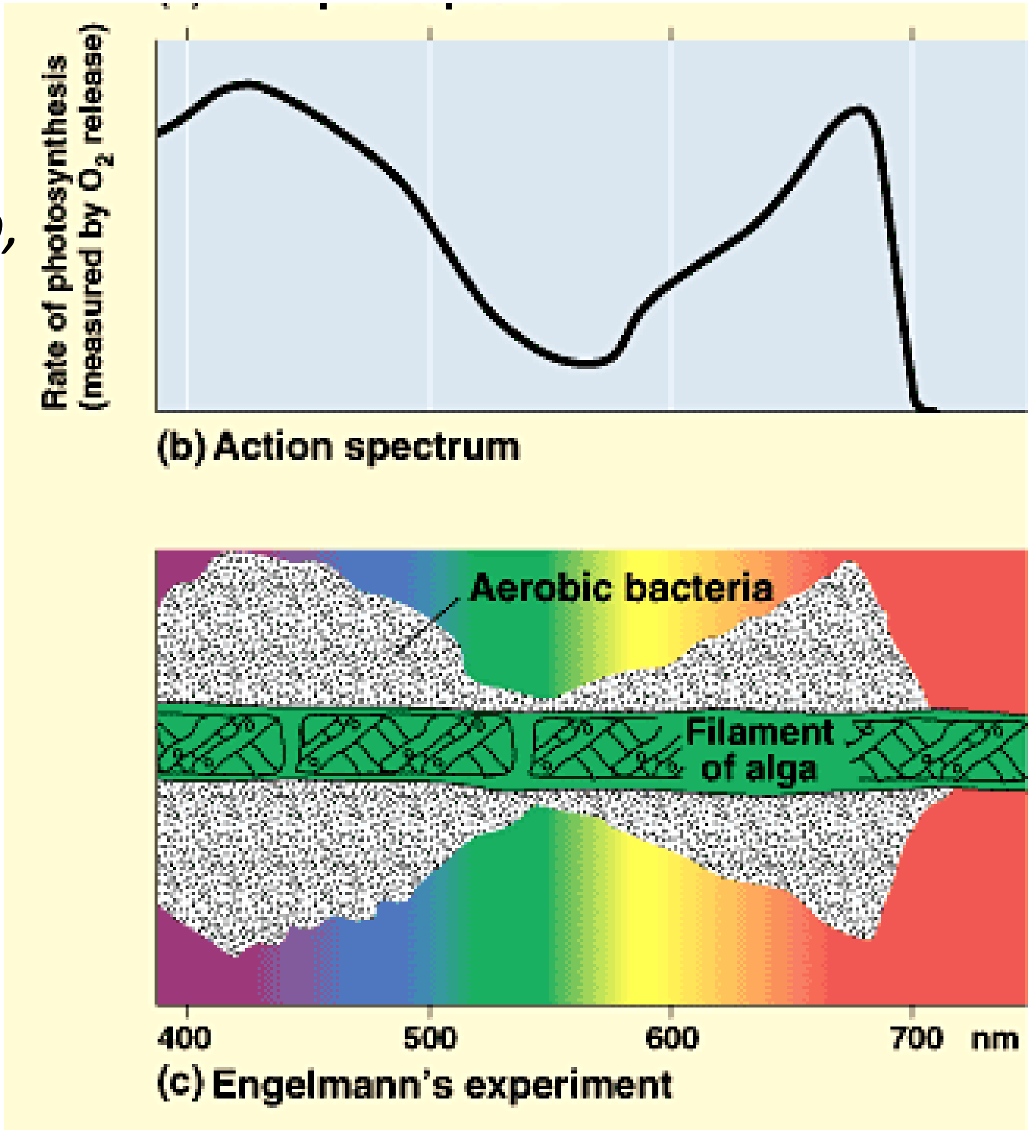
(a) Absorption spectra

<u>Action Spectrum</u>: plots rate of photosynthesis vs. wavelength

(absorption of chlorophylls a, b, & carotenoids combined)

Engelmann: used bacteria to measure rate of photosynthesis in algae; established action spectrum

Which wavelengths of light are most effective in driving photosynthesis?



(b) Action spectrum

(c) Engelmann's experiment

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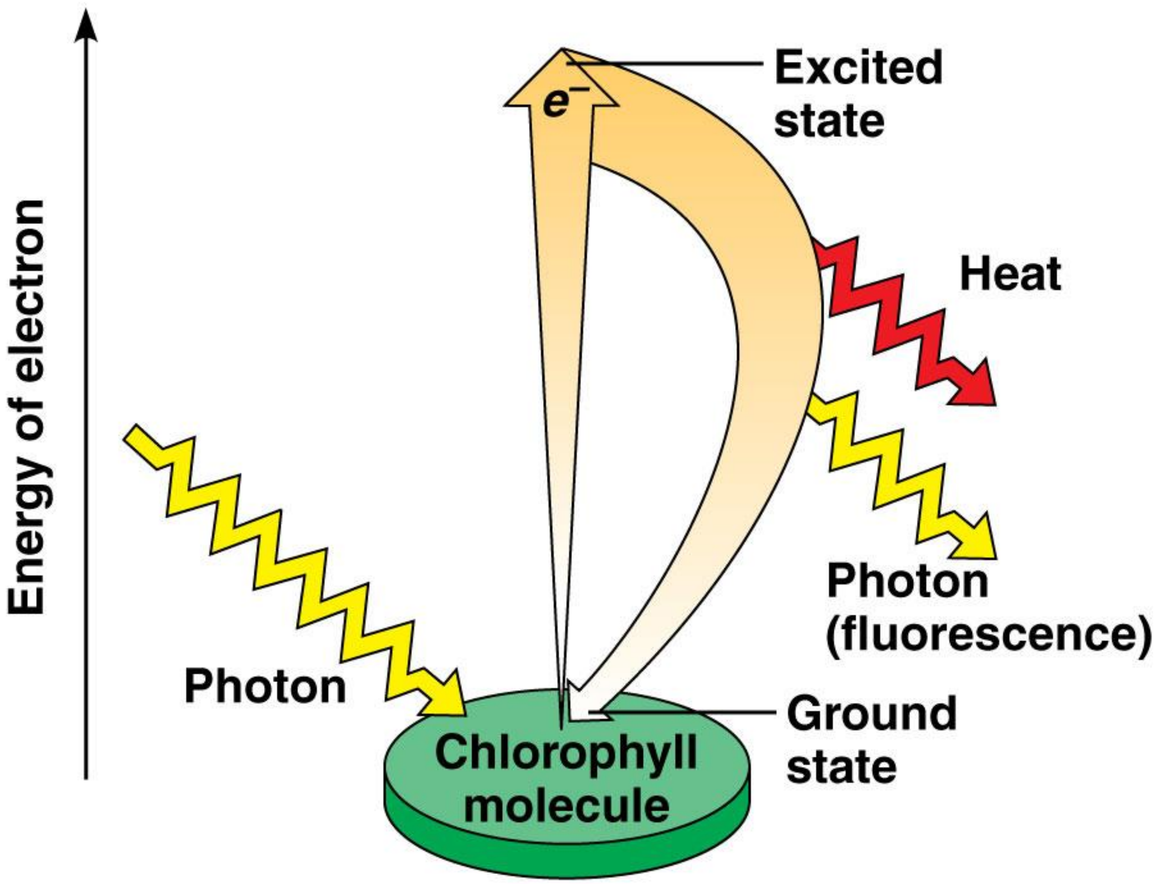
Warm-Up

(Refer to notes / Campbell)

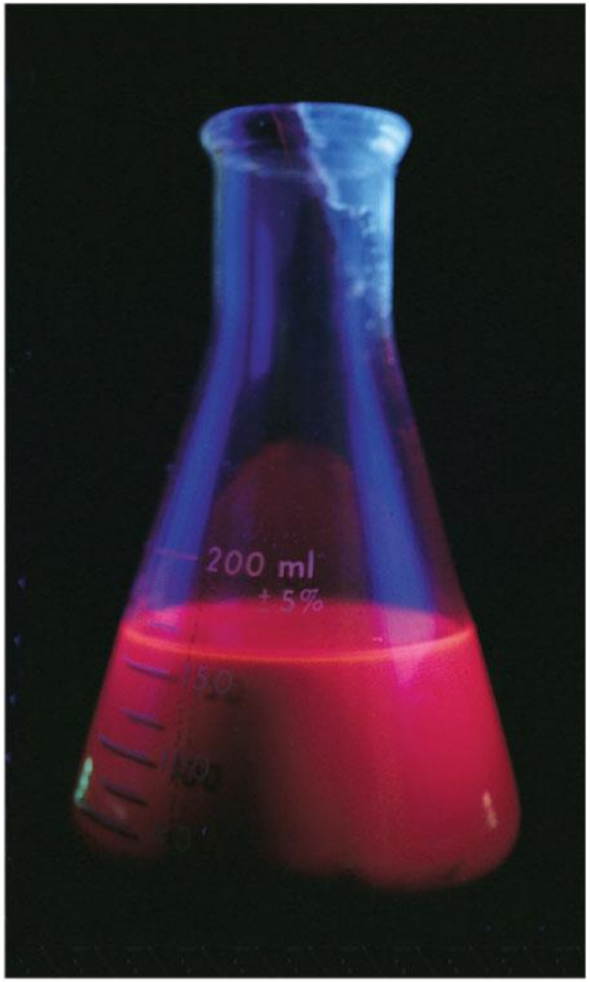
1. What is the main function of the Light Reactions?
2. What are the reactants of the Light Reactions? What are the products?
3. Where does the Light Reactions occur?
4. What were the main pigments present in the leaves tested in class yesterday?

Light Reactions

Electrons in chlorophyll molecules are excited by absorption of light



(a) Excitation of isolated chlorophyll molecule



(b) Fluorescence

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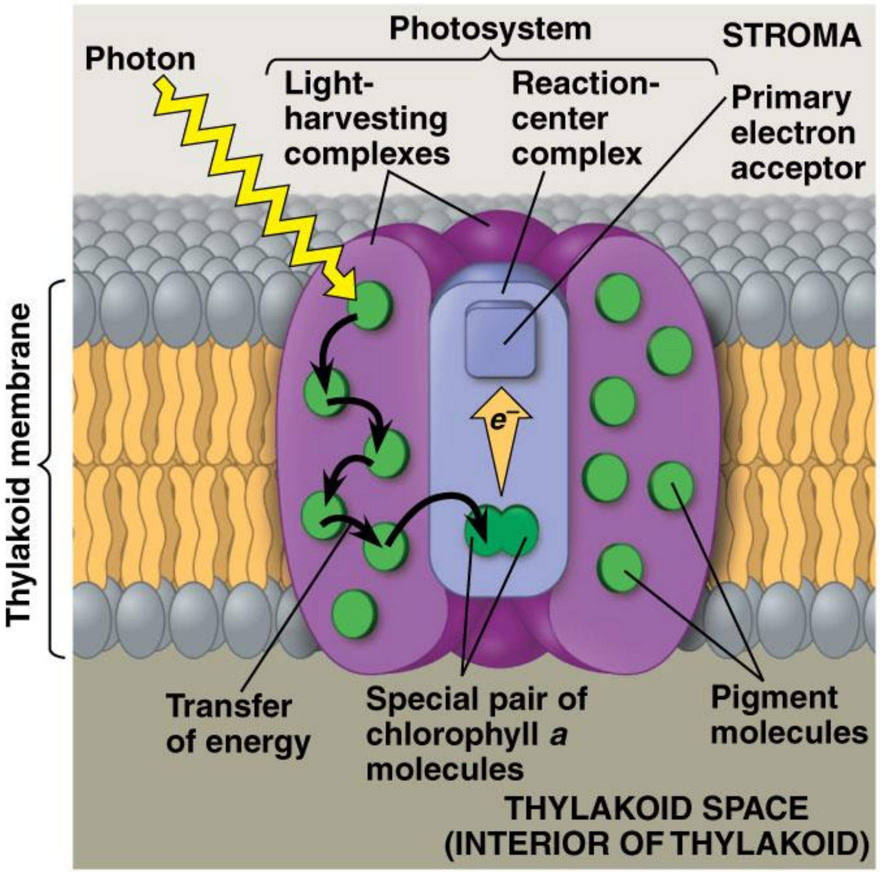
Photosystem: reaction center & light-harvesting complexes (pigment + protein)



(a) How a photosystem harvests light

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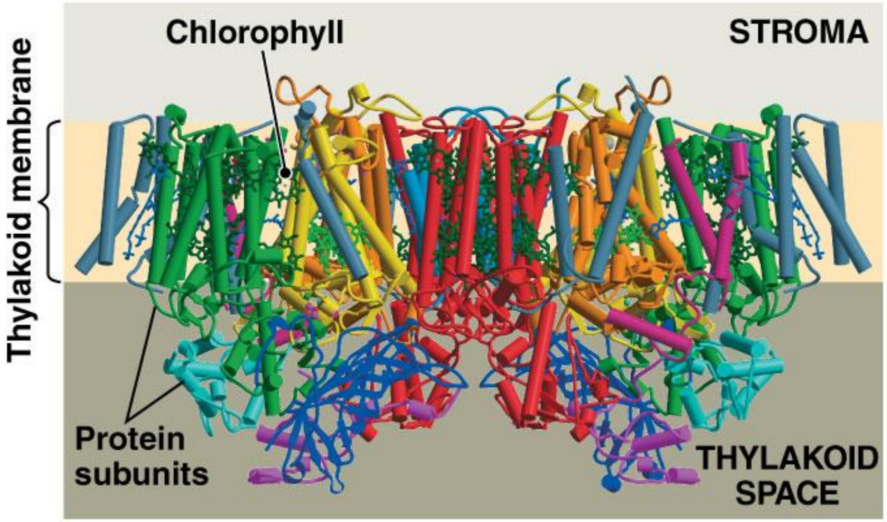


(b) Structure of photosystem II

Light Reactions

Two routes for electron flow:

A. Linear (noncyclic) electron flow

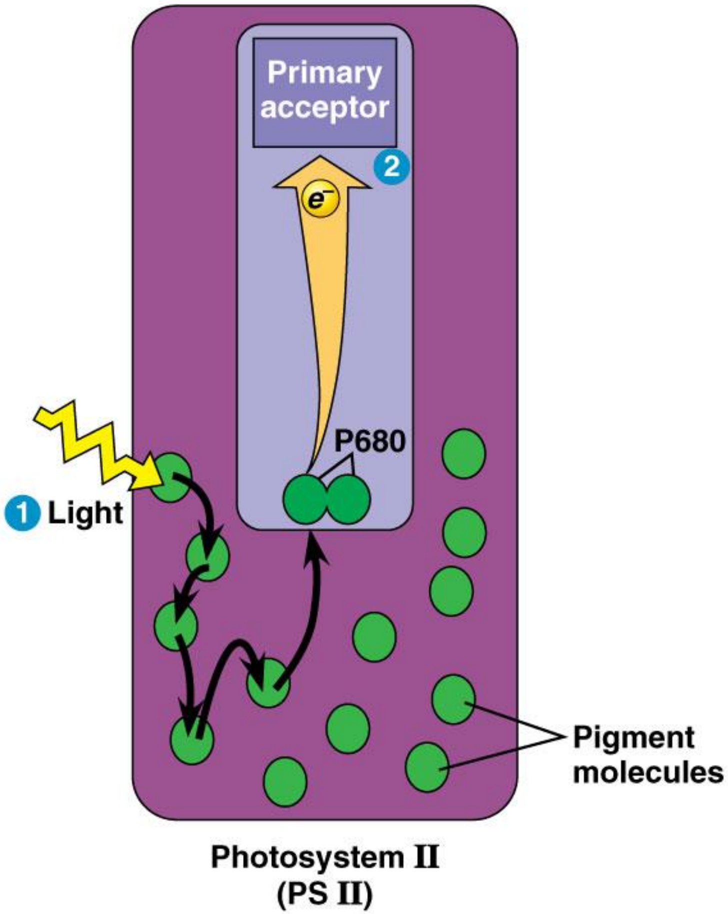
B. Cyclic electron flow

Light Reaction (Linear electron flow)

1. Chlorophyll excited by light absorption
2. E passed to reaction center of **Photosystem II** (protein + chlorophyll a)
3. e^- captured by primary electron acceptor
   - Redox reaction → e^- transfer
   - e- prevented from losing E (drop to ground state)
4. **H_2O is split** to replace e^- → **O_2 formed**

5. e^- passed to **Photosystem I** via ETC
6. E transfer pumps H^+ to thylakoid space
7. **ATP** produced by photophosphorylation
8. e^- moves from PS I's primary electron acceptor to 2nd ETC
9. $NADP^+$ reduced to NADPH

MAIN IDEA: *Use solar E to generate ATP & NADPH to provide E for Calvin cycle*



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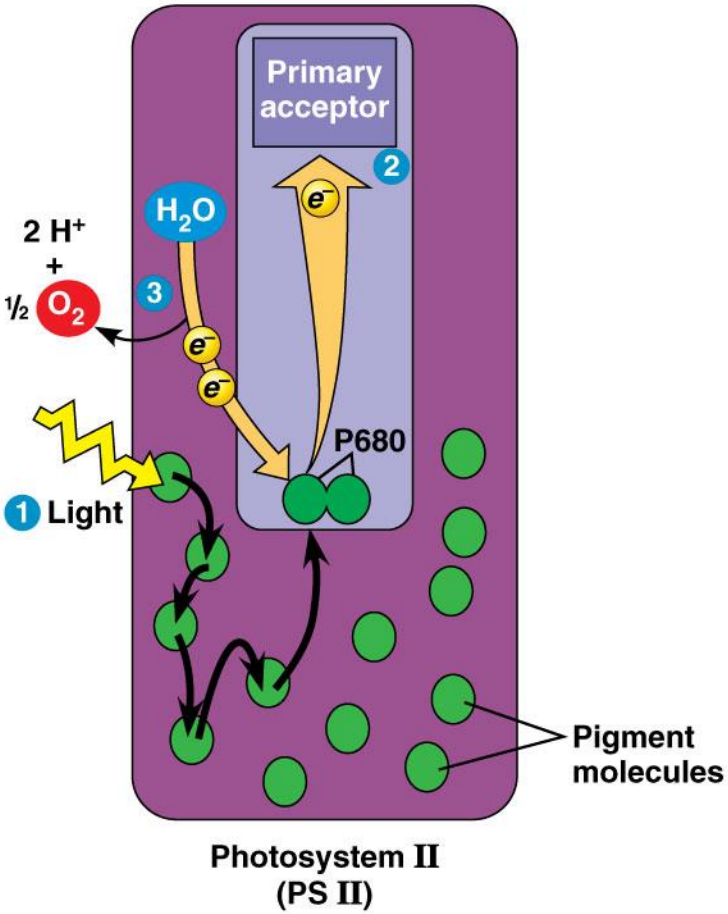

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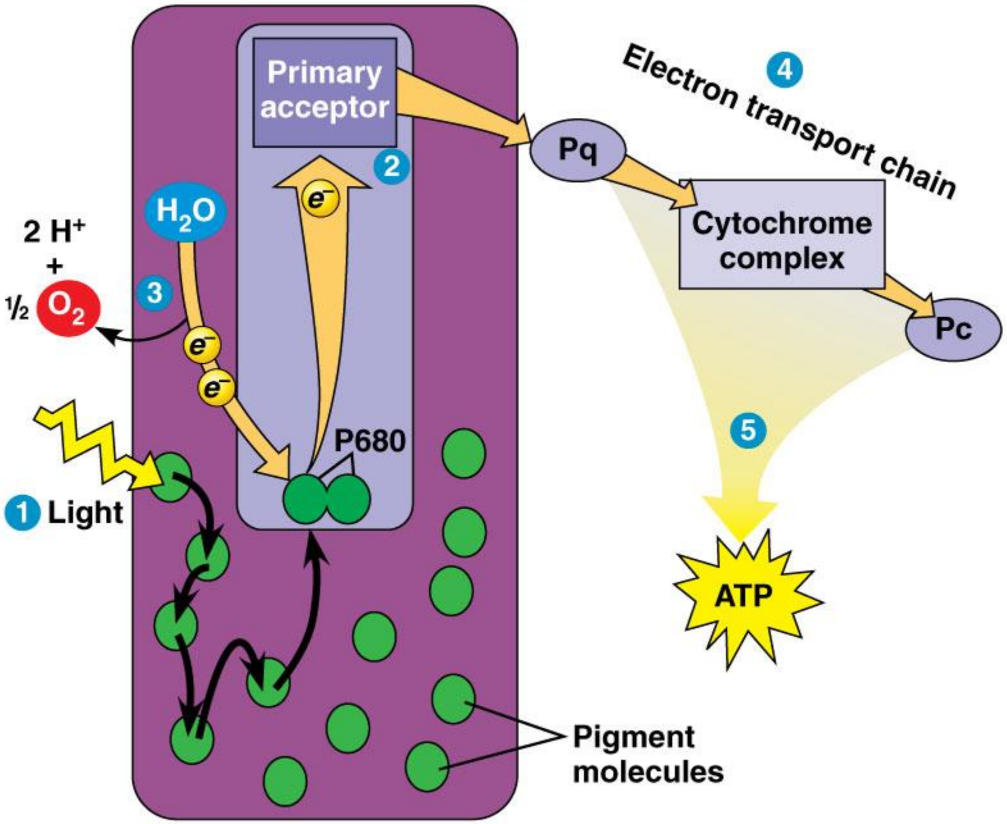

Photosystem II
(PS II)

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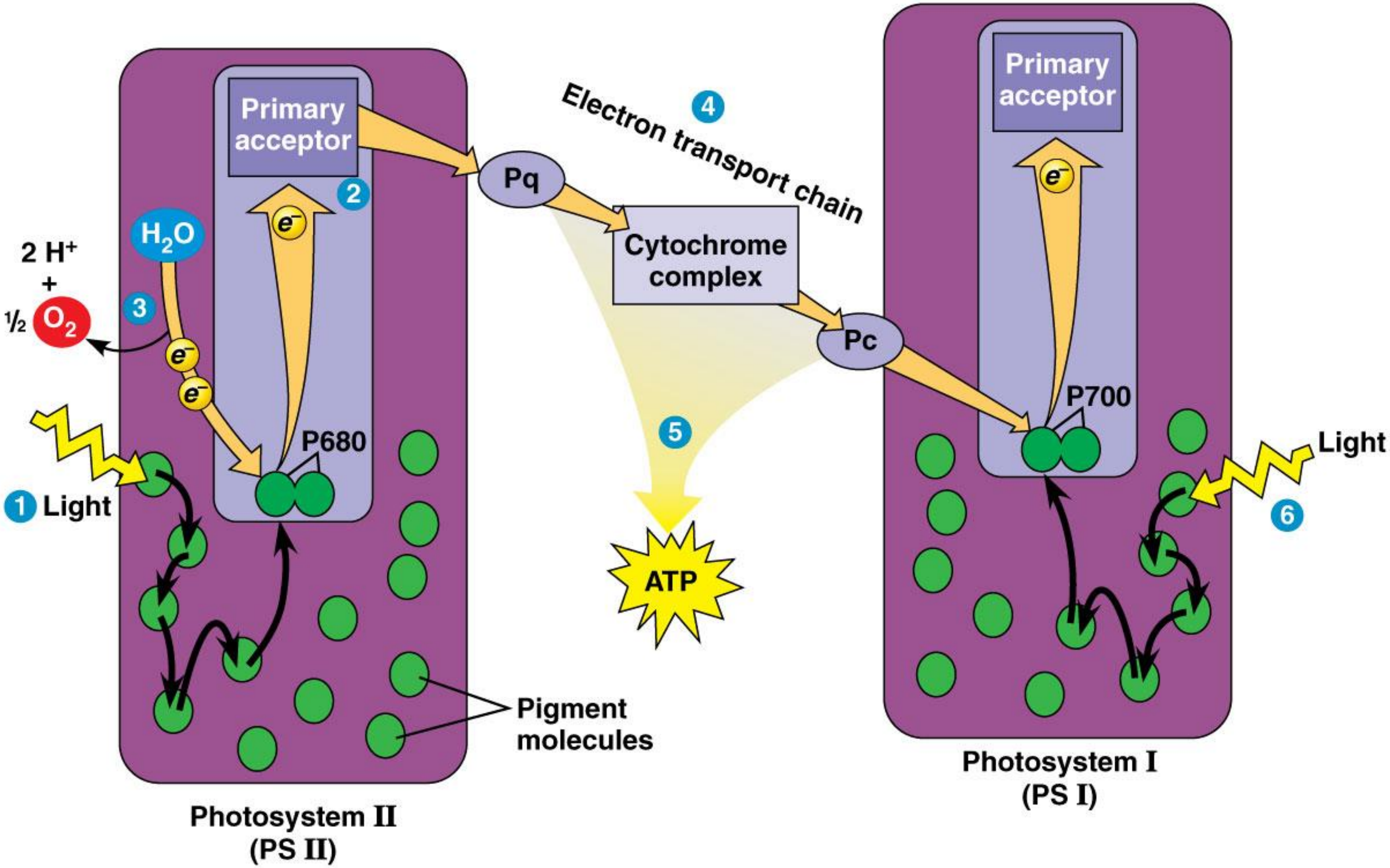

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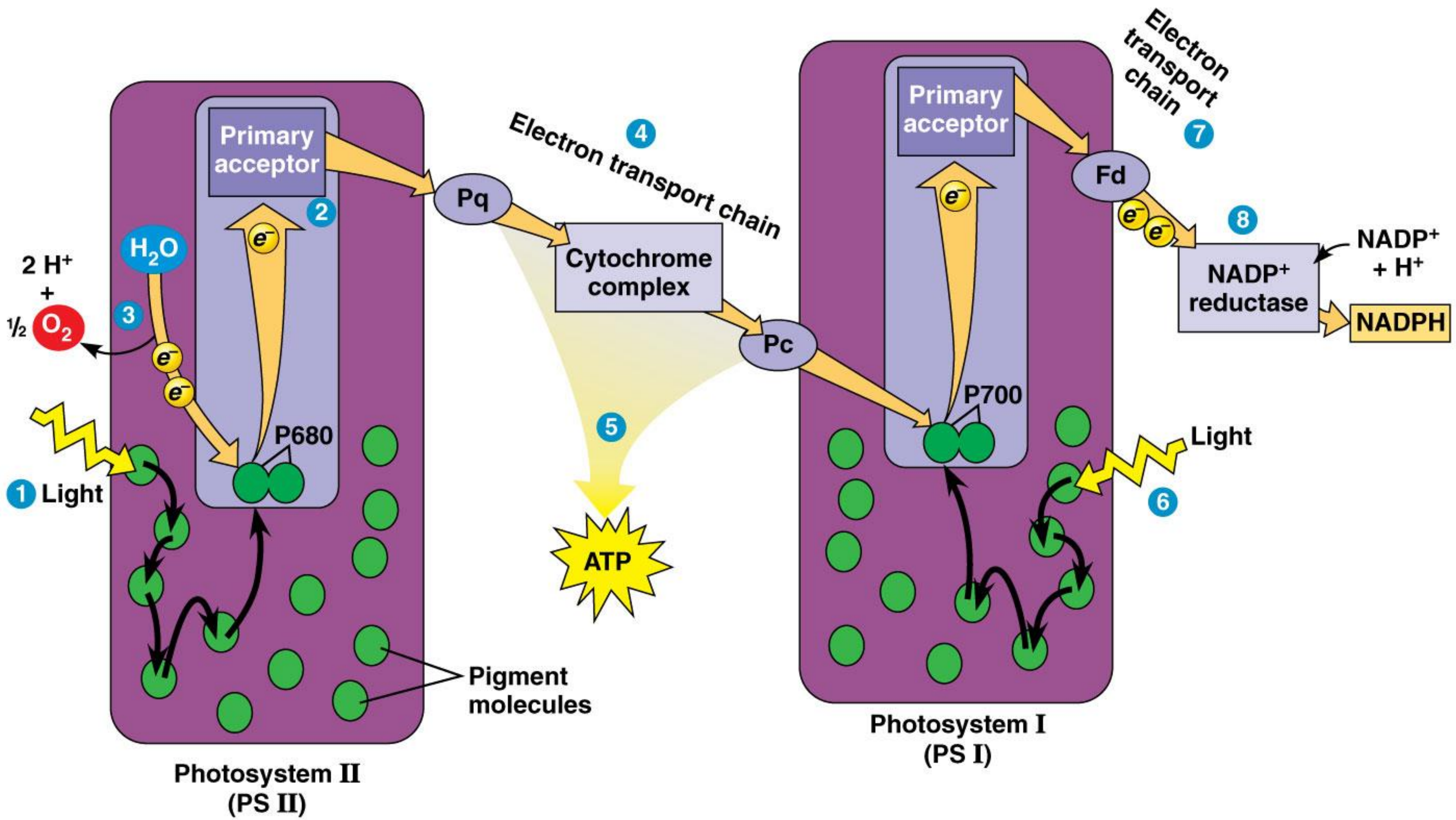

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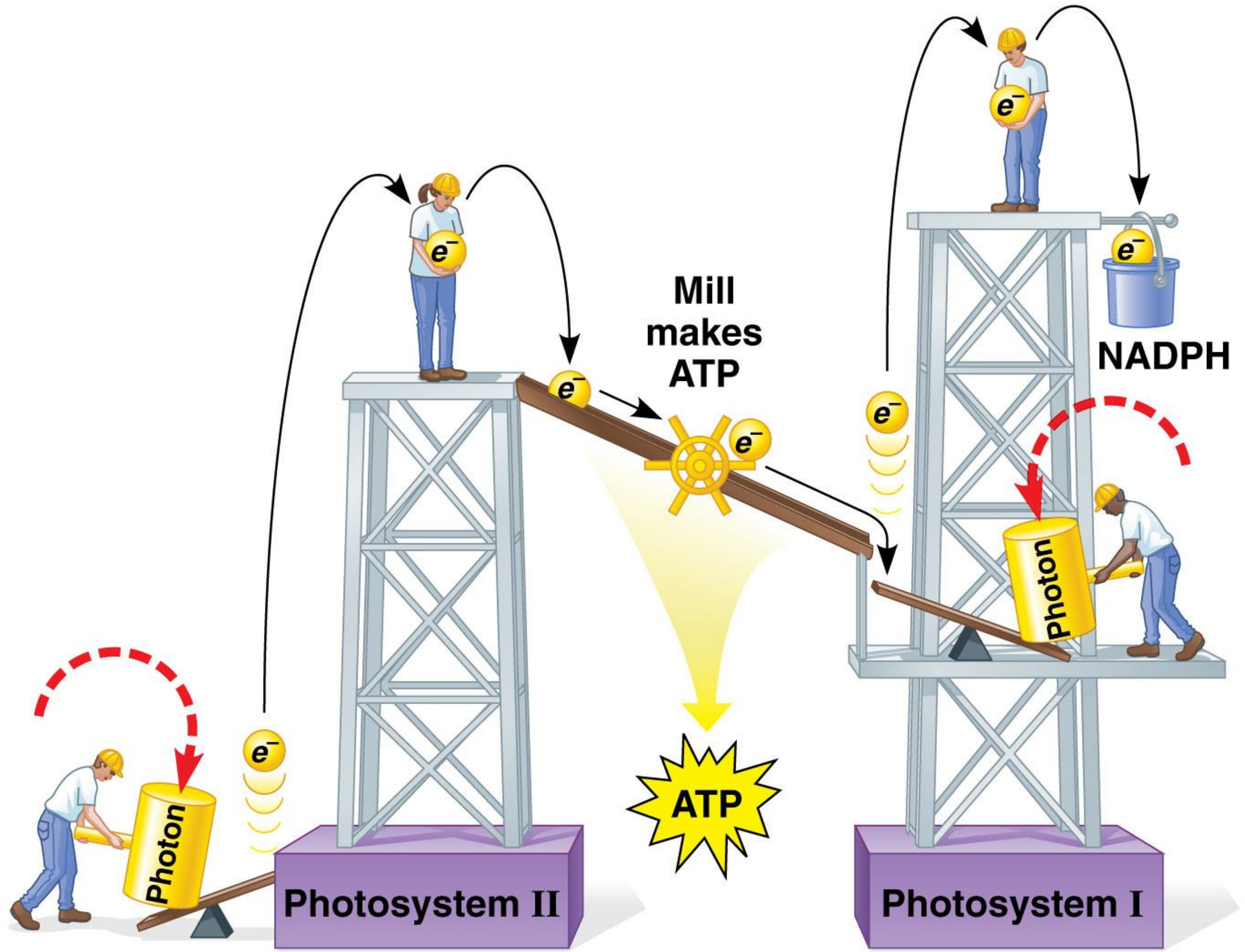

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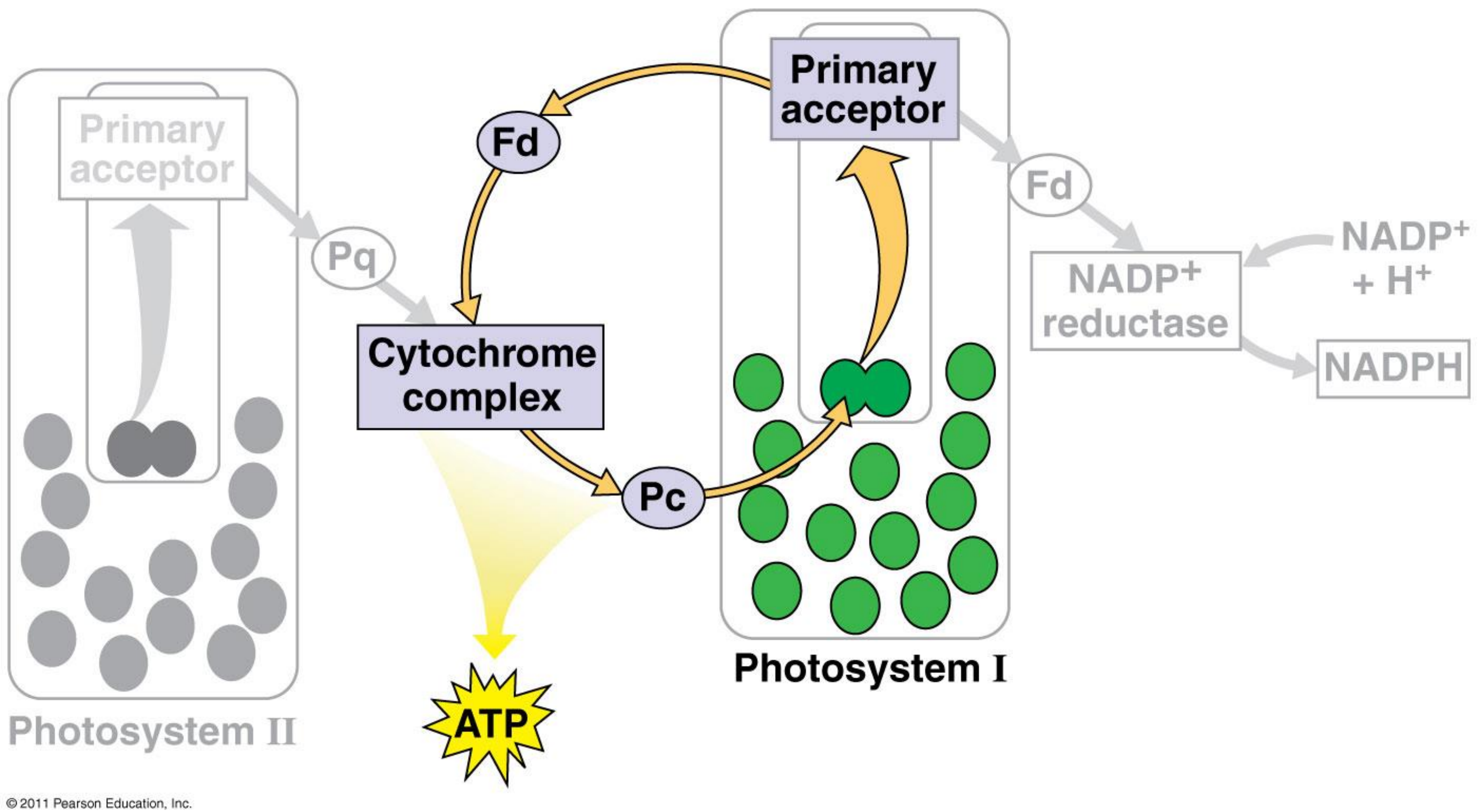
Mechanical analogy for the light reactions

Cyclic Electron Flow: uses PS I only; produces ATP for Calvin Cycle (no O_2 or NADPH produced)



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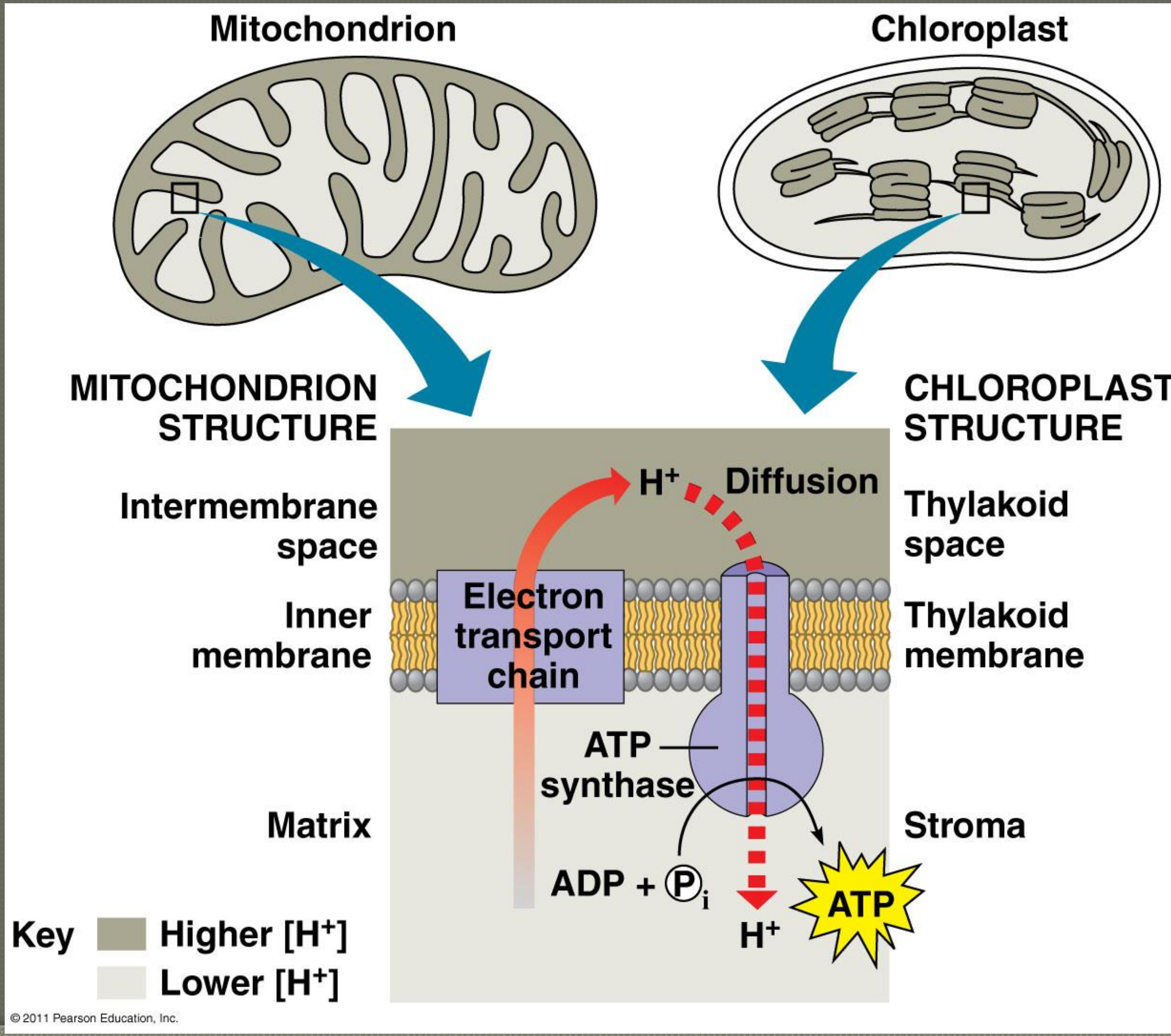
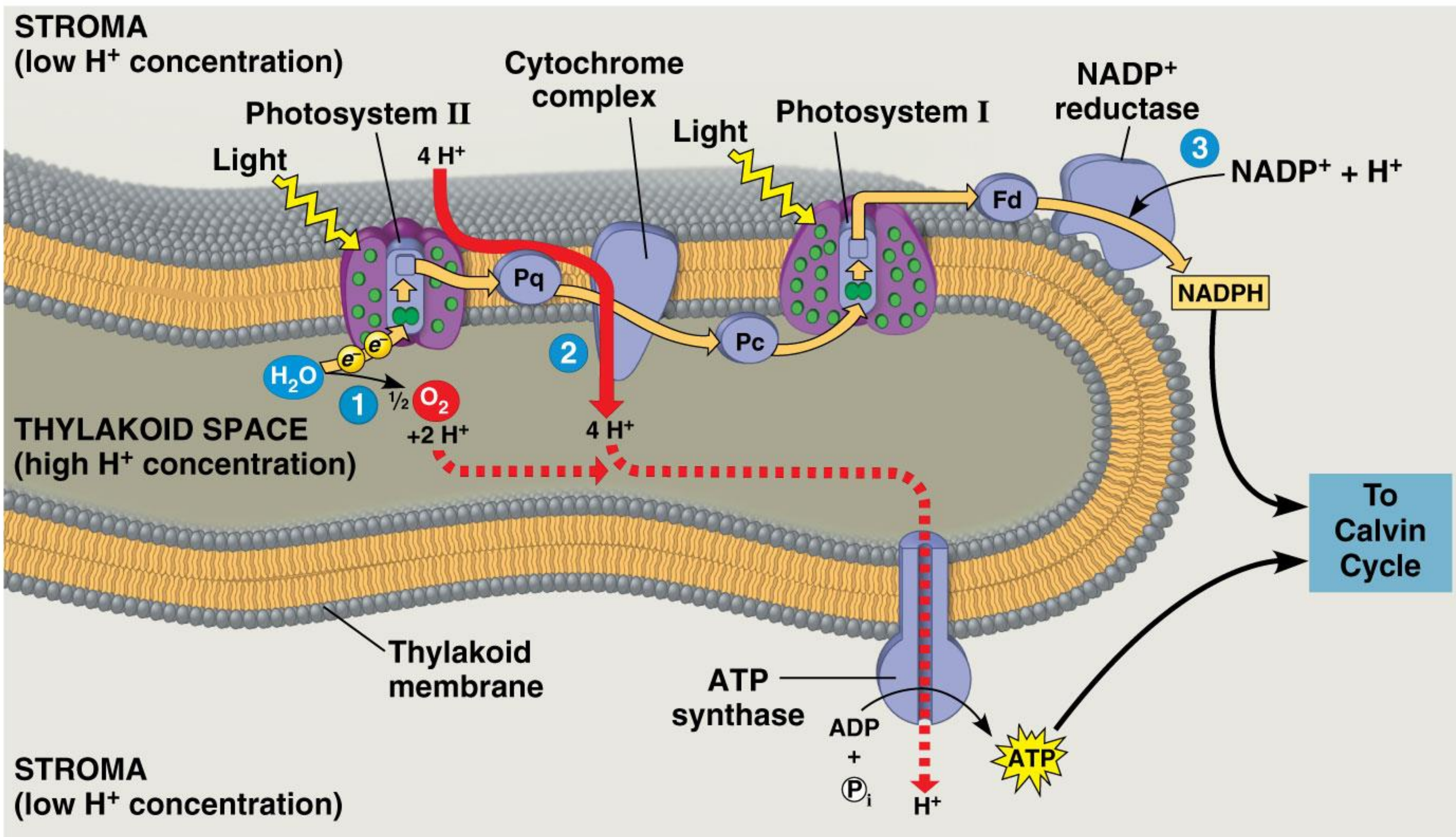
Both respiration and photosynthesis use <u>chemiosmosis</u> to generate ATP



Proton motive force generated by:

(1) H^+ from water
(2) H^+ pumped across by cytochrome
(3) Removal of H^+ from stroma when $NADP^+$ is reduced



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Warm-Up

1. Write a short synopsis of the light reaction.
2. What is its function? Where does it occur?
3. (See Fig. 10.5) What products of the Light Reaction are used for the Calvin Cycle?

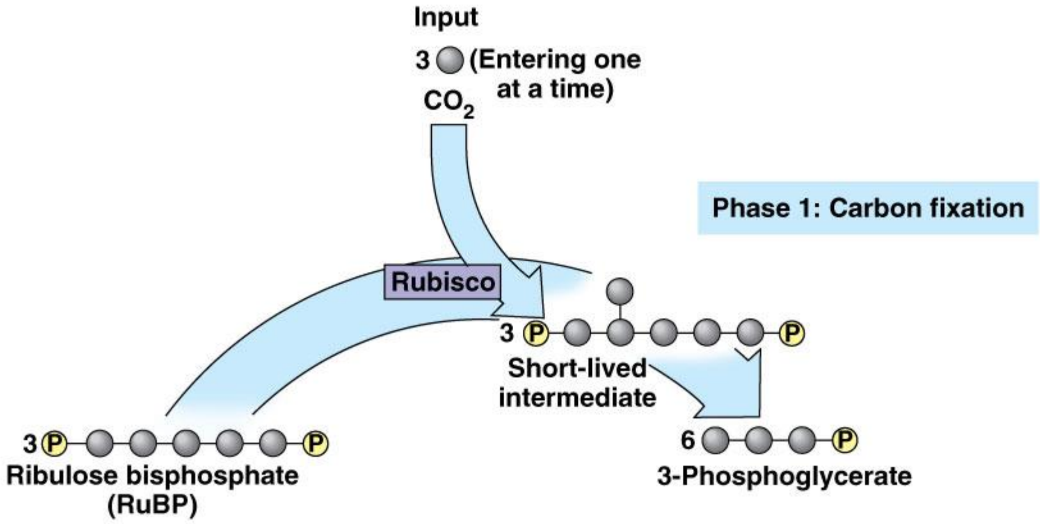
Calvin Cycle

Calvin Cycle: Uses ATP and NADPH to convert CO_2 to sugar

- Uses ATP, NADPH, CO_2
- Produces 3-C sugar G3P *(glyceraldehyde-3-phosphate)*

Three phases:

1. Carbon fixation
2. Reduction
3. Regeneration of RuBP (CO_2 acceptor)



Phase 1: 3 CO_2 + **RuBP** (5-C sugar *ribulose bisphosphate)*

- Catalyzed by enzyme **rubisco** (*RuBP carboxylase*)

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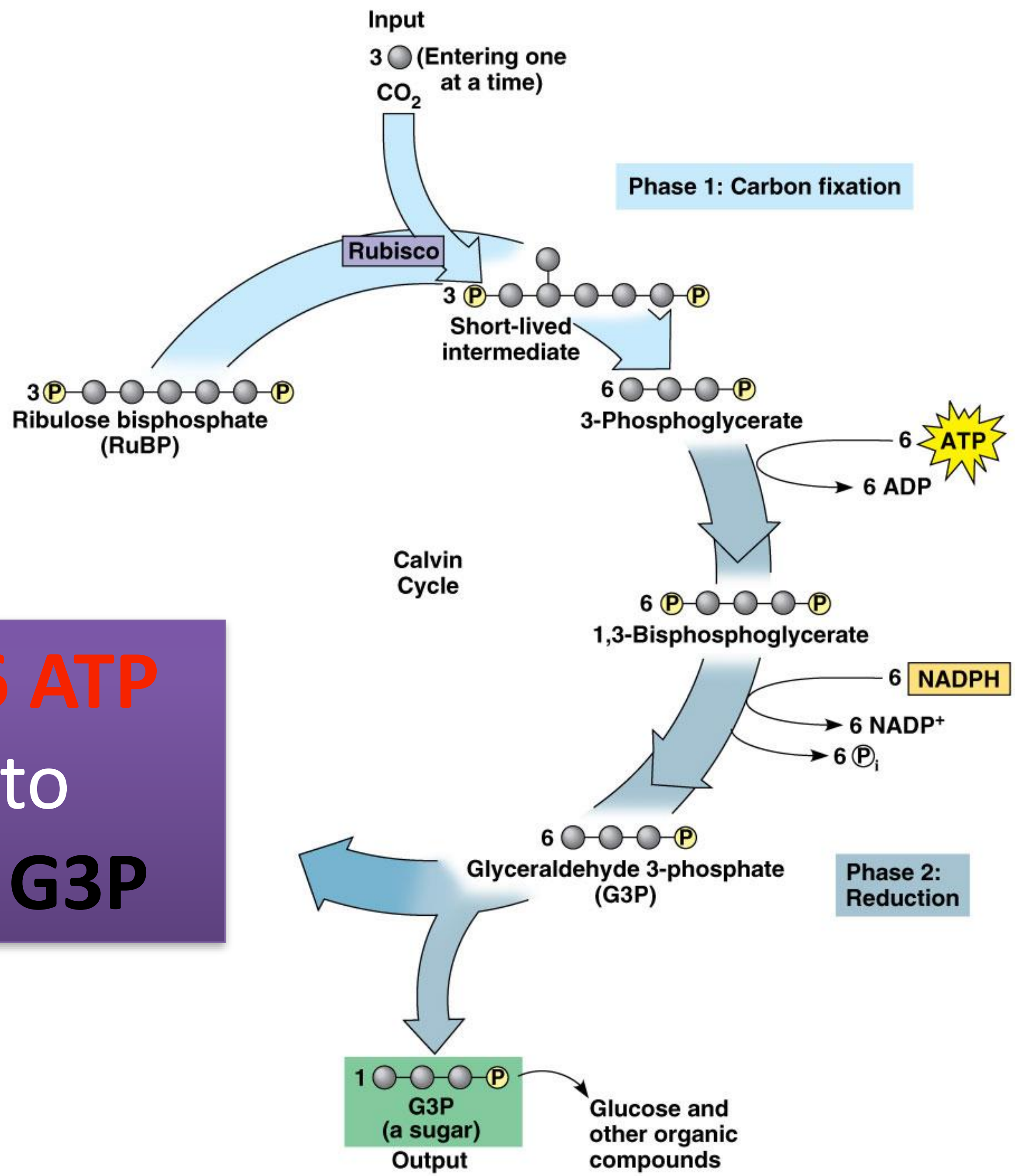
Phase 2: Use **6 ATP** and **6 NADPH** to produce 1 net **G3P**



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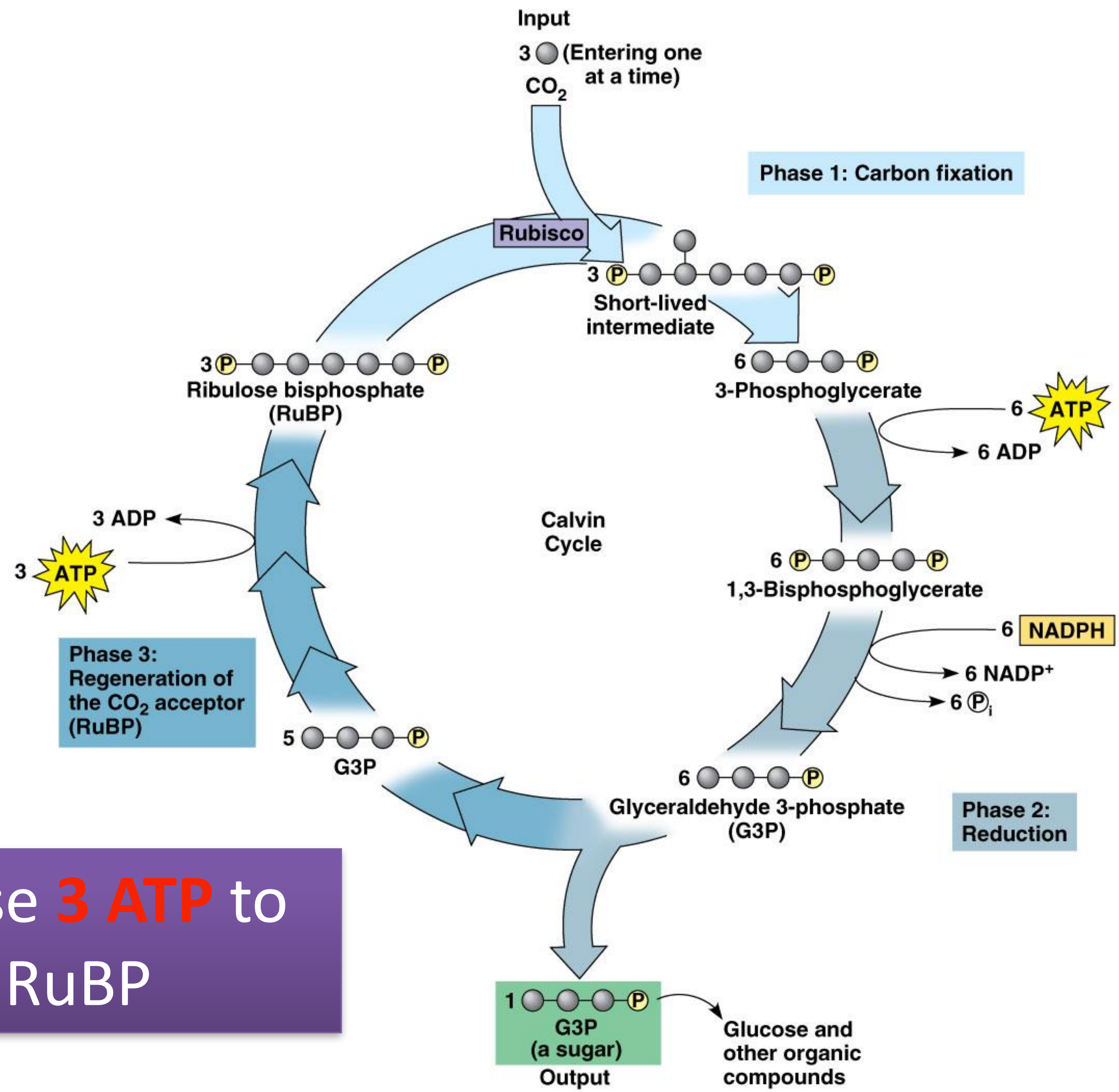

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Phase 3: Use **3 ATP** to regenerate RuBP

Warm-Up

1. (See Figure 10.17) What are the 3 locations that H+ is used to create the proton gradient?
2. What purpose does cyclic e^- flow serve?
3. What is the main function of the Calvin Cycle? Where does it occur?
4. What are the reactants of the Calvin cycle? What are the products?
5. Which enzyme is responsible for carbon fixation?

Alternative mechanisms of carbon fixation have evolved in hot, arid climates

Photorespiration

- Metabolic pathway which:
  - Uses O_2 & produces CO_2
  - Uses ATP
  - No sugar production (rubisco binds O_2 → breakdown of RuBP)
- Occurs on hot, dry bright days when stomata close (conserve H_2O)
- **Why?** Early atmosphere: low O_2, high CO_2?

Evolutionary Adaptations

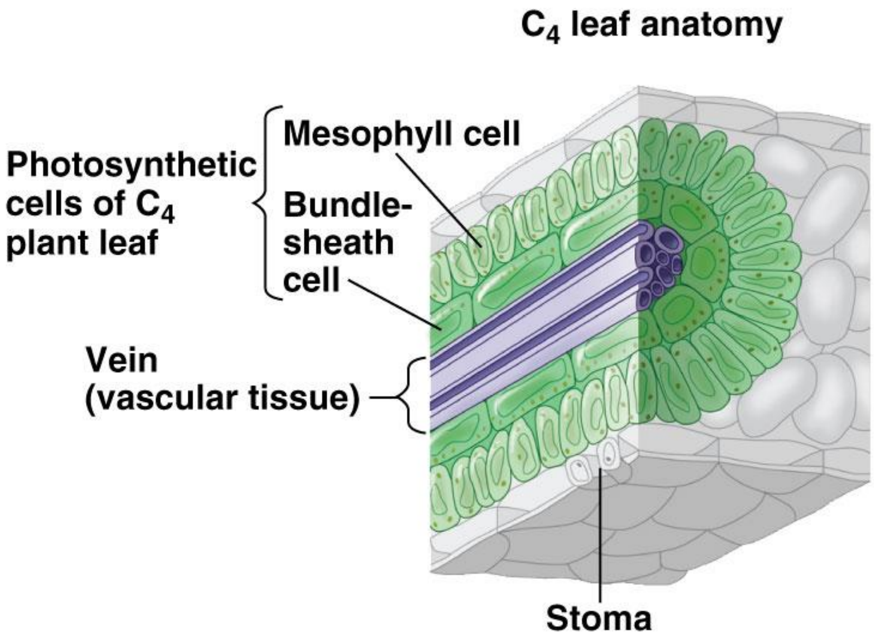
1. **Problem with C_3 Plants**:
   - CO_2 fixed to 3-C compound in Calvin cycle
   - Ex. Rice, wheat, soybeans
   - <u>Hot, dry days</u>:
     - partially close stomata, ↓CO_2
     - Photorespiration
     - ↓ photosynthetic output (no sugars made)

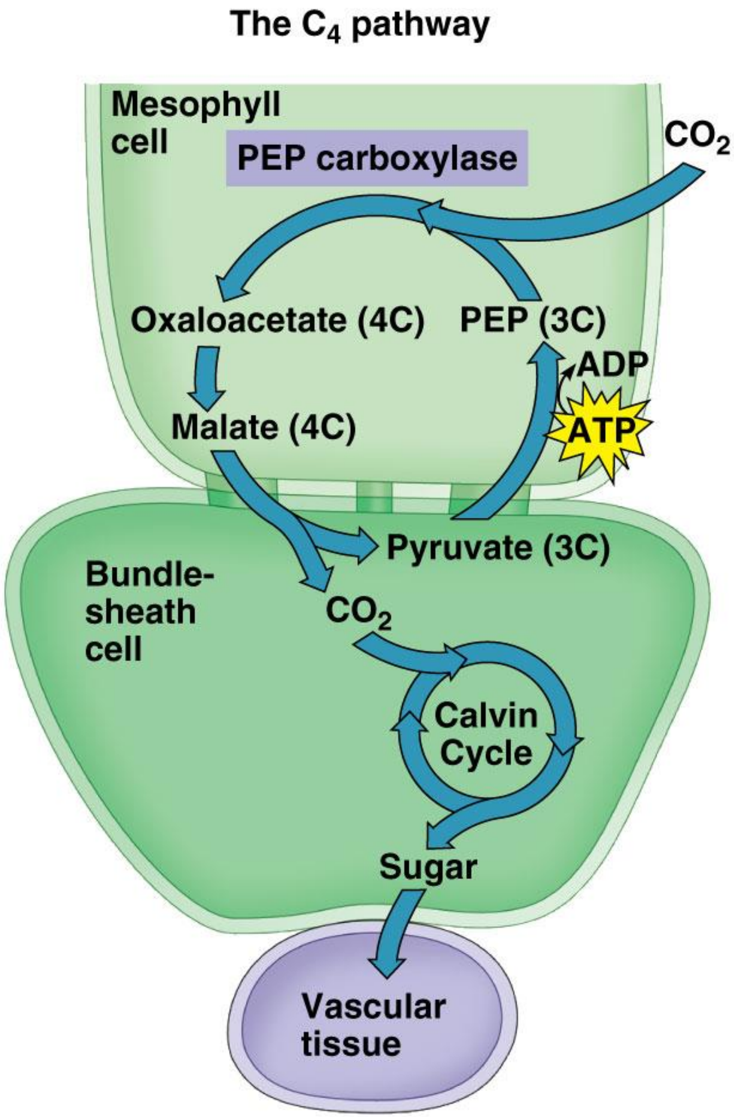


2. **C_4 Plants**:

- CO_2 fixed to 4-C compound
- Ex. corn, sugarcane, grass
- Hot, dry days → stomata close
  - 2 cell types = **mesophyll** & **bundle sheath** cells
    - mesophyll : PEP carboxylase fixes CO_2 (4-C), pump CO_2 to bundle sheath
    - bundle sheath: CO_2 used in Calvin cycle
- ↓photorespiration, ↑sugar production
- **WHY?** Advantage in hot, sunny areas

C_4 Leaf Anatomy





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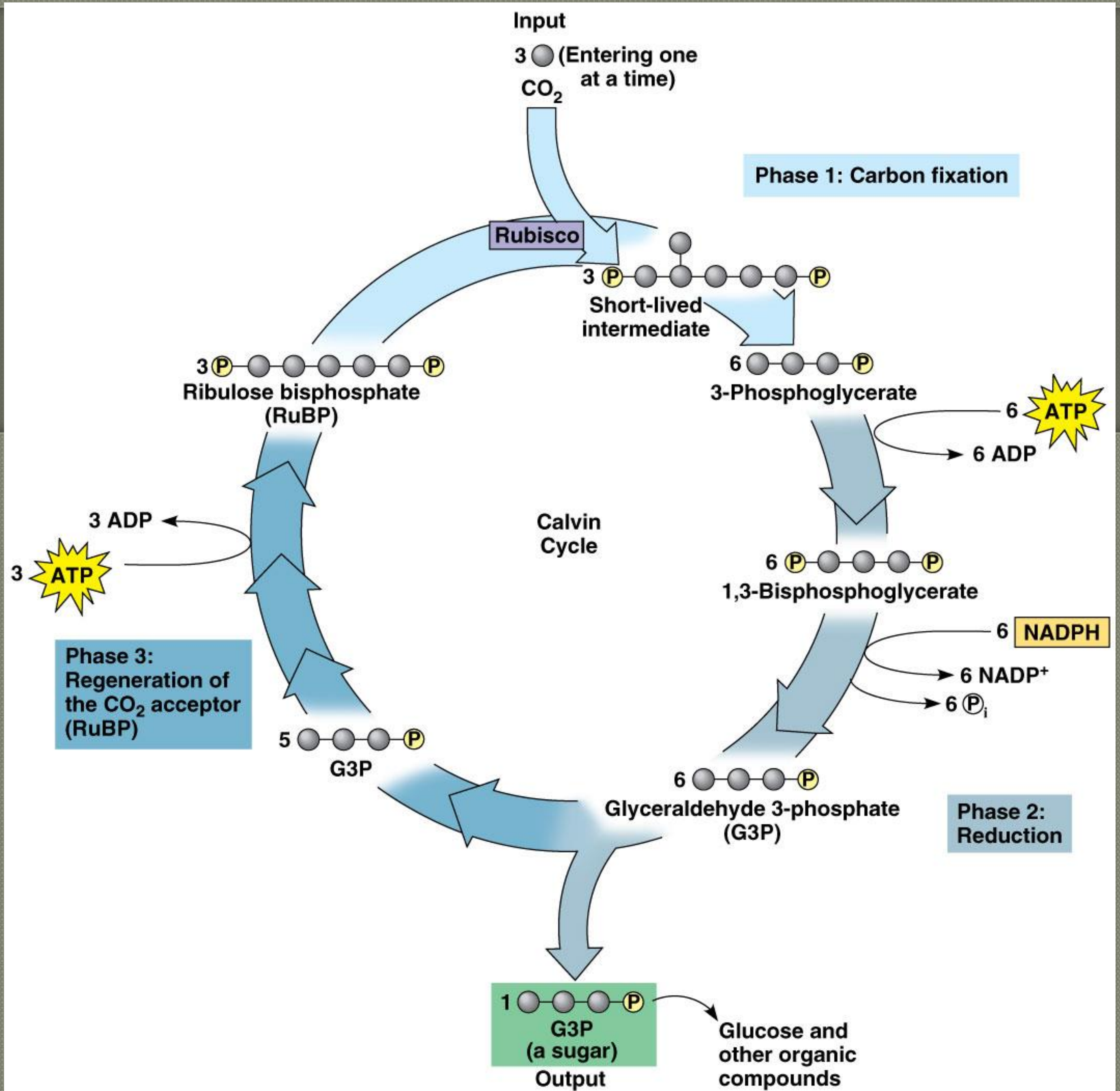
3. **CAM Plants**:



- *Crassulacean acid metabolism (CAM)*
- NIGHT: stomata open → CO_2 enters → converts to organic acid, stored in mesophyll cells
- DAY: stomata closed → light reactions supply ATP, NADPH; CO_2 released from organic acids for Calvin cycle
- Ex. cacti, pineapples, succulent (H_2O-storing) plants
- **WHY?** Advantage in arid conditions

Warm-Up

1. Draw a T-Chart. Compare/contrast Light Reactions vs. Calvin Cycle.
2. What is photorespiration? How does it affect C3 plants?
3. In lab notebook: Graph data from yesterday's lab. Determine the ET50 for the "With CO2" test group.
4. In lab notebook: Brainstorm at list of possible factors that could affect the rate of photosynthesis. (Think of factors you could test with the leaf disk technique.)



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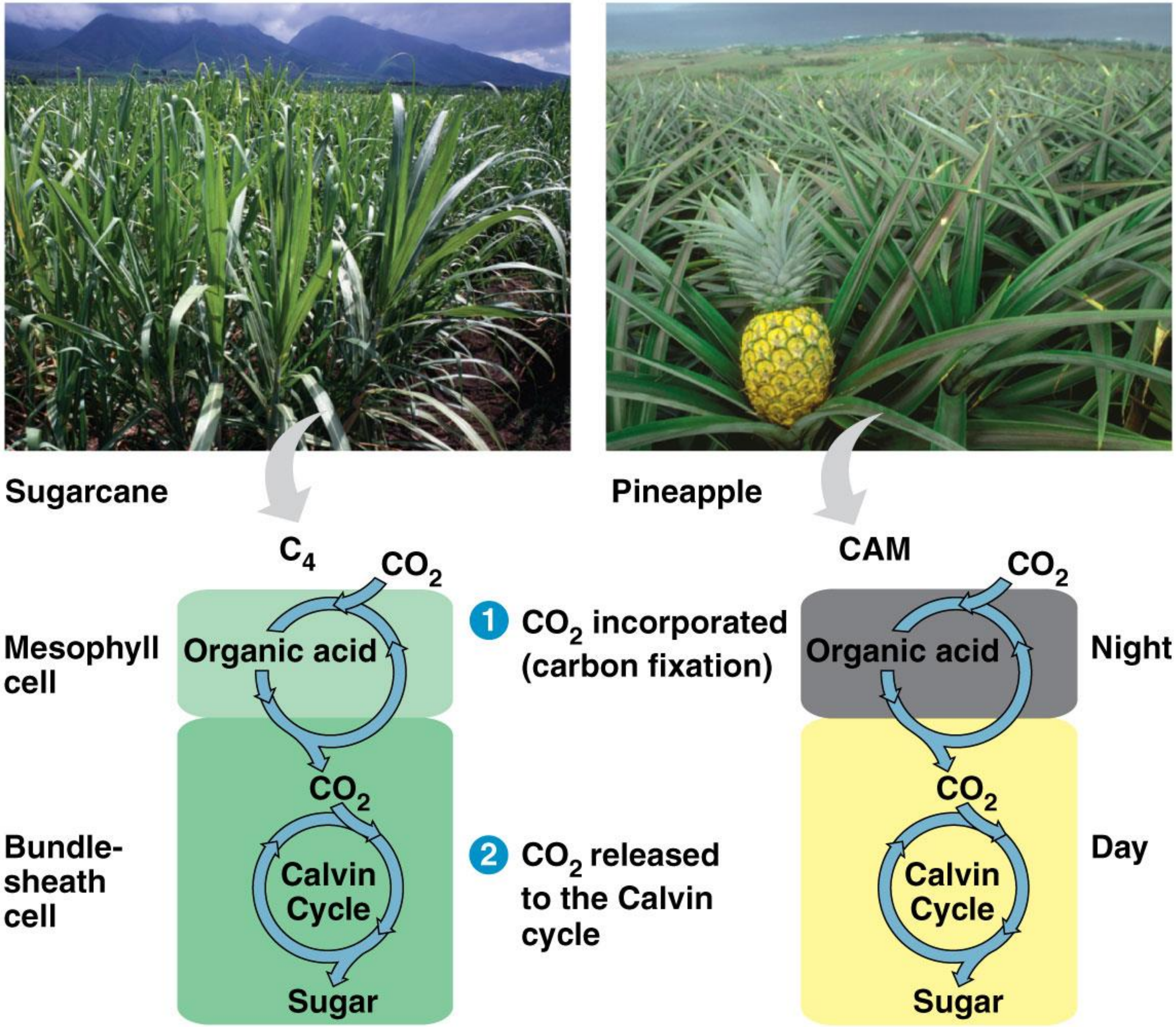

(a) Spatial separation of steps

(b) Temporal separation of steps

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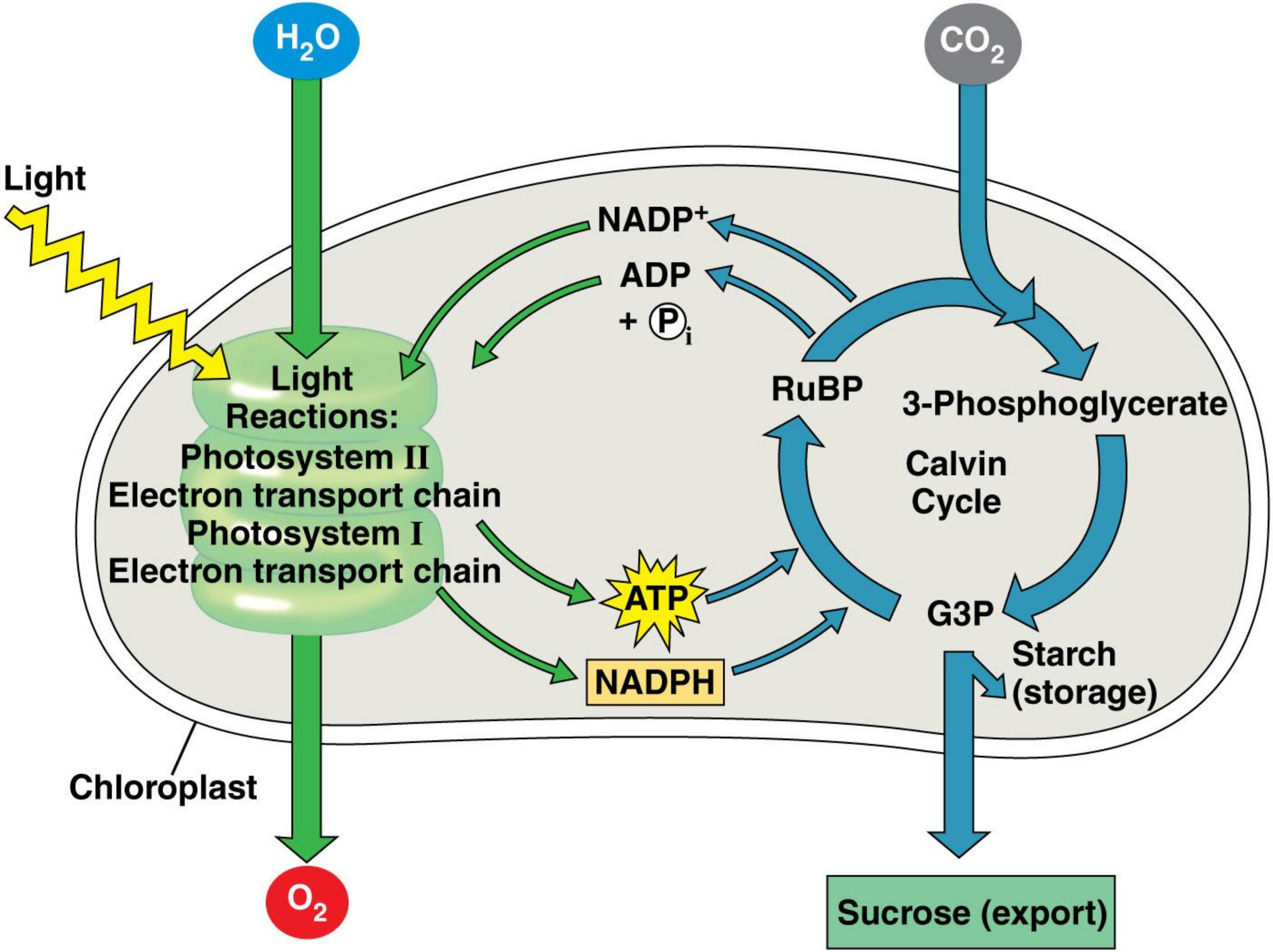
Comparison

C_3	C_4	CAM
C fixation & Calvin together	C fixation & Calvin in different cells	C fixation & Calvin at different TIMES
Rubisco	PEP carboxylase	Organic acid

Importance of Photosynthesis

Plant:	• Glucose for respiration • Cellulose
Global:	• O_2 Production • Food source

Review of Photosynthesis



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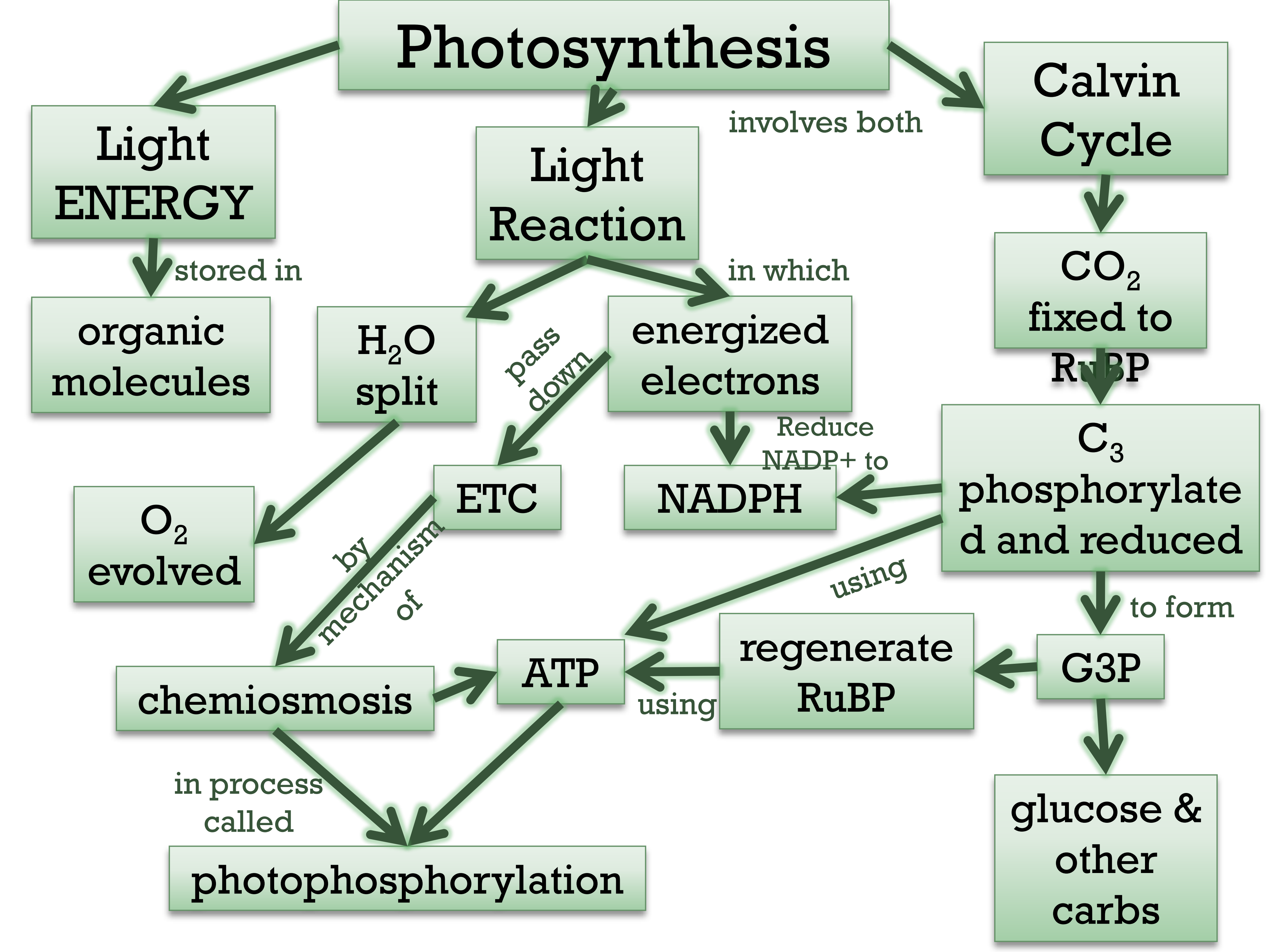


Photosynthesis
Light ENERGY
stored in
organic molecules
Light Reaction
involves both
Calvin Cycle
H_2O split
in which
energized electrons
pass down
ETC
Reduce NADP+ to
NADPH
CO_2 fixed to RuBP
C_3 phosphorylated and reduced
O_2 evolved
by mechanism of
using
to form
chemiosmosis
ATP
using
regenerate RuBP
G3P
in process called
photophosphorylation
glucose & other carbs

LIGHT REACTIONS

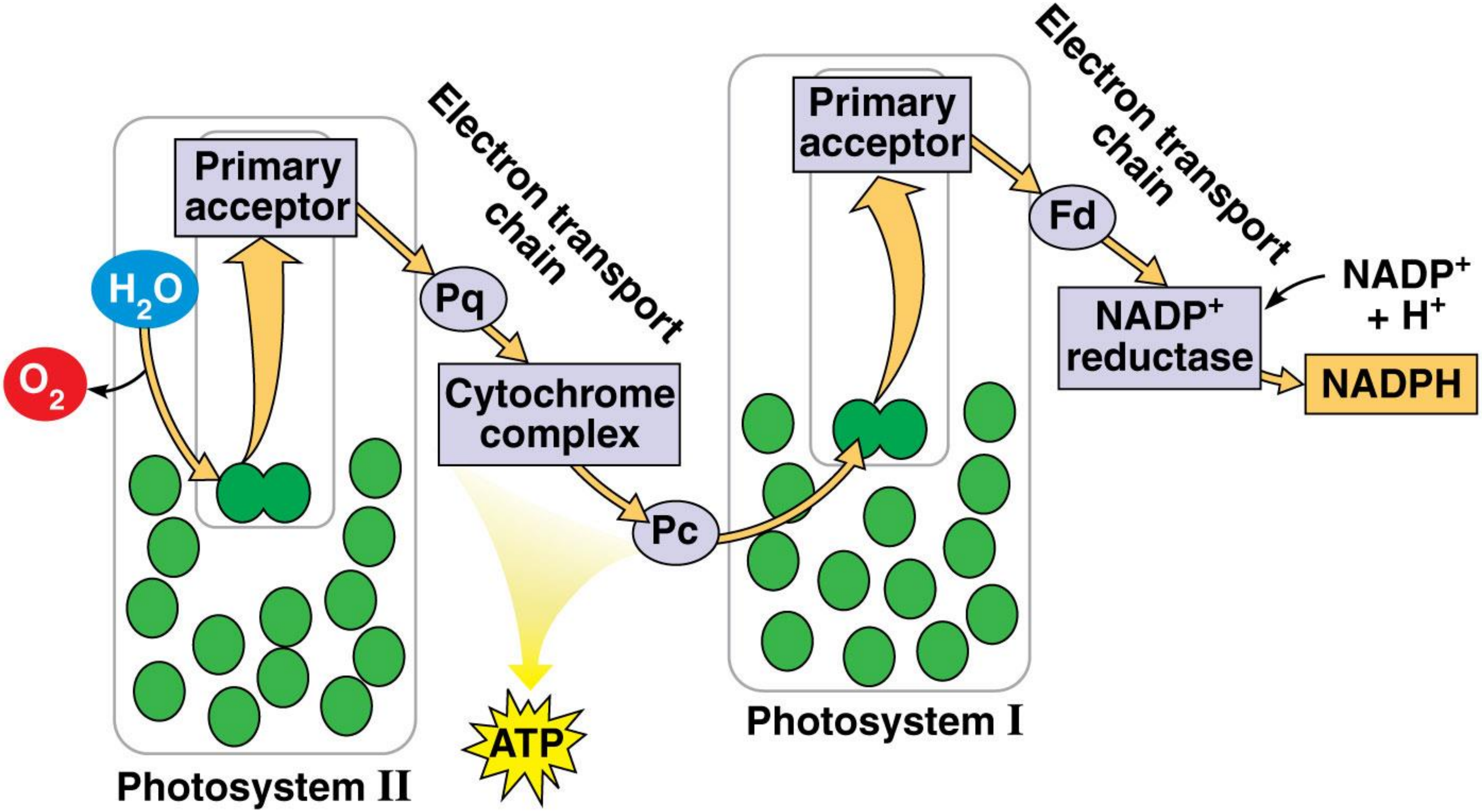
CALVIN CYCLE

MITOCHONDRIA

CHLOROPLAST

Comparison

RESPIRATION	PHOTOSYNTHESIS
Plants + Animals	Plants
Needs O_2 and food	Needs CO_2, H_2O, sunlight
Produces CO_2, H_2O and ATP, NADH	Produces glucose, O_2 and ATP, NADPH
Occurs in mitochondria membrane & matrix	Occurs in chloroplast thylakoid membrane & stroma
Oxidative phosphorylation	Photorespiration
Proton gradient across membrane	Proton gradient across membrane



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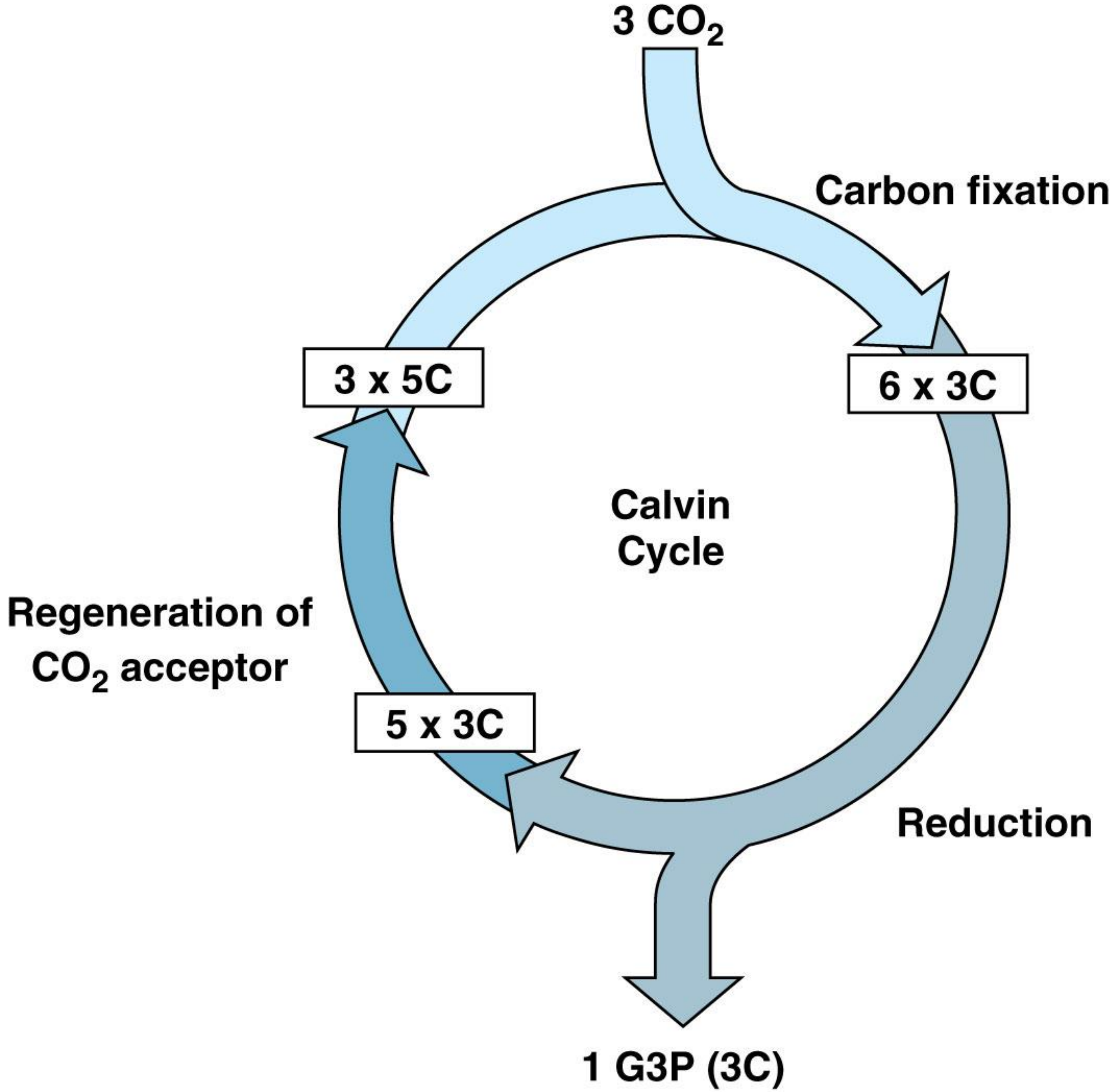

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