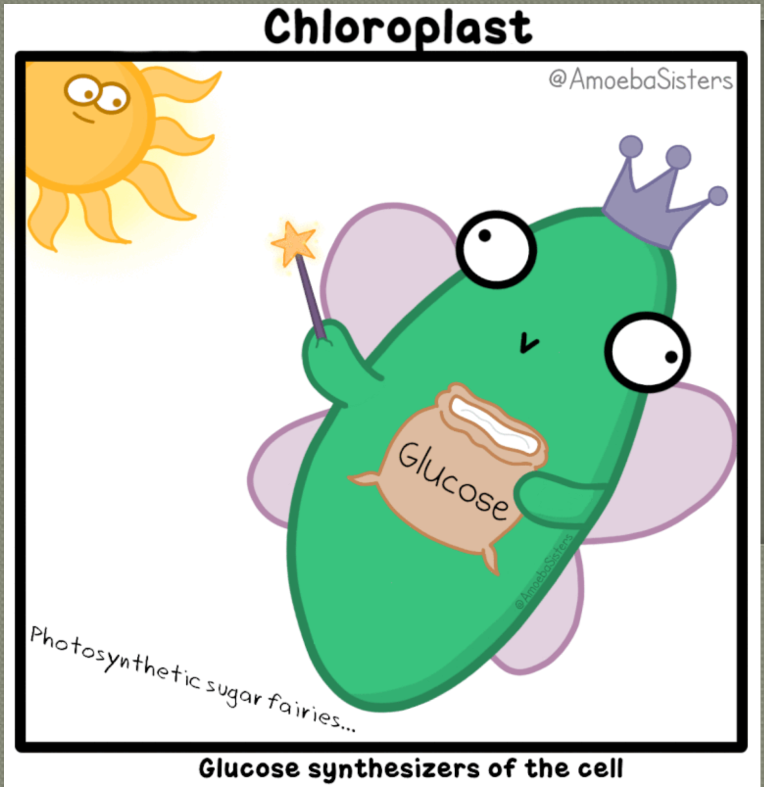
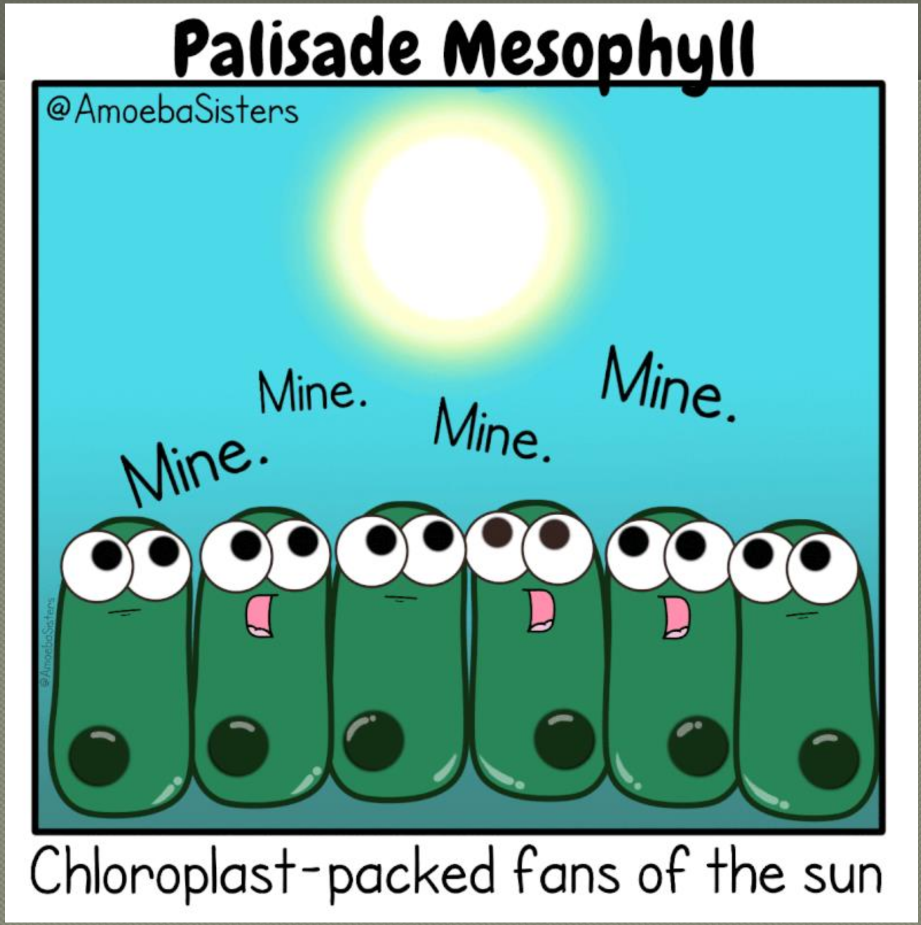
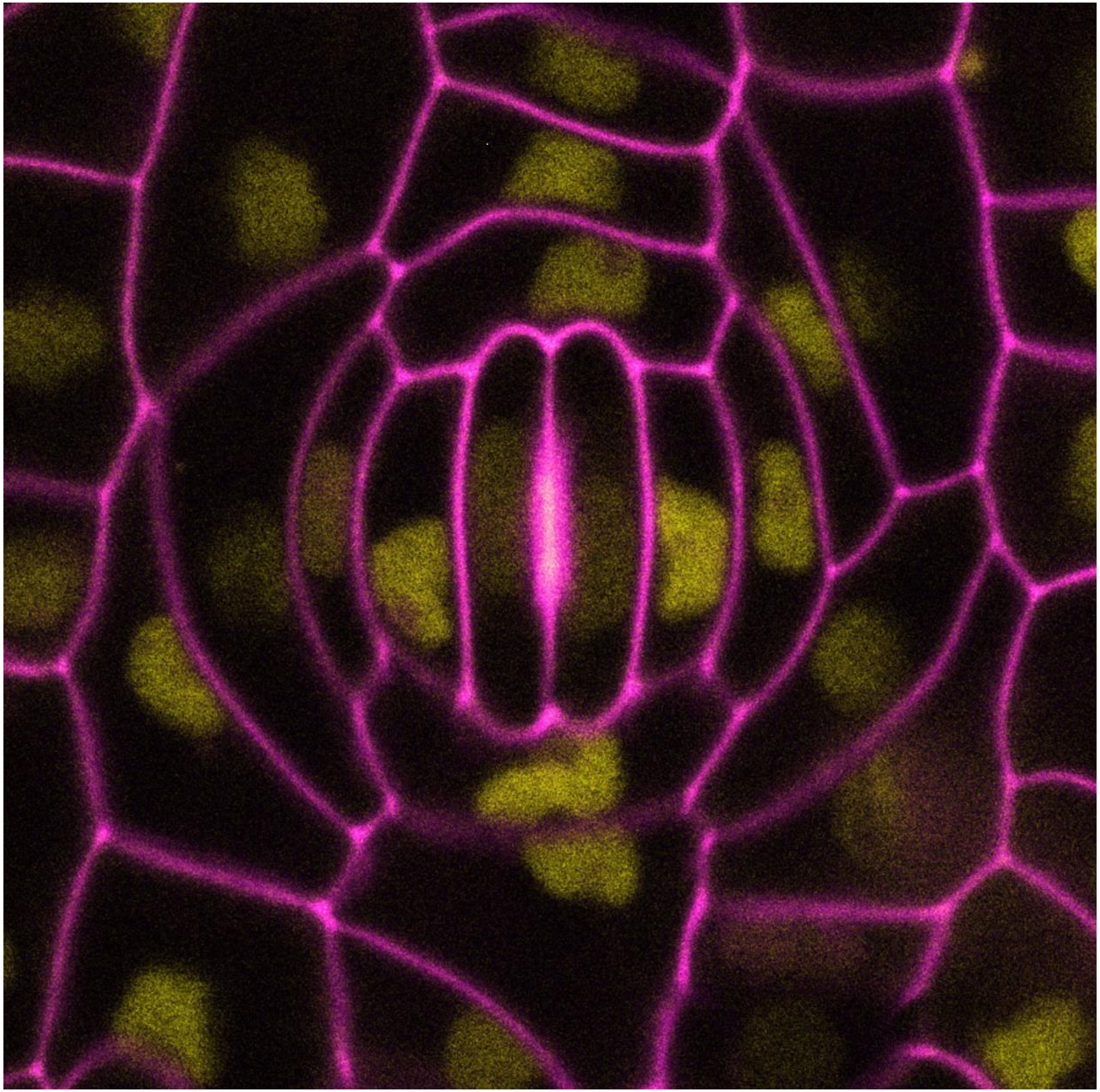
Chapter 10 Photosynthesis







TURN & TALK

I SEE…

I THINK…

I WONDER…

Stomata of grass

- **Stomata are adjustable pores** that plants use to **control the amount of carbon dioxide they take in for photosynthesis** and the amount of water they lose by transpiration. Plants have been around for 400 million years, and judging by their fossil record, **all of them have had stomata consisting of two guard cells**.
- The grass family began to diversify in the late Cretaceous, and it is thought that gradual changes in the shape of their guard cells, and the addition of two support cells, have enabled them to more easily adapt to changing environments. In this example, scientists are starting to understand the mechanisms of change by studying the grass *Brachypodium distachyon*, and have produced stomata with the usual two guard cells (center of the image), but with many support cells (surrounding the guard cells). It is hoped that by understanding how the stomata are formed, it will be practical to produce crops with improved carbon assimilation and water use, which could lead to plants that can more easily adapt to our rapidly changing climate.
- The grass tissue was stained with a fluorescent dye that reveals cell outlines (in magenta) and a fluorescent protein attached to a factor involved with the control of gene expression (in yellow), and imaged using laser scanning confocal microscopy

Learning Objectives:

1. Describe how photosynthesis allows organisms to capture and store energy.

2. Explain how cells capture energy from light and transfer it to biological molecules for storage and use.

Cellular Respiration Formula

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

$$6CO_2 + 6H_2O \xrightarrow{\text{LIGHT}} C_6H_{12}O_6 + 6O_2$$

Photosynthesis Formula

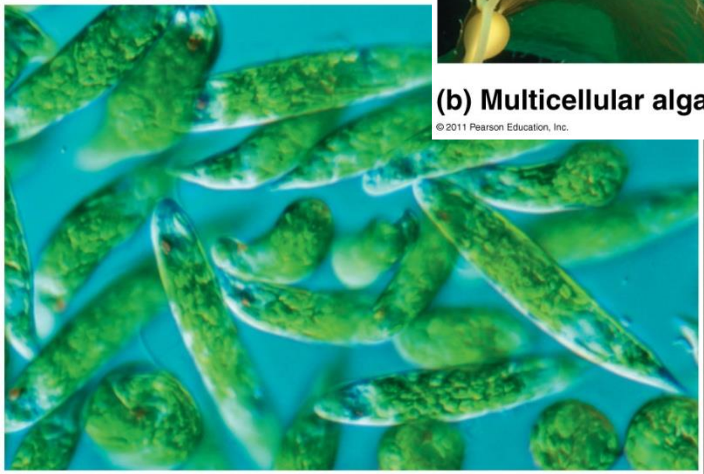
Photosynthesis in Nature

- Plants and other autotrophs are producers of biosphere
- PHOTOautotrophs: use light energy to make organic molecules
- CHEMOautotrophs: use other chemicals (sulfur, nitrogen) to make organic materials
- Heterotrophs: consume organic molecules from other organisms for E and carbon

Photoautotrophs

(a) Plants

(b) Multicellular alga

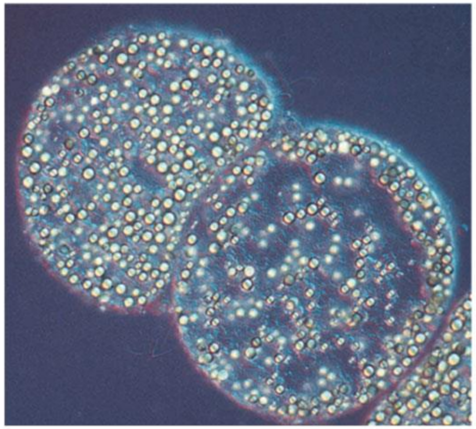


(c) Unicellular protists

10 µm

(d) Cyanobacteria

40 µm

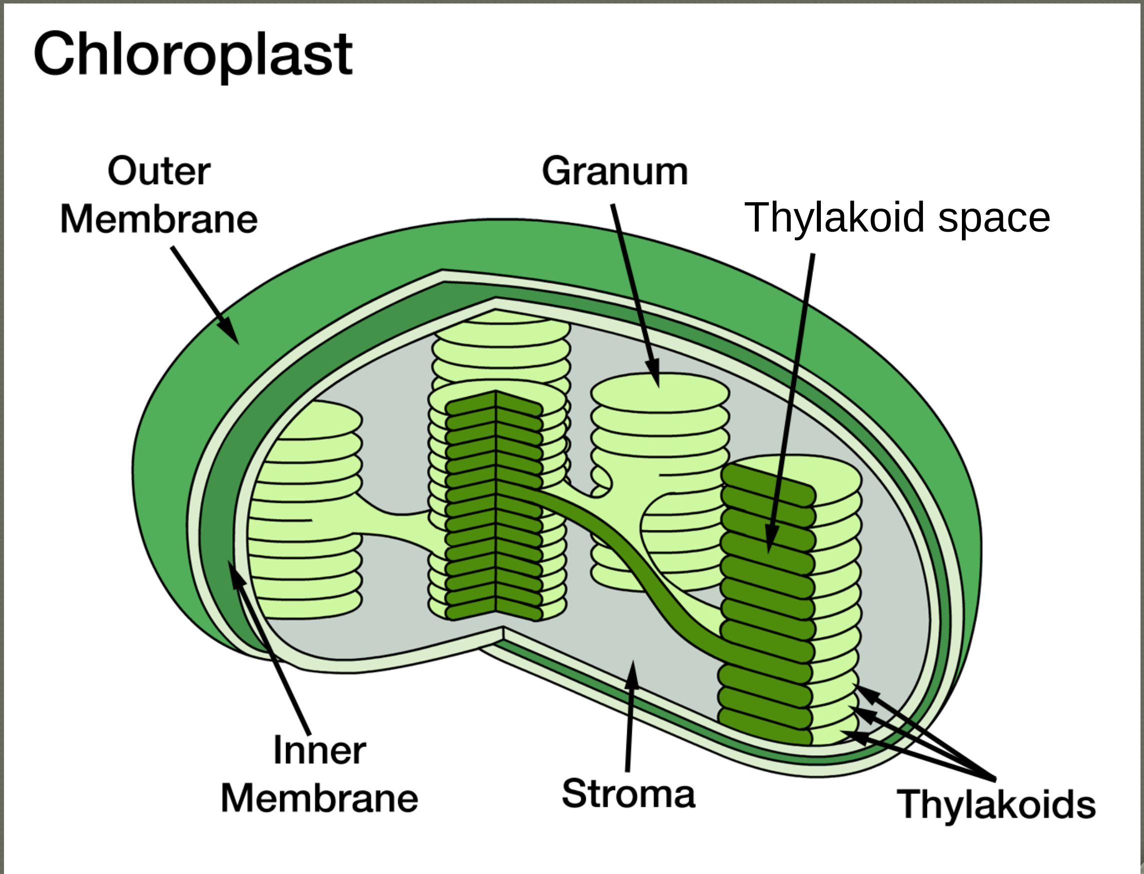


(e) Purple sulfur bacteria

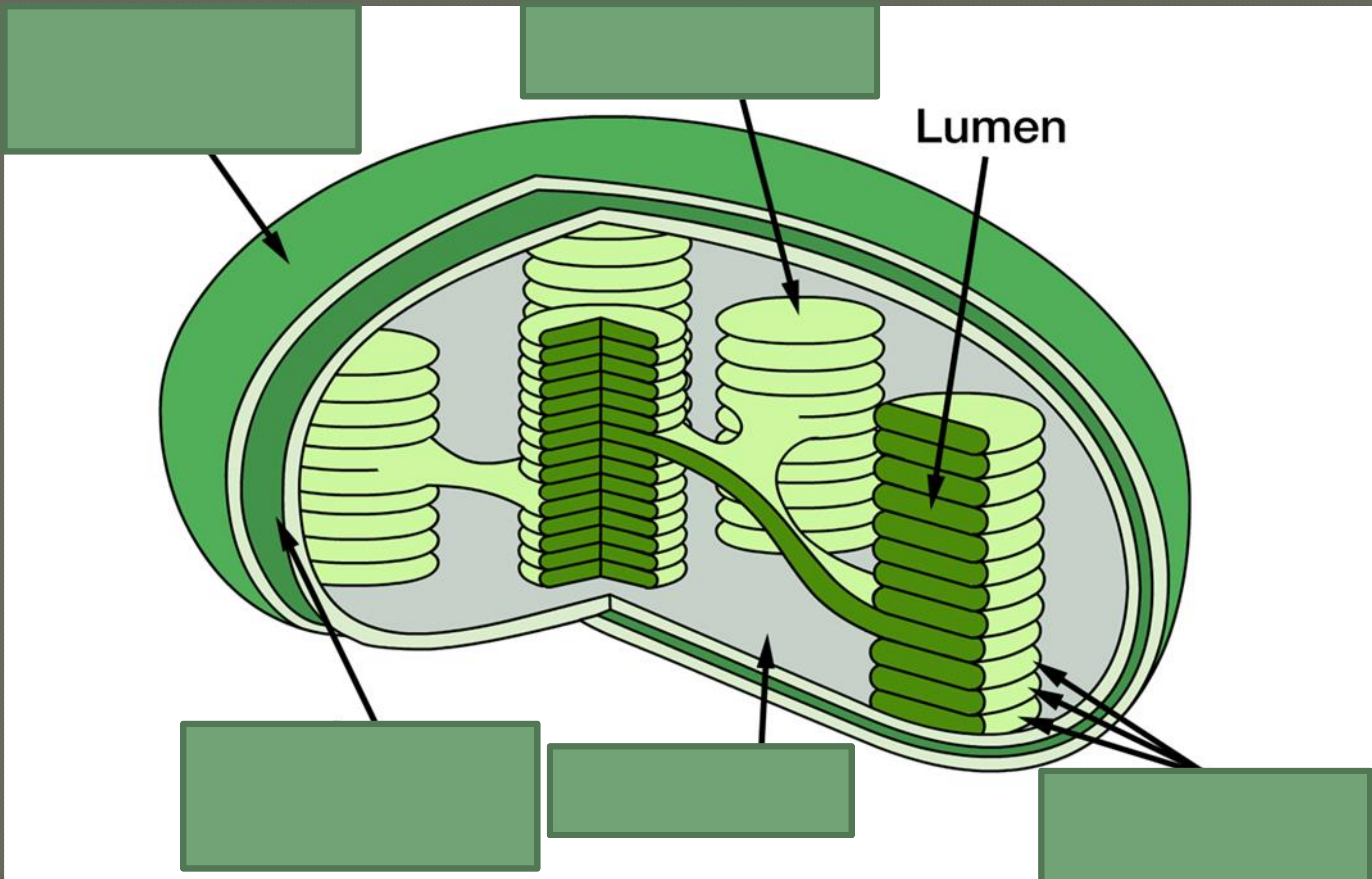
1 µm

Photosynthesis: Converts light energy to chemical energy of food

- Chloroplasts: sites of photosynthesis in plants

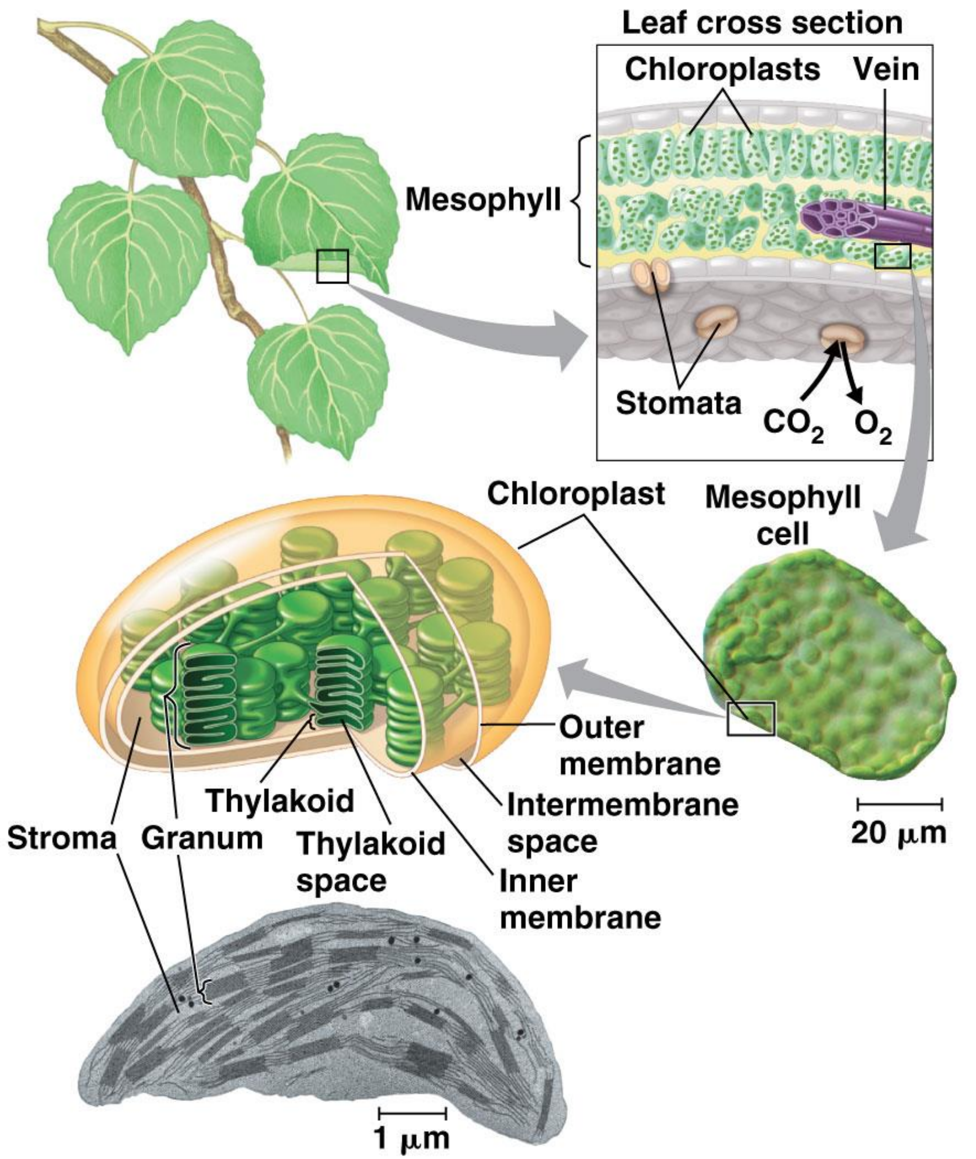


Structure of the Chloroplast



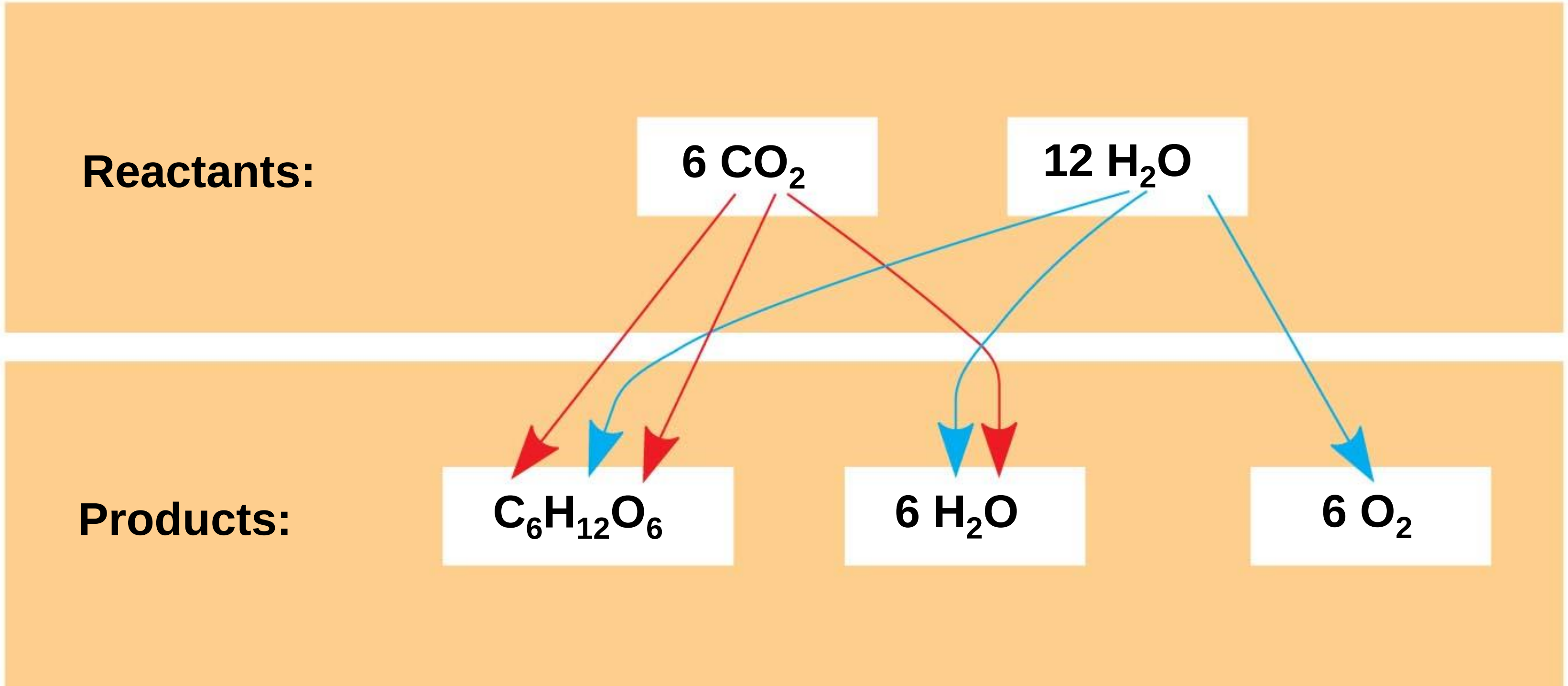
Sites of Photosynthesis

- **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



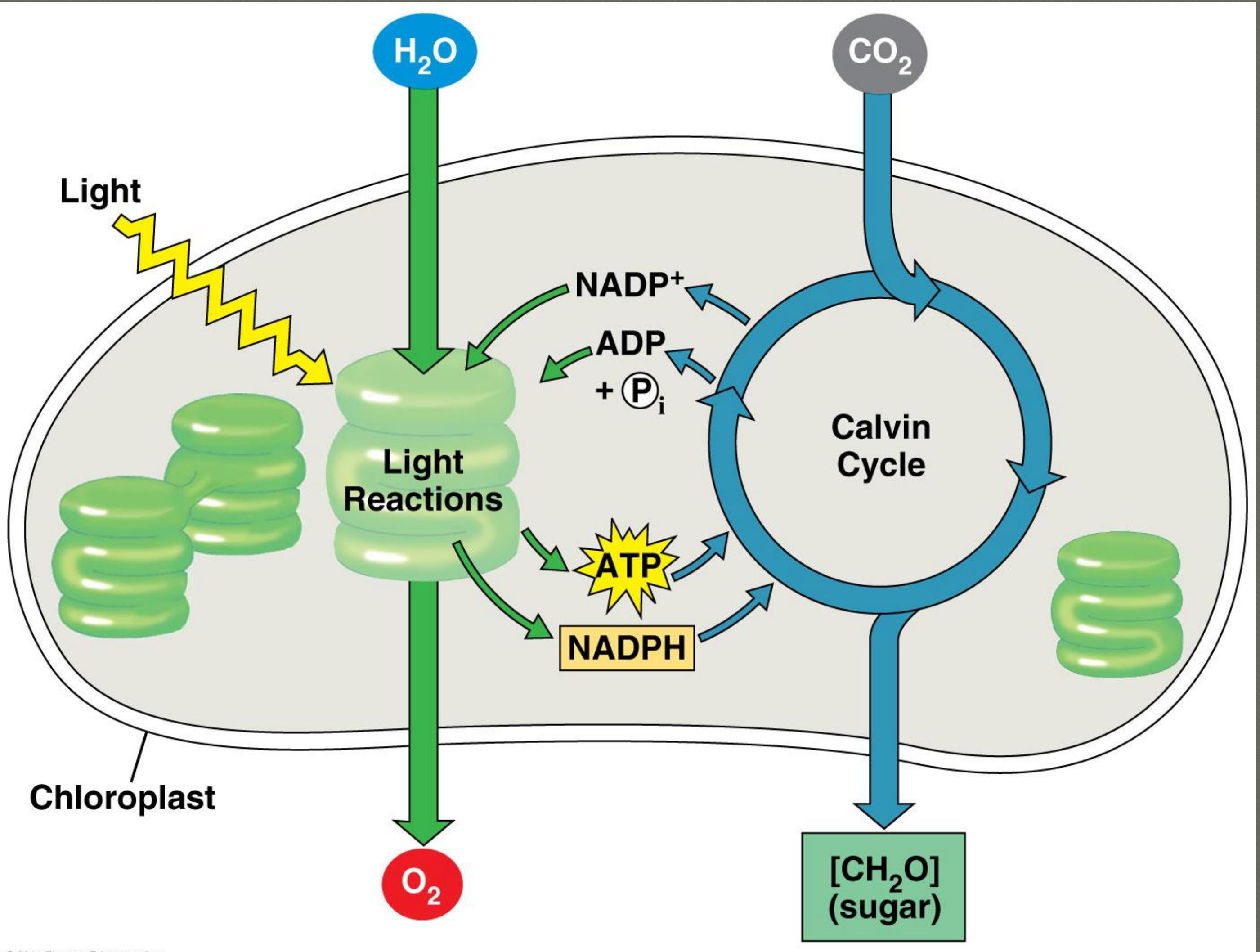
Tracking atoms through photosynthesis

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



Photosynthesis = Light Reactions + Calvin Cycle

"photo" *"synthesis"*

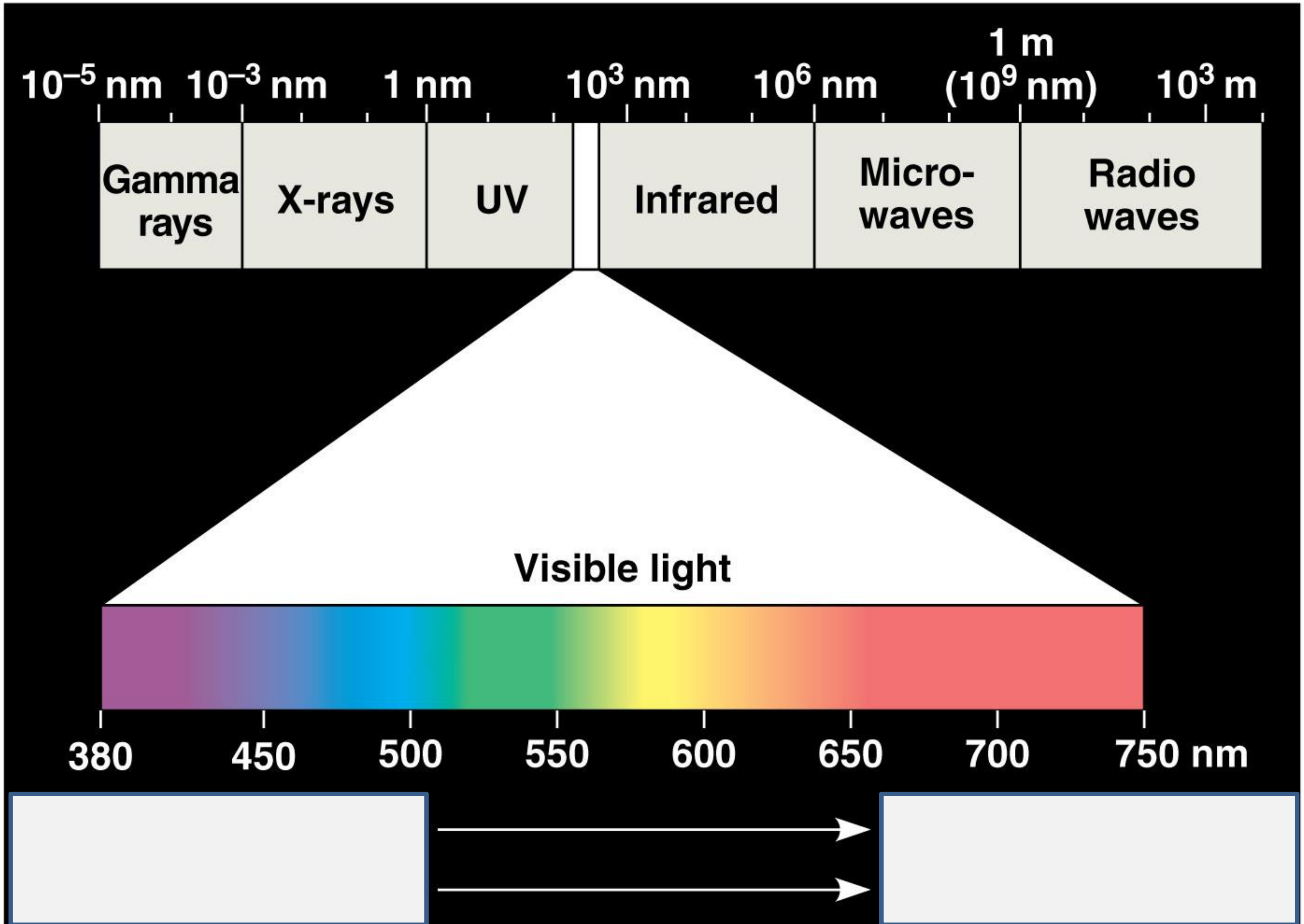


Light Reactions: Convert solar energy to chemical energy of ATP and NADPH

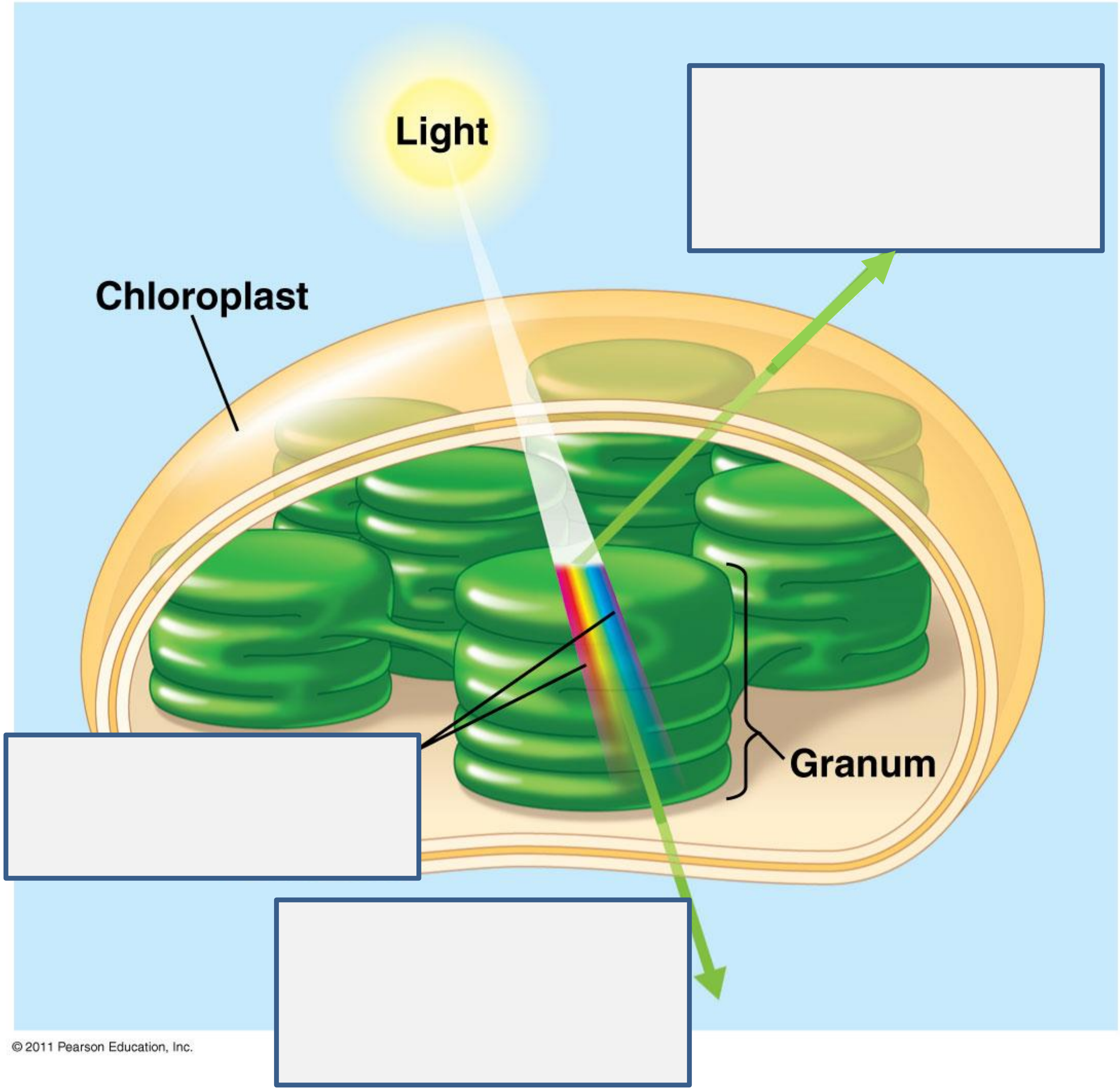
Nature of sunlight

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

Electromagnetic Spectrum



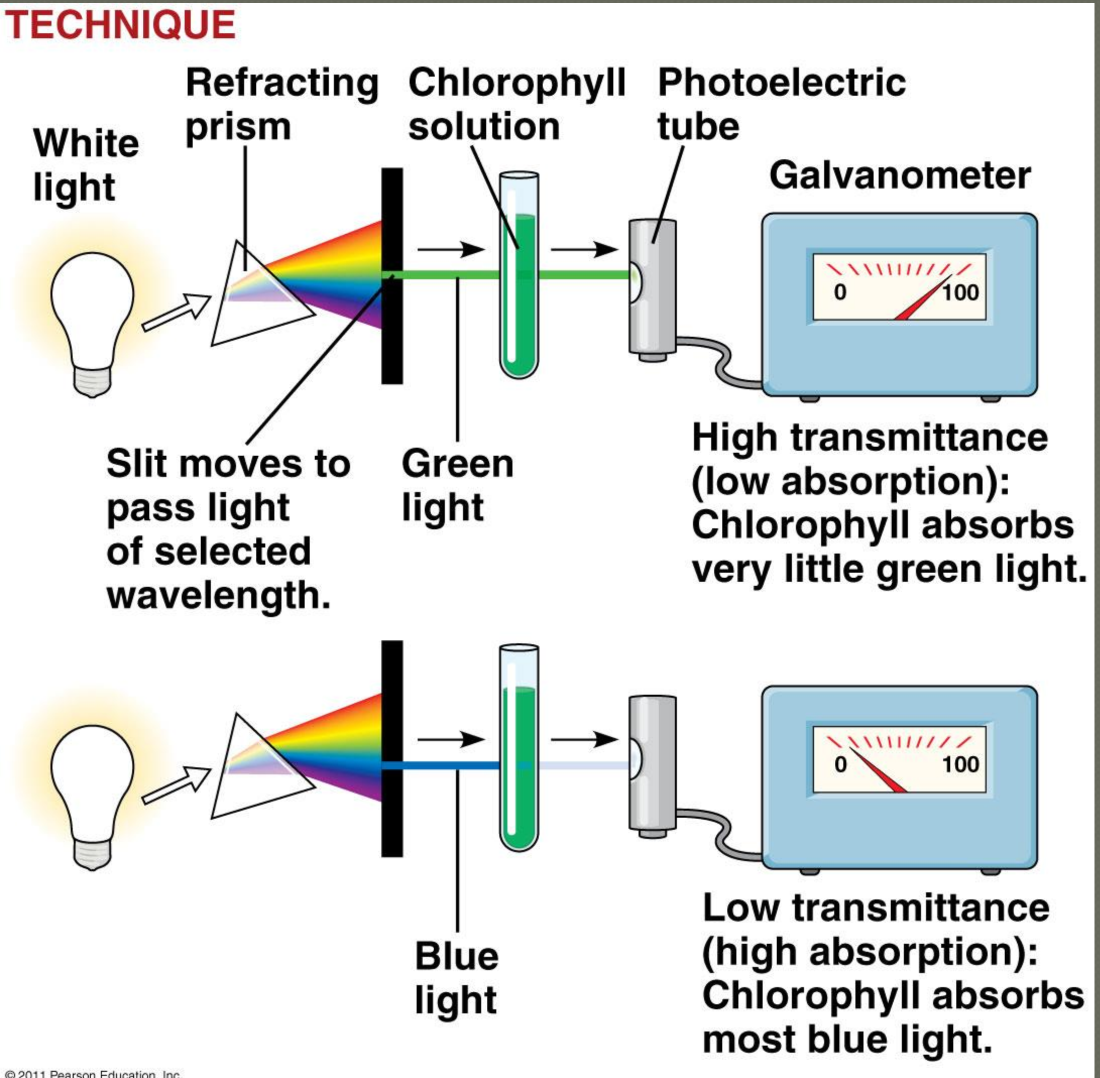
Interaction of light with chloroplasts



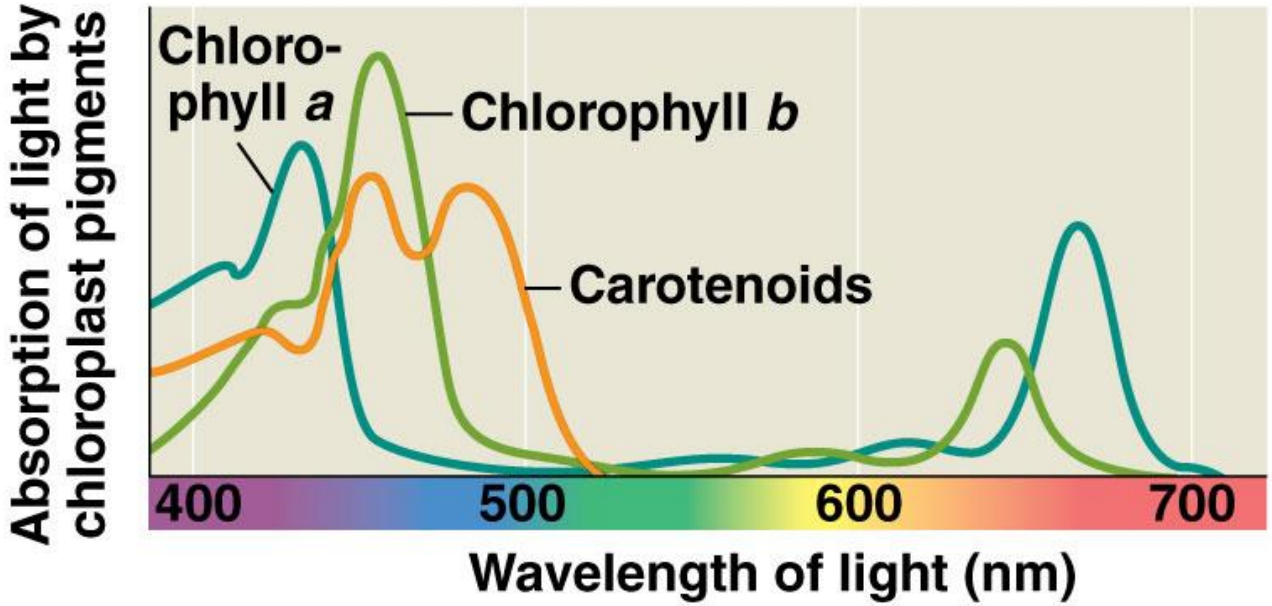
Photosynthetic pigments

- 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
    - Types: **xanthophyll** (yellow) & **carotenes** (orange)
  - **anthocyanin** (red, purple, blue): photoprotection, antioxidants

Absorption Spectrum: determines effectiveness of different wavelengths for photosynthesis



RESULTS



(a) Absorption spectra

1. Which color/wavelength of light provides the MOST energy to plants?

   Purple/Violet/Blue (400-450 nm) because highest absorption levels

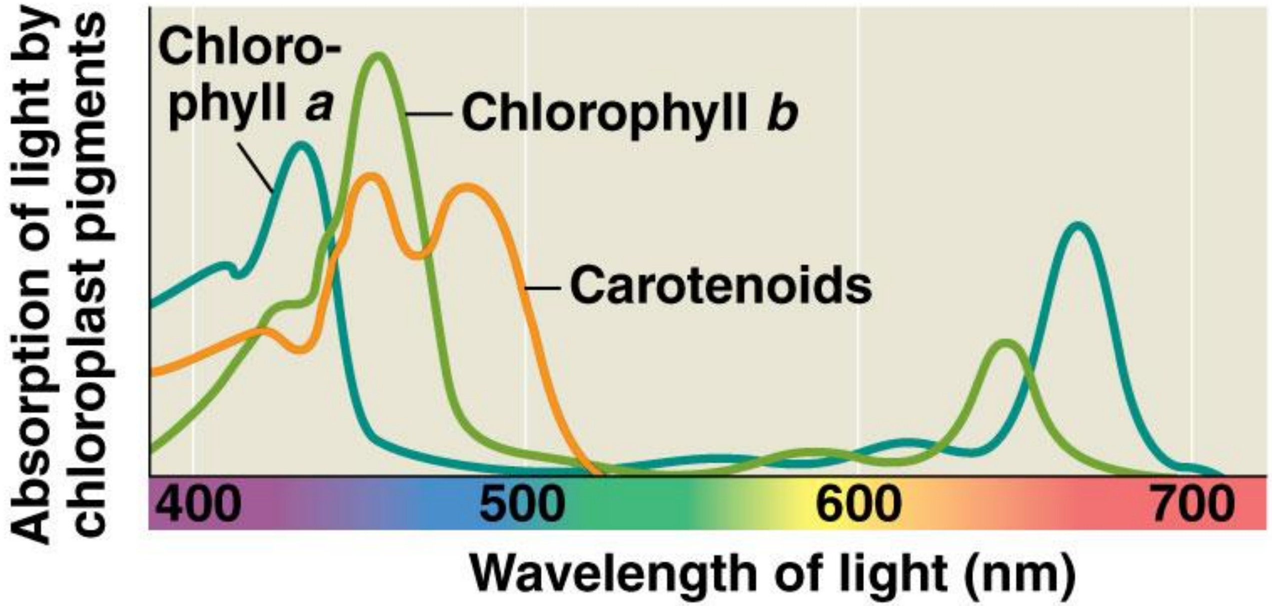
2. Why do most pigments have greater absorbance of shorter wavelengths of light vs. longer wavelengths?

   Long wavelengths don't provide as much energy so photosynthesis rates/products would be less

3. Why would a plant not have pigments to capture ALL wavelengths of light?

   Takes too much energy to synthesize so many pigments;
   Might absorb too much energy which could damage the plant

RESULTS



(a) Absorption spectra

4. Why do most plants appear green?

Green wavelengths not absorbed by chlorophyll, but reflected instead

5. If a plant contained mostly carotenoids, what color would you expect them to appear?

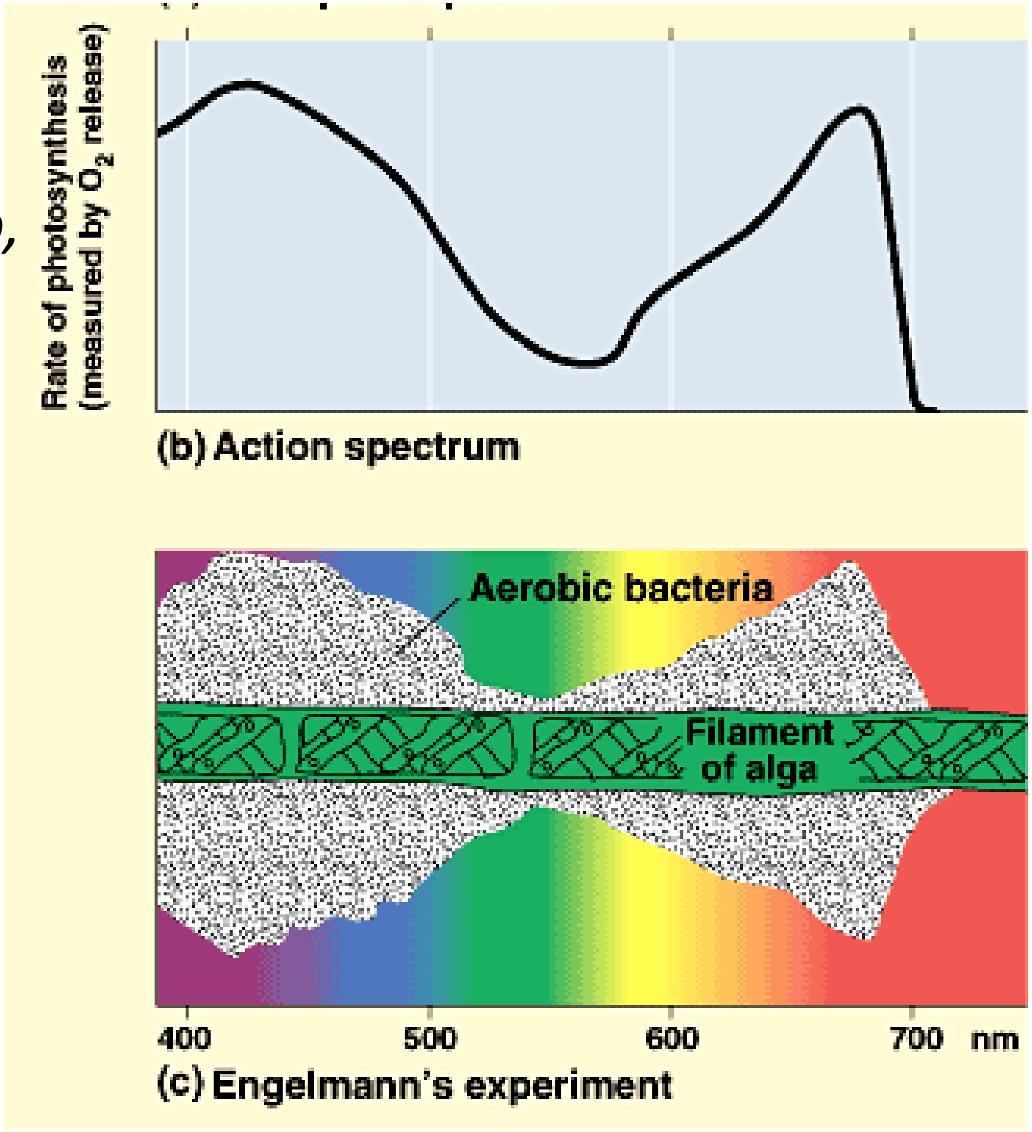
Yellow/orange/red

Action Spectrum: plots rate of photosynthesis vs. wavelength

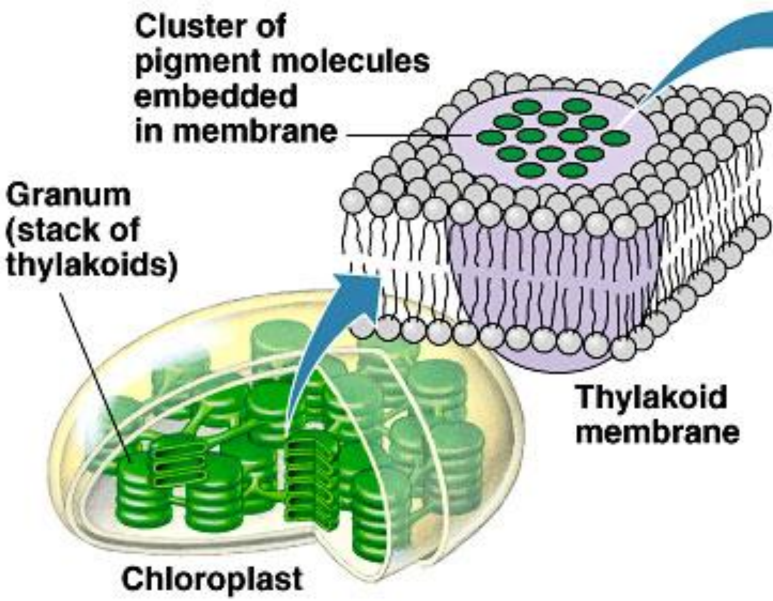
(absorption of chlorophylls a, b, & carotenoids combined)

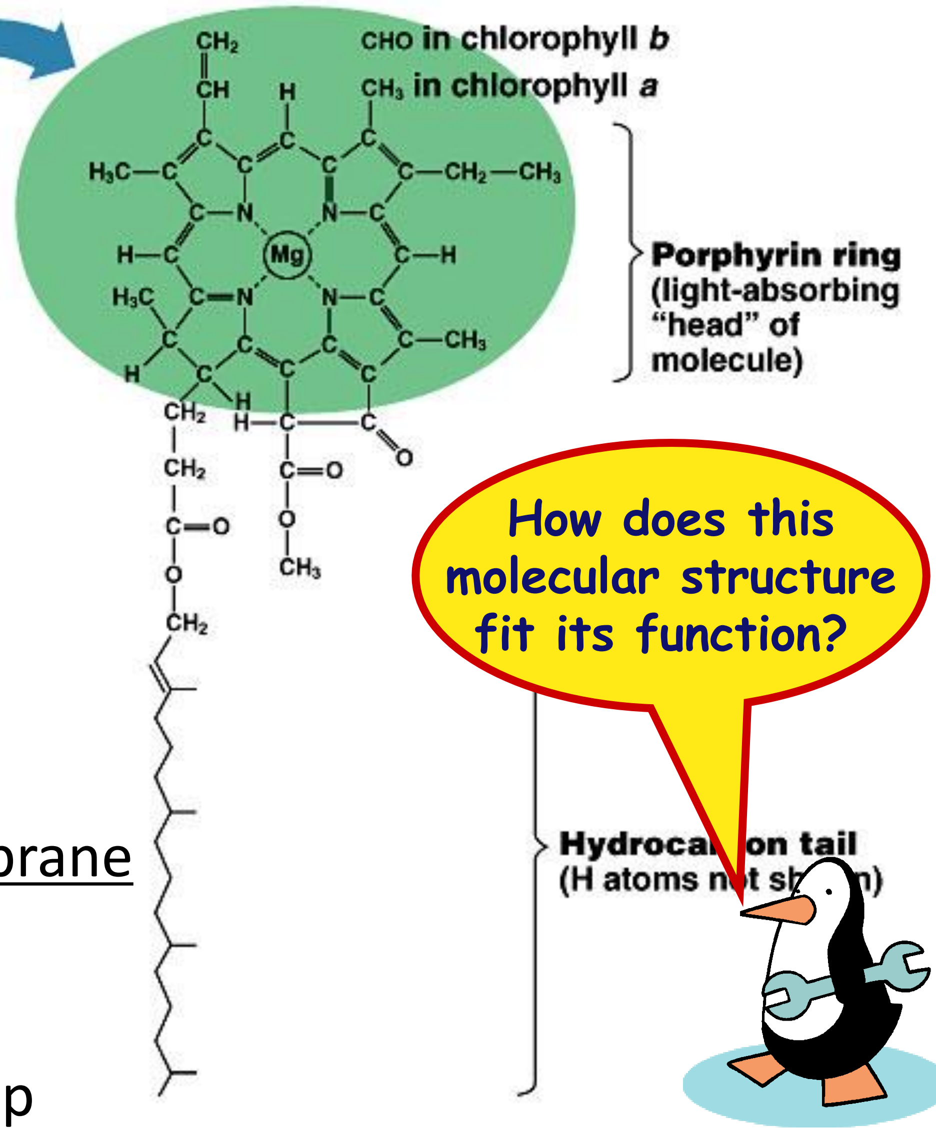
Engelmann: used bacteria to measure rate of photosynthesis in algae; established action spectrum

Which wavelengths of light are most effective in driving photosynthesis?



Pigments of photosynthesis





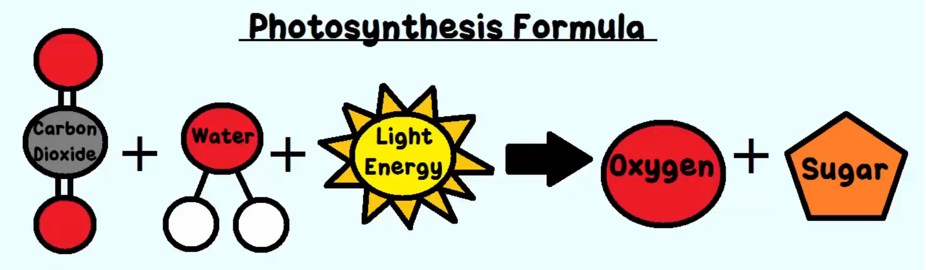
- Chlorophylls & other pigments
  - embedded in thylakoid membrane
  - arranged in a "photosystem"
    - collection of molecules
  - structure-function relationship

Amoeba Sisters:

Photosynthesis

Light *Dependent* Reactions

- Location: ____
- Reaction: Light + __________ → ____
- Why is water "split"?
- Circle all of the components involved in the Light Reactions in the equation below.



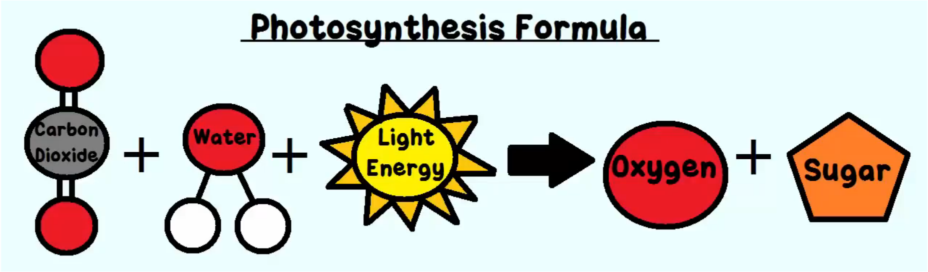
- Would the light reactions be able to occur at night? Why or why not?

Amoeba Sisters:

Photosynthesis

Light *Independent* Reactions

- A.k.a ______________________________ or _______________________________________
- When can this stage occur? ____
- Location: ____
- Reaction: ___________ + ____________ + ______________ → ______________________
- Circle all of the components involved in the Light Independent Reactions in the equation below.



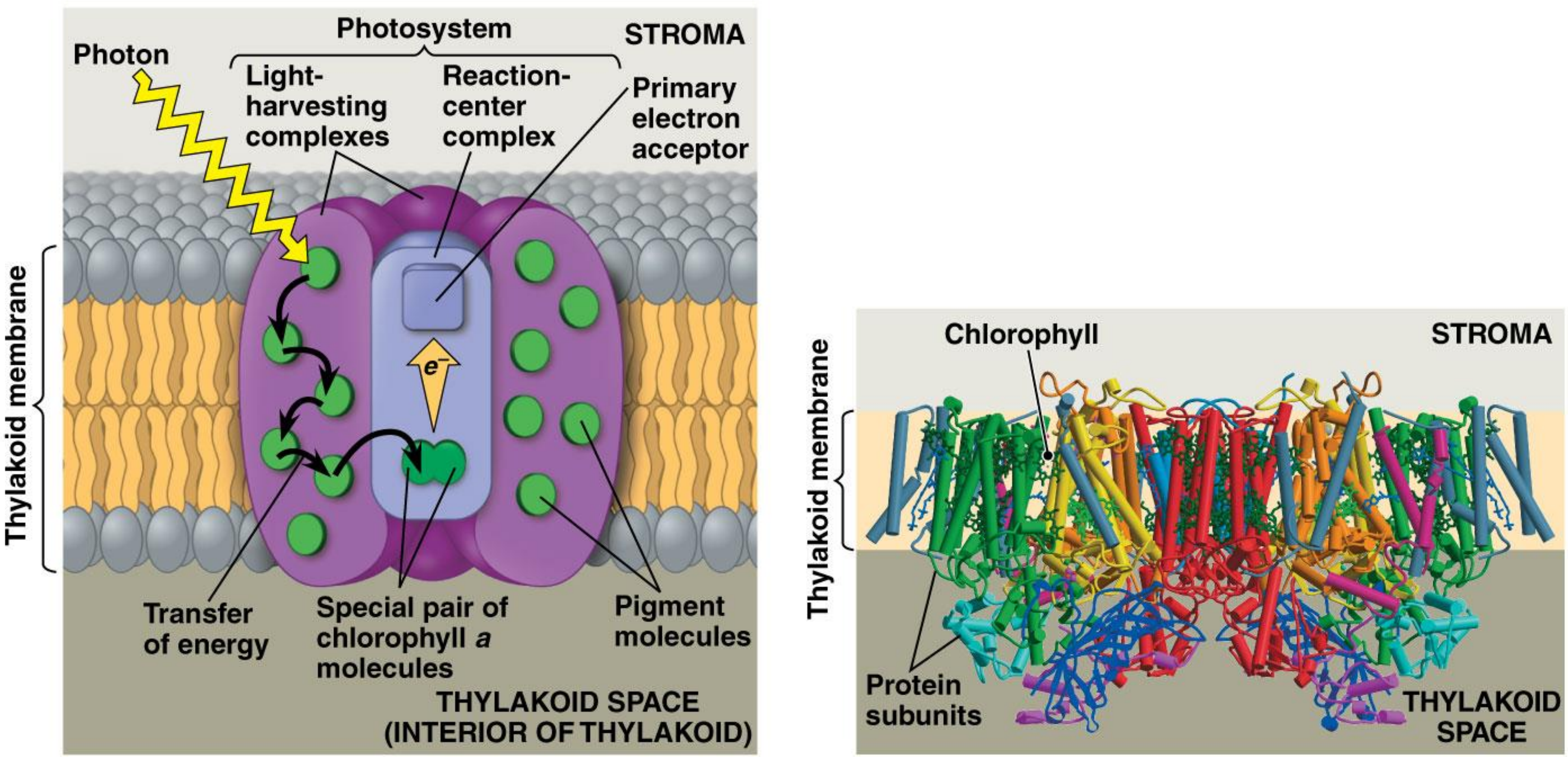
Light Reactions

Light Reactions

Overview:

1. Light energy splits **H_2O to O_2** releasing high energy electrons (e^-)
2. Movement of e^- used to generate **ATP**
3. Electrons end up on $NADP^+$, reducing it to **NADPH**

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

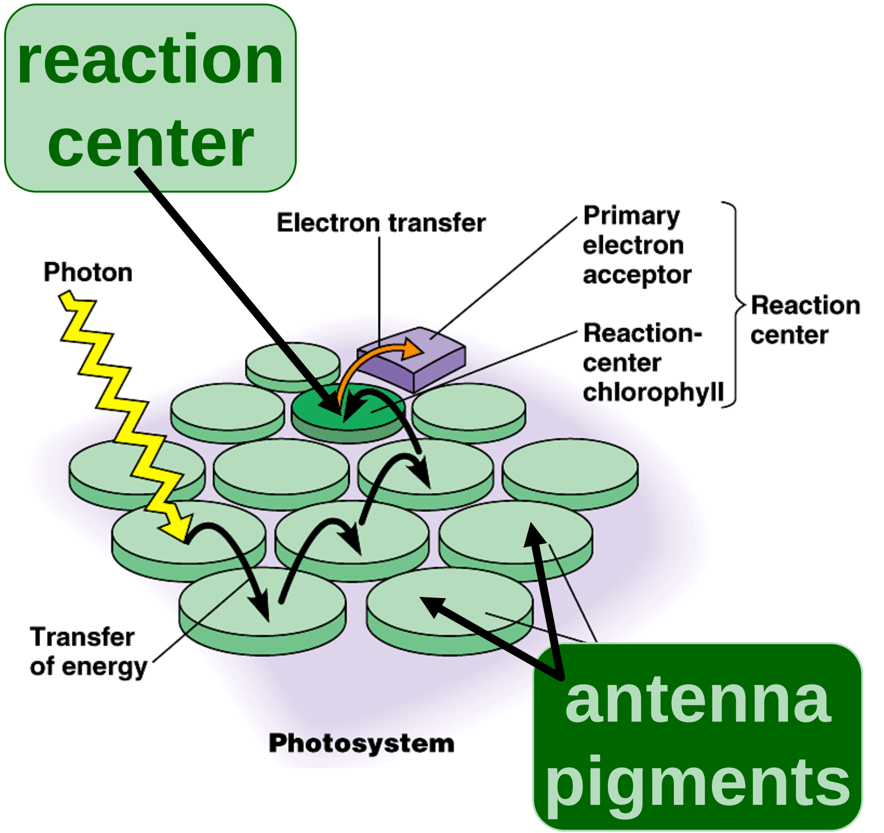


(a) How a photosystem harvests light

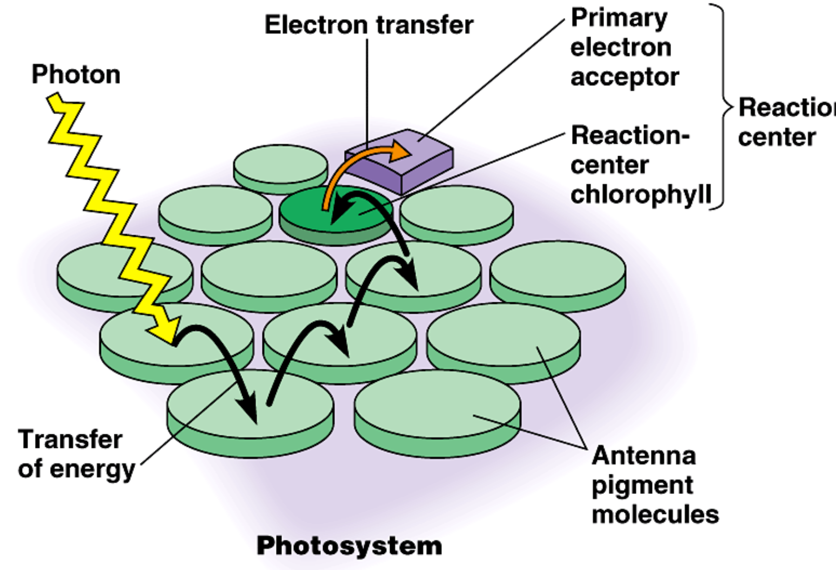
(b) Structure of photosystem II

Photosystems of photosynthesis

- 2 photosystems in thylakoid membrane
  - collections of chlorophyll molecules
  - act as light-gathering molecules
  - Photosystem II
    - chlorophyll *a*
    - P_{680} = absorbs 680nm wavelength red light
  - Photosystem I
    - chlorophyll *b*
    - P_{700} = absorbs 700nm wavelength red light



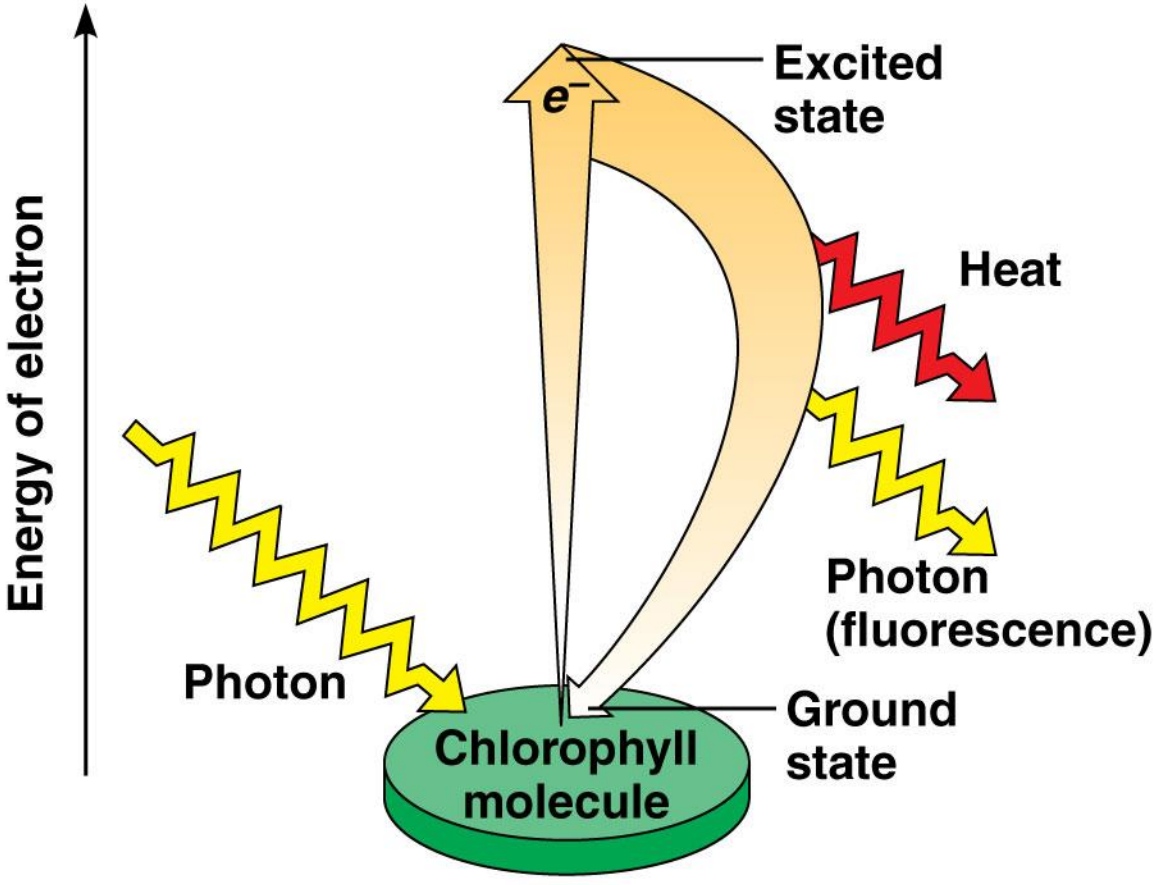
What's Happening?



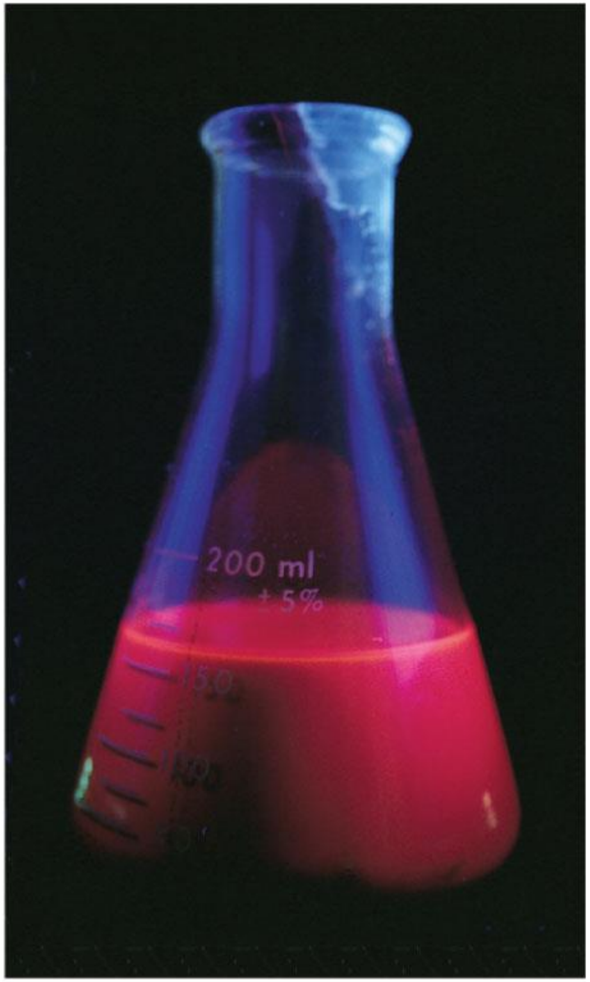
1. Photons of light are absorbed by clusters of pigment molecules (antenna molecules) in the thylakoid membrane.

2. When any antenna molecule absorbs a photon, it is transmitted from molecule to molecule until it reaches a particular chlorophyll *a* molecule = the **reaction center**.
3. At the reaction center is a **primary electron acceptor** which removes an excited electron from the reaction center chlorophyll a.
4. **This starts the light reactions.**
5. Don't compete with each other, work synergistically using different wavelengths

Electrons in chlorophyll molecules are excited by absorption of light



(a) Excitation of isolated chlorophyll molecule



(b) Fluorescence

Electron Flow

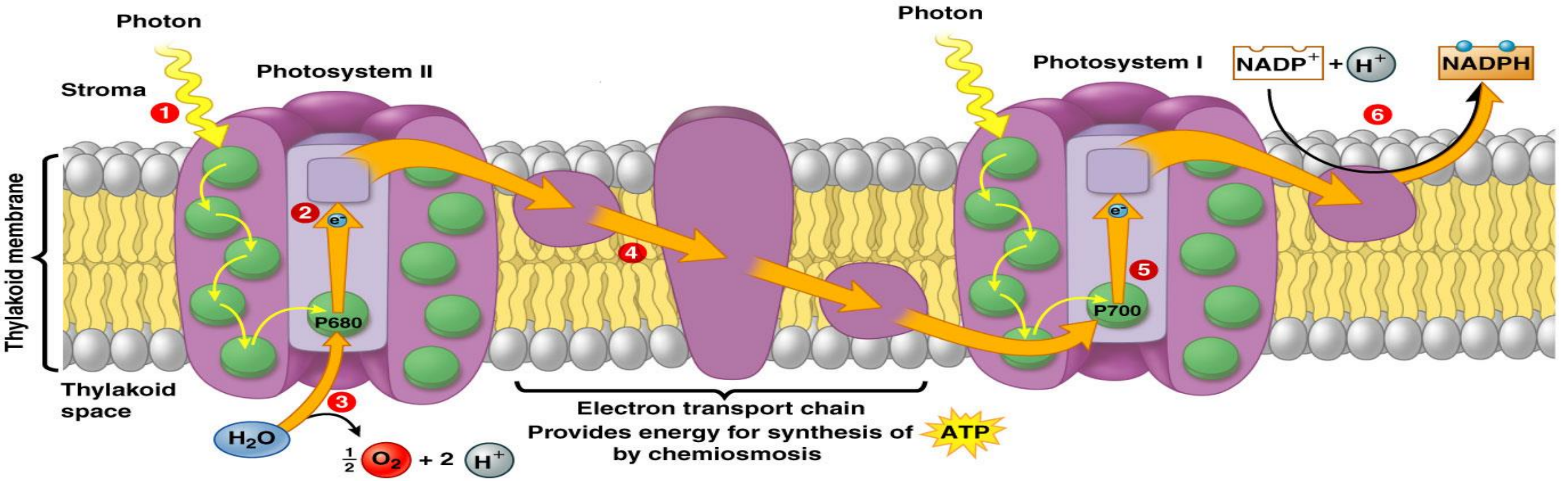
Two routes for electron flow:

1. Linear (noncyclic) electron flow
   1. PSII → PSI → Calvin Cycle
   2. Water is split; O2 released
   3. Normal/preferred pathway

Generates ATP, NADPH, and releases Oxygen

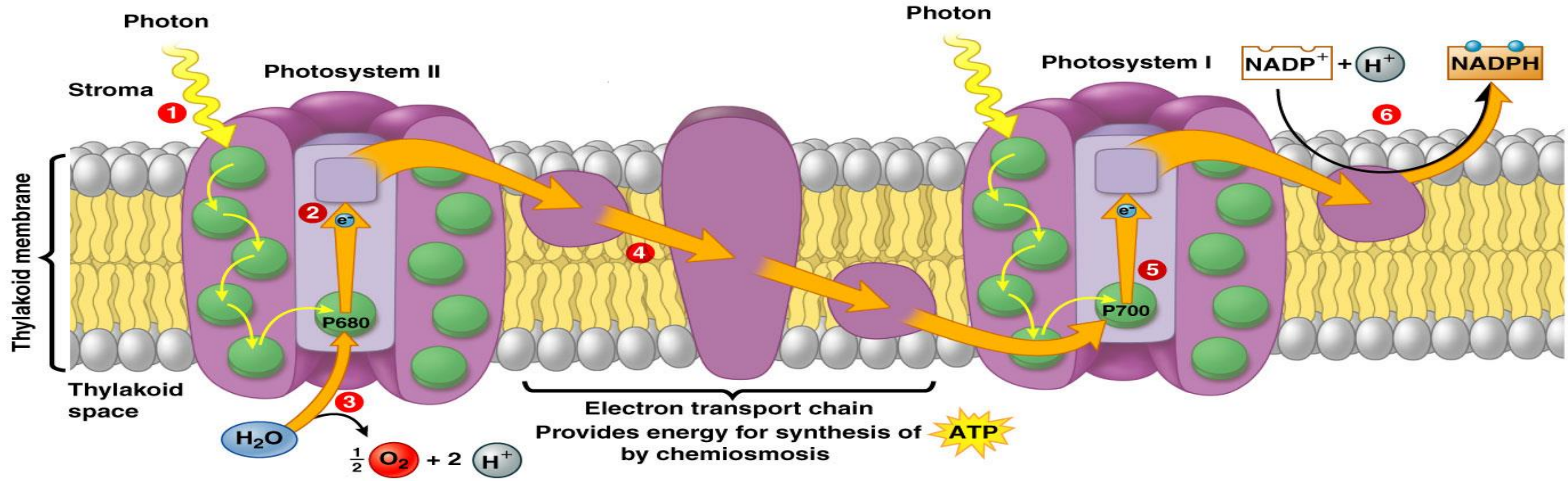
2. Cyclic electron flow
   1. PSI only → Calvin Cycle
   2. No water splitting
   3. No NADPH or O2 produced
   4. Utilized when ATP supplies are low or when NADPH is high

Generates ATP only



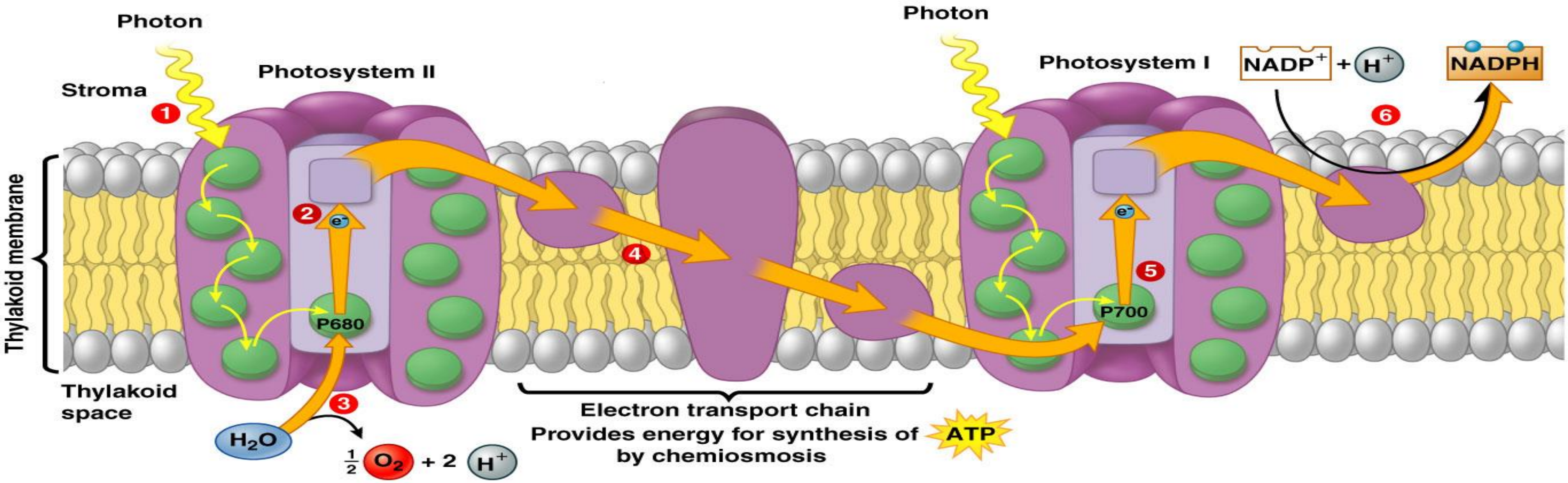
1. Photons of light are absorbed by chlorophyll (& accessory pigment molecules) which excites electrons (e-)

2. Excited e- are passed to the primary electron acceptor in the reaction center of Photosystem II.



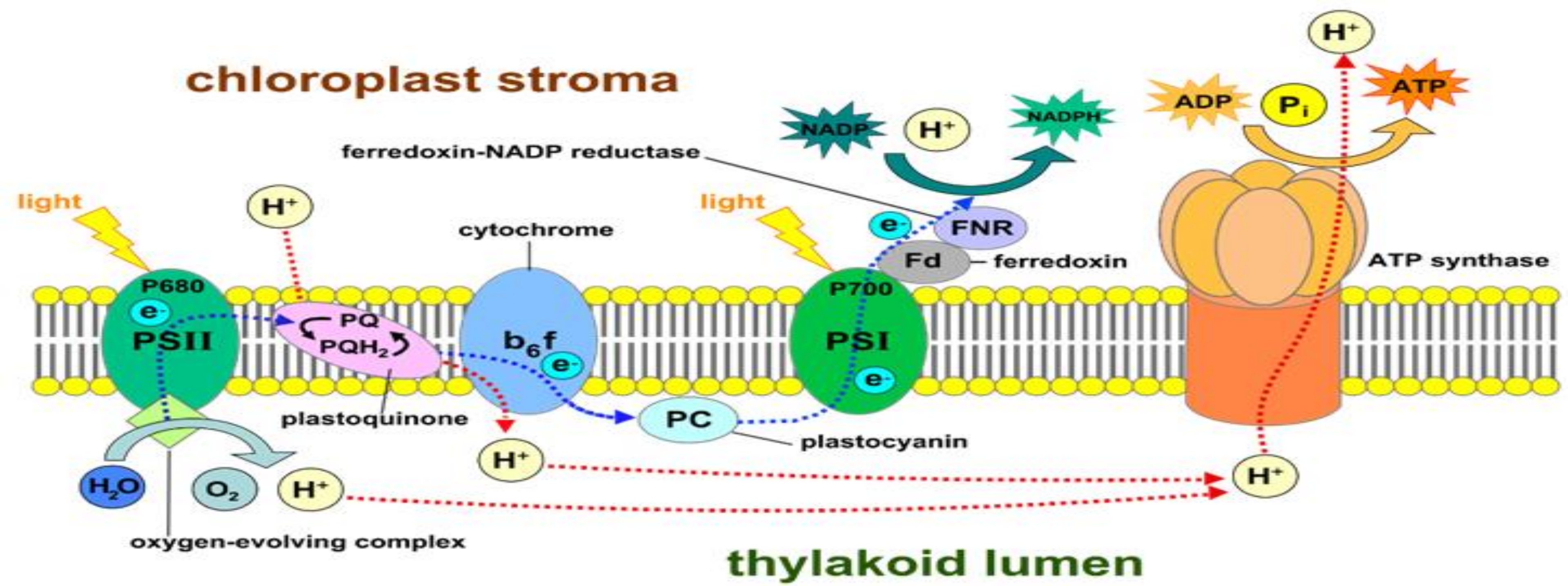
3. Water is split (regenerates more e-) and O_2 is released.

4. e- are passed through an ETC (electron transport chain)



5. e- activate primary e- acceptor of Photosystem I. PSI also captures more photons of light here.

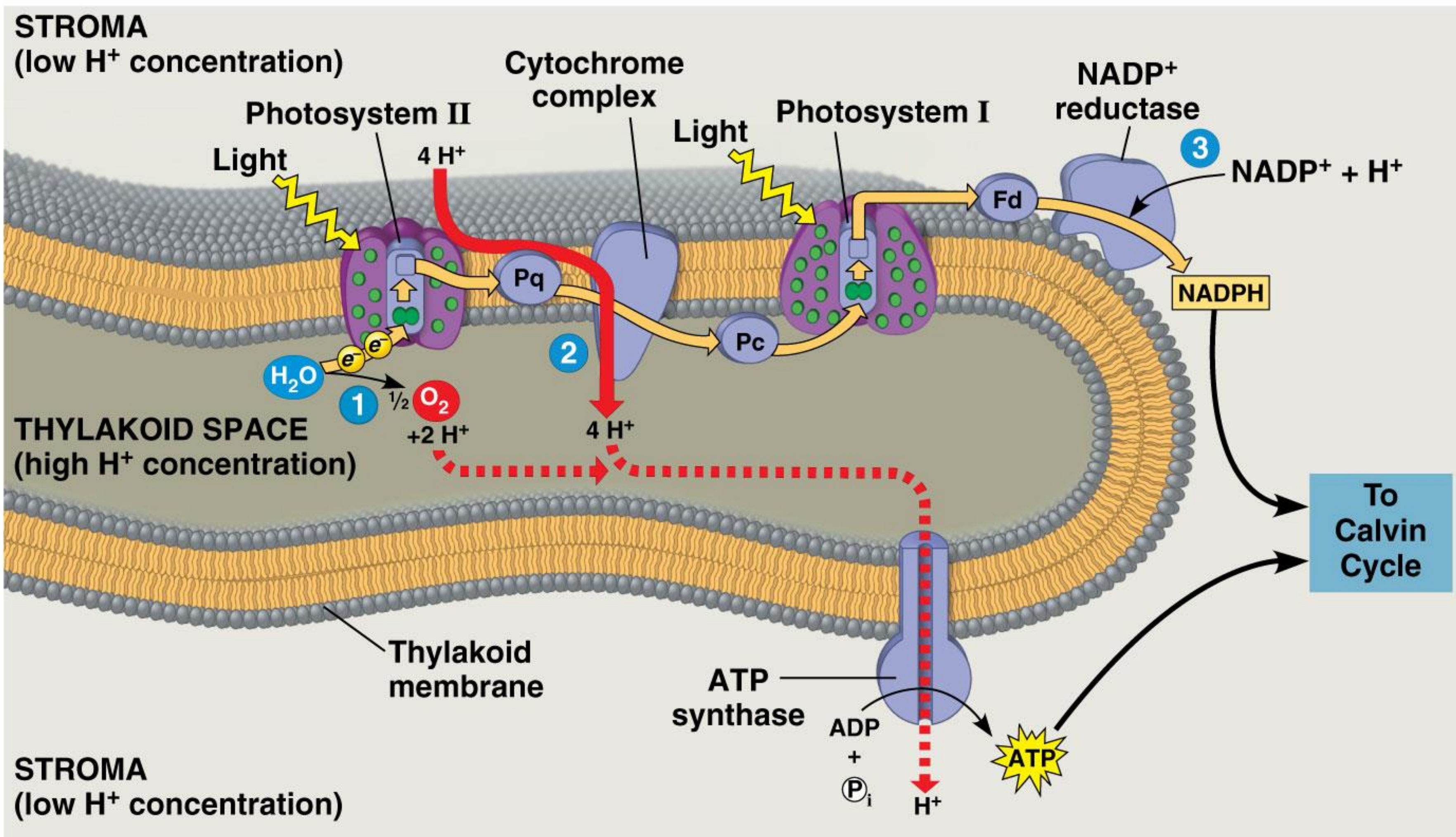
6. e- are passed through a second ETC and NADP is reduced to make NADPH.

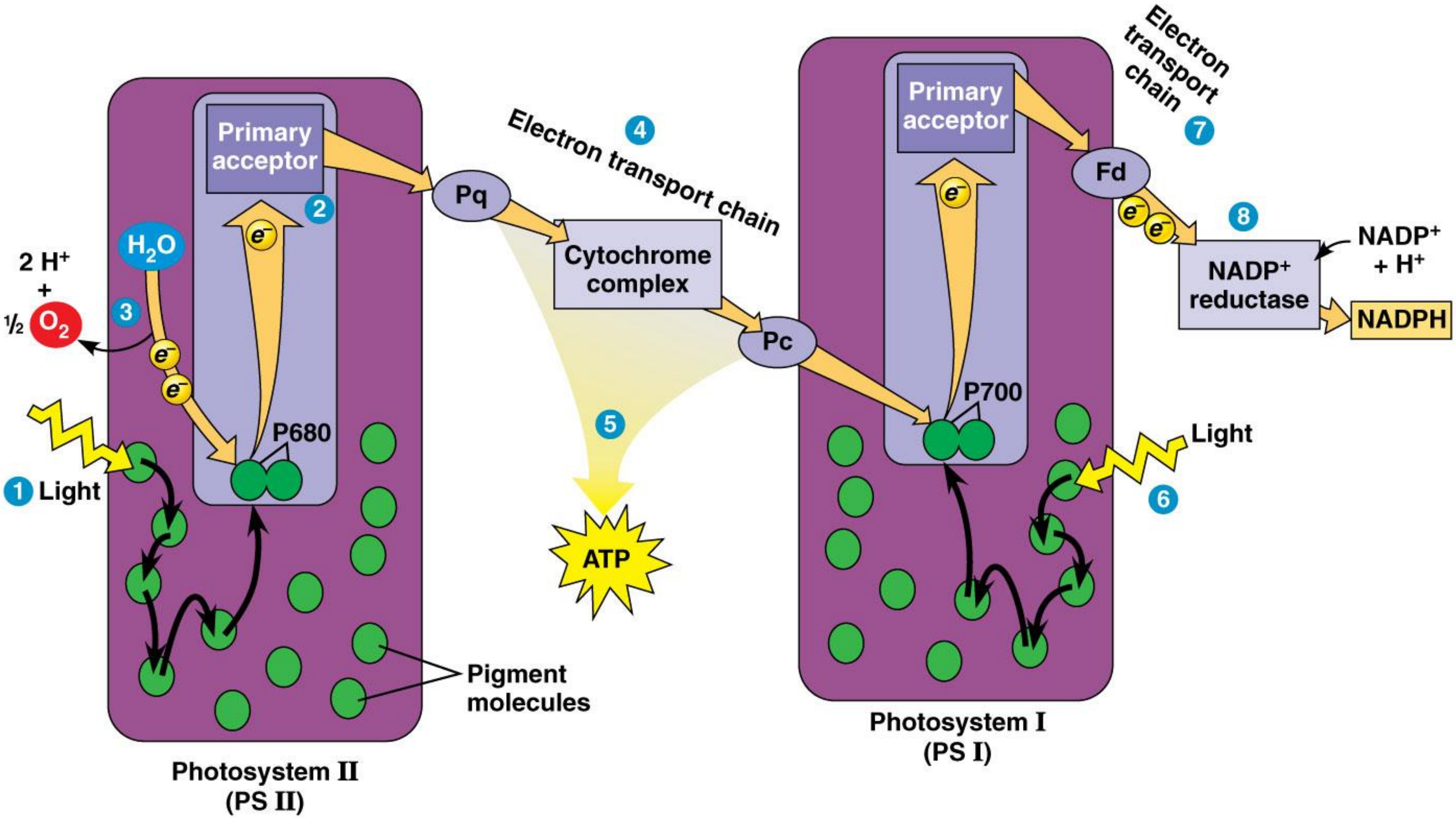


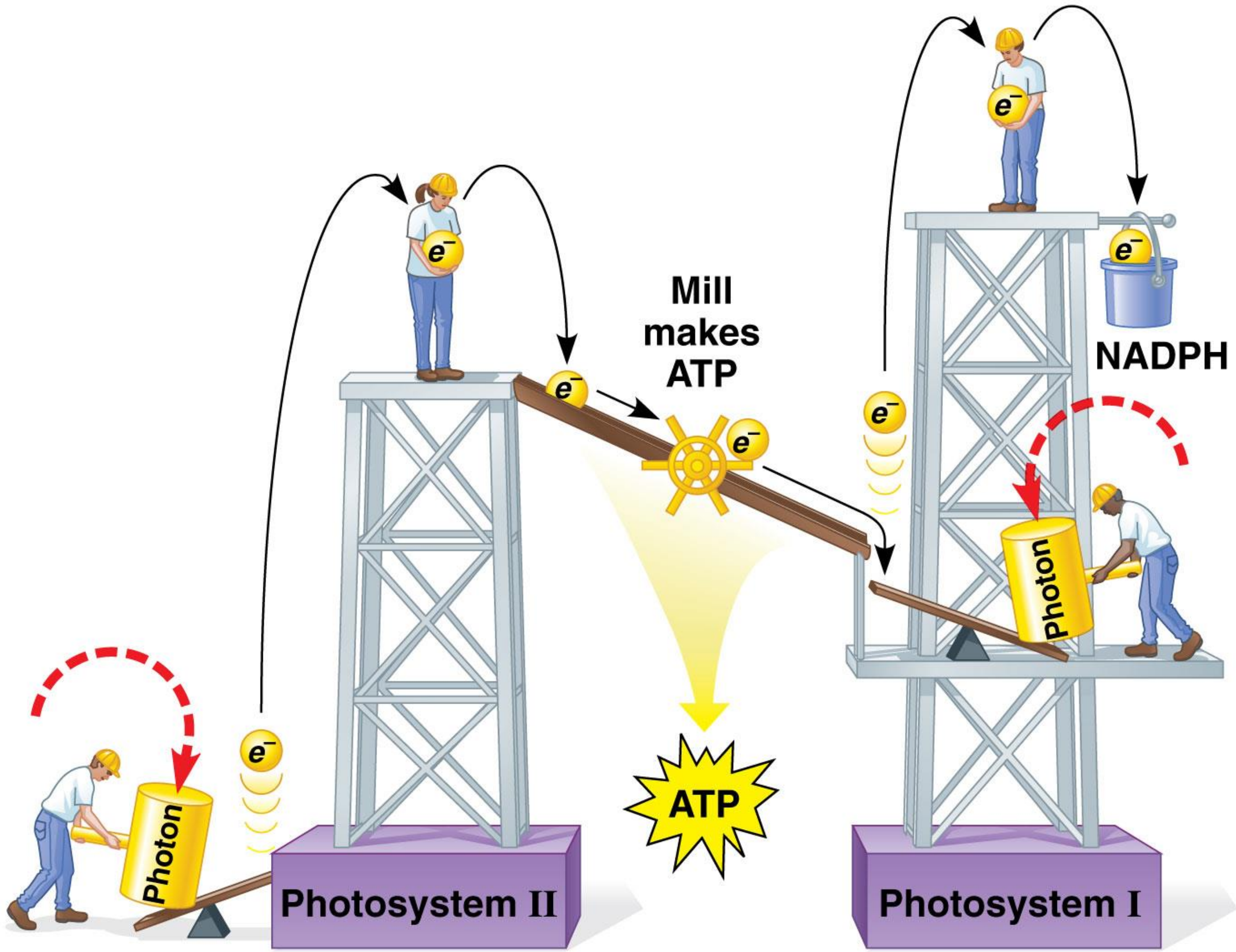
- During the e- transfers through the ETC, H+ are pumped across the thylakoid membrane to set up a proton-motive force (H+ gradient).
- As protons flow through ATP Synthase by chemiosmosis, ATP is produced.
- These steps together are called photophosphorylation

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




Electron transport chain
Primary acceptor
Pq
Cytochrome complex
Pc
Primary acceptor
Fd
Electron transport chain
NADP+ reductase
NADP+ + H+
NADPH
H2O
2 H+ + ½ O2
e−
P680
P700
Light
Light
ATP
Pigment molecules
Photosystem II (PS II)
Photosystem I (PS I)
1
2
3
4
5
6
7
8

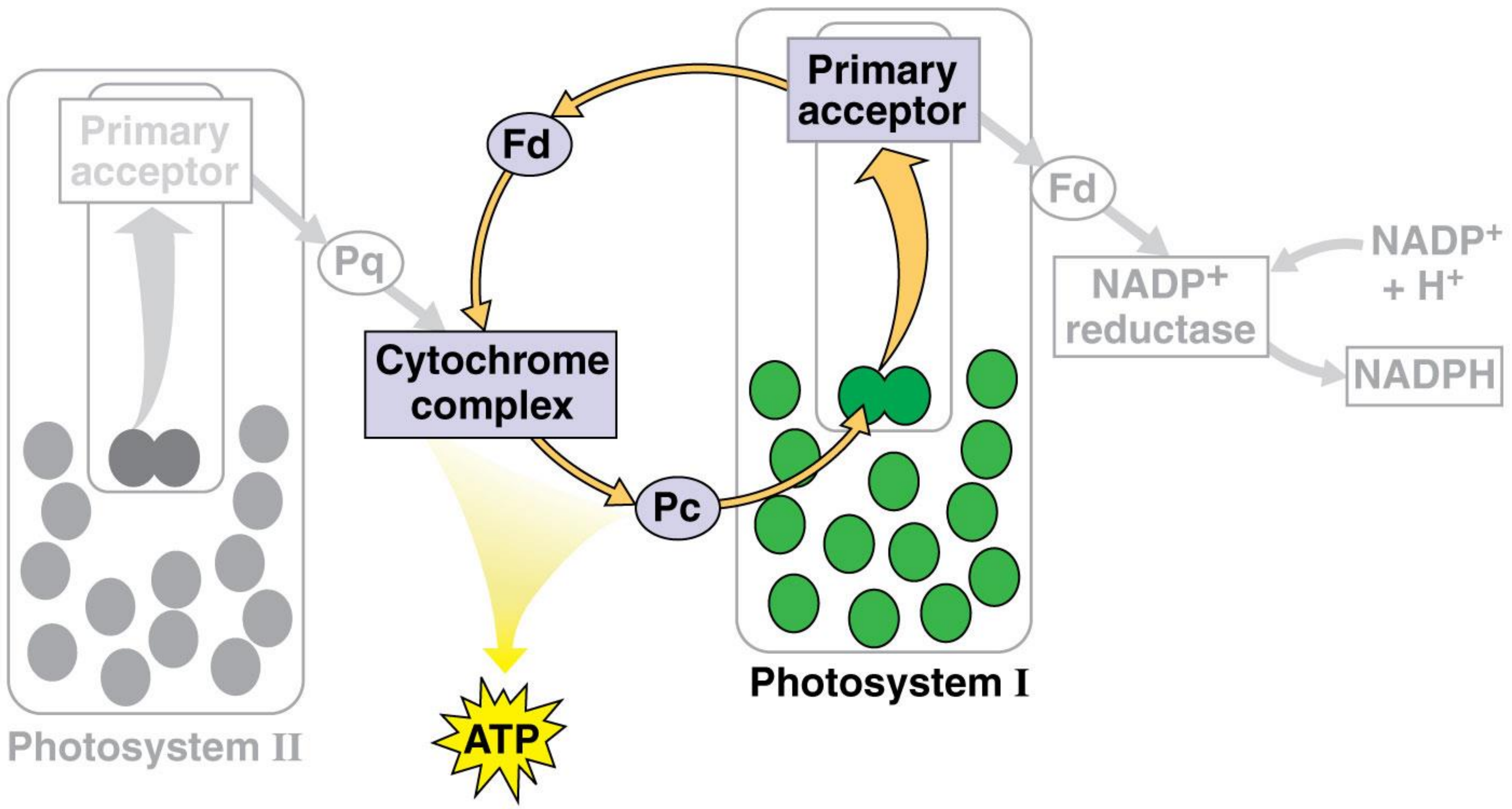


Mechanical analogy for the light reactions

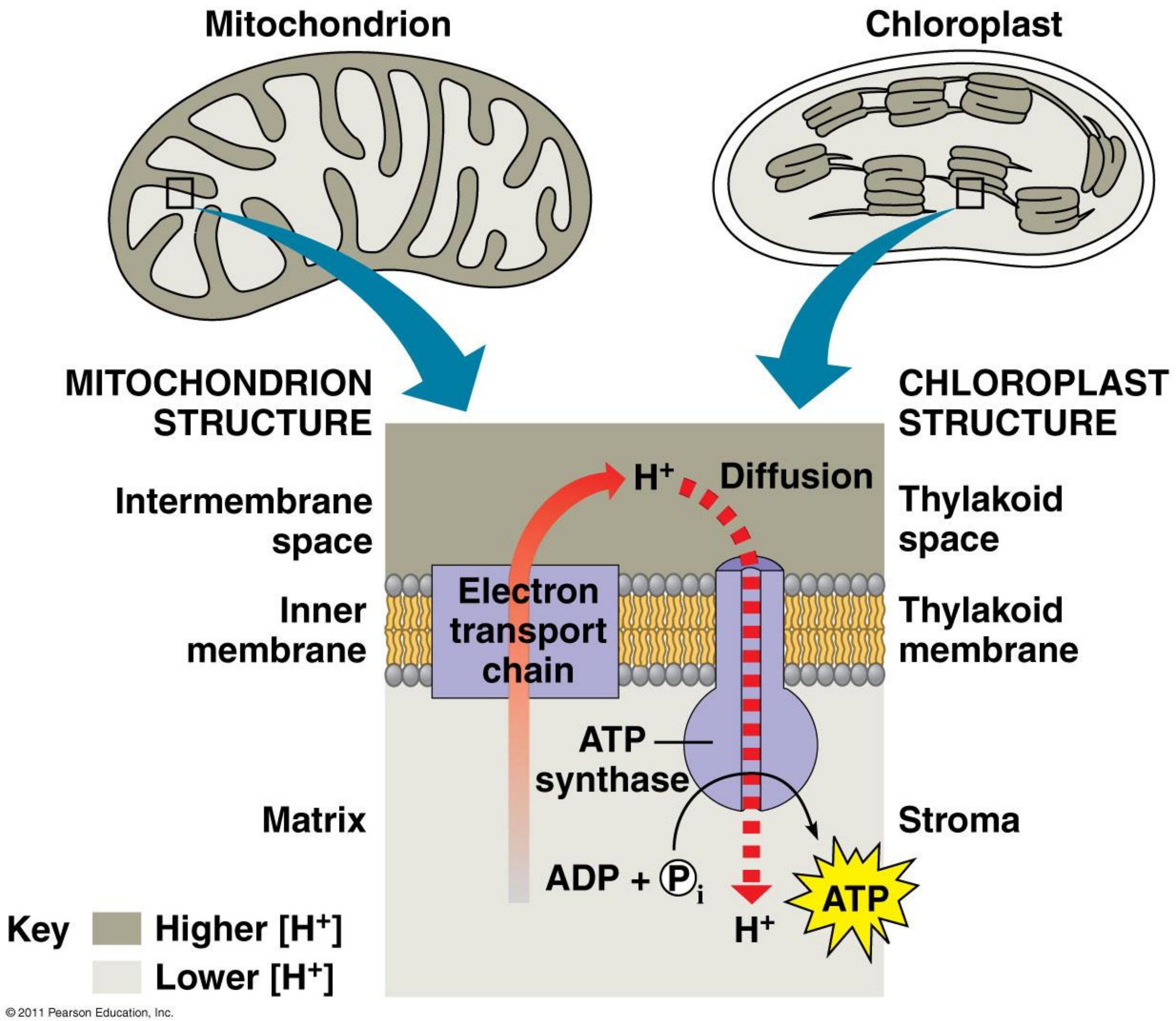
MAIN IDEA of LIGHT REACTIONS:

- Use solar E to generate ATP & NADPH to provide E for Calvin cycle

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



Both respiration and photosynthesis use **chemiosmosis** to generate ATP



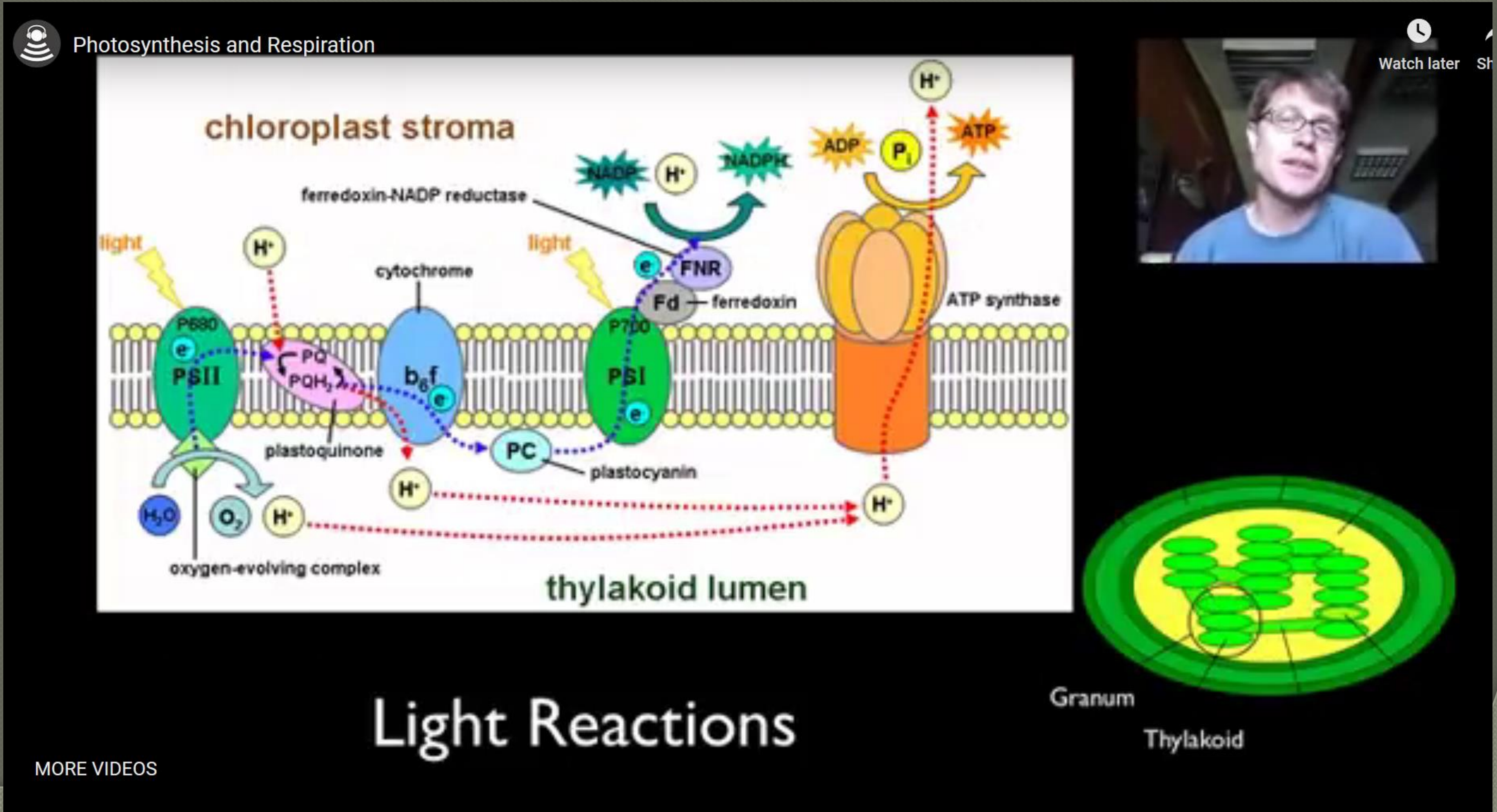
Recap - McGraw Hill

- https://video.search.yahoo.com/yhs/search;_ylt=AwrEeSV0sy9cLTgAM6EnnIlQ;_ylu=X3oDMTByMjB0aG5zBGNvbG8DYmYxBHBvcwMxBHZ0aWQDBHNlYwNzYw--?p=bioflix+photosynthesis&fr=yhs-mozilla-004&hspart=mozilla&hsimp=yhs-004#id=4&vid=5e07661af4ef8ab17f9720b48841dd97&action=view

Start at 1:46
Pause at 4:36

Bozmeman Science

- "Photosynthesis & Respiration"



Calvin Cycle

TedEd: Nature's smallest factory: The Calvin cycle - Cathy Symington

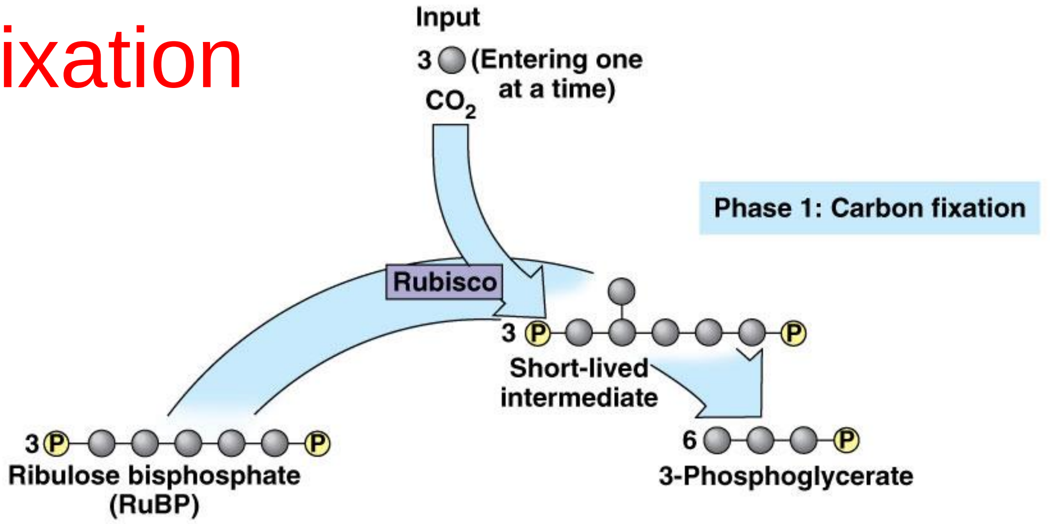
Calvin Cycle (Light Independent Rxns): Uses ATP and NADPH to convert CO_2 to sugar

- Occurs in the stroma
- Uses ATP, NADPH, CO_2
- Produces 3-C sugar G3P *(glyceraldehyde-3-phosphate)*
  - *Ultimately used to form glucose*

Three phases:

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

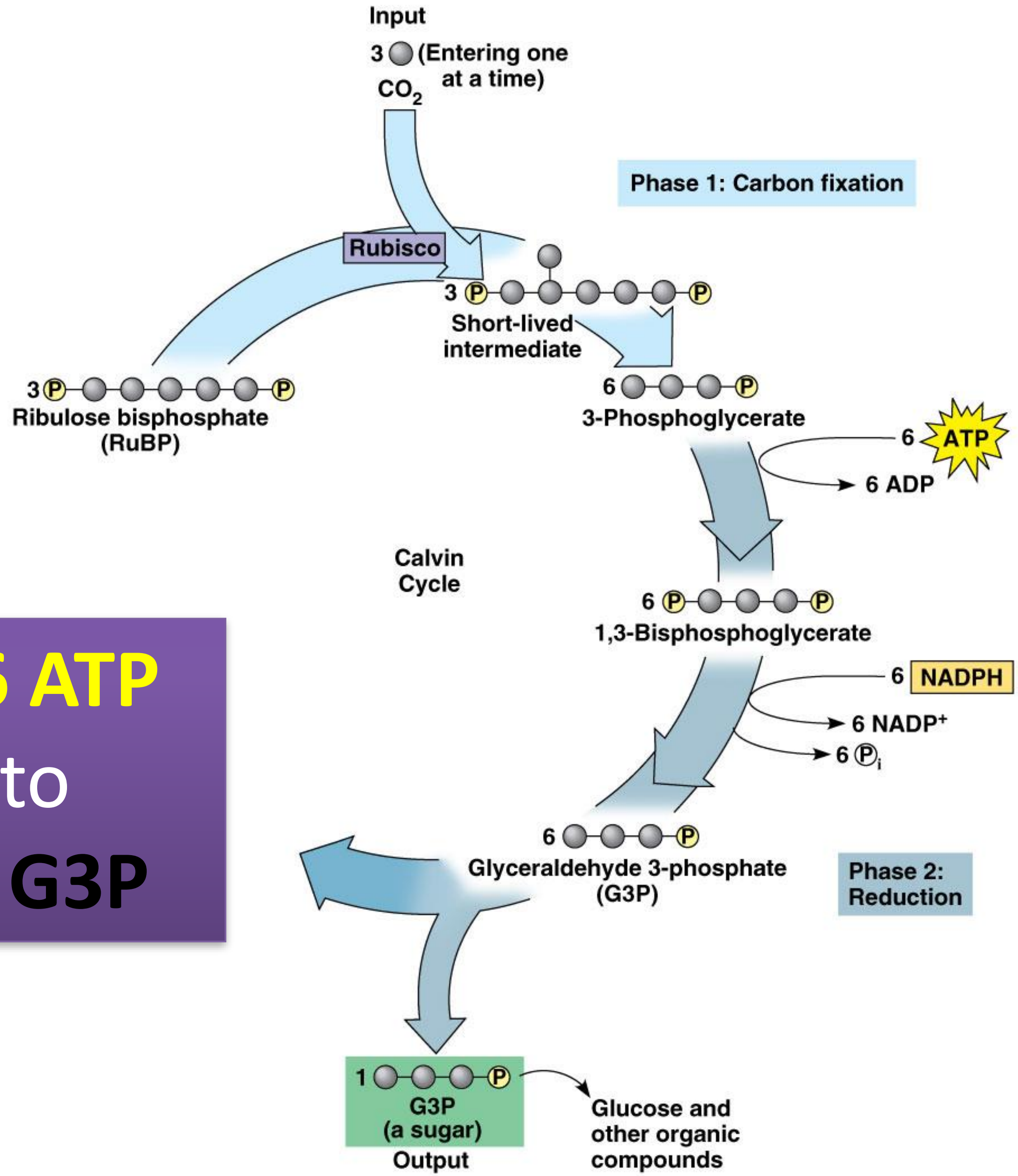
1. Carbon Fixation



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

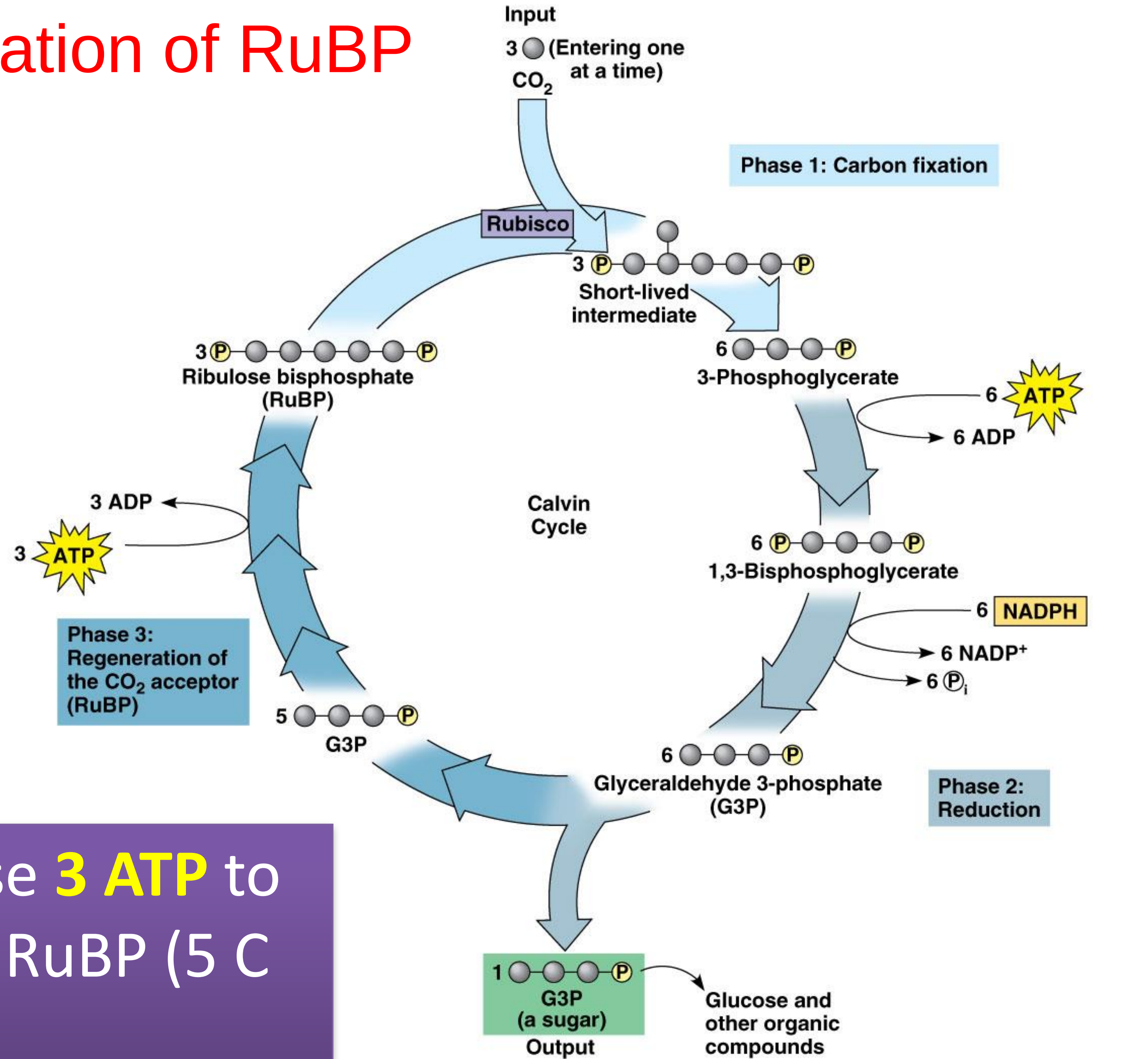
- Catalyzed by enzyme **rubisco** (*RuBP carboxylase*)

2. Reduction



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

3. Regeneration of RuBP



Phase 3: Use **3 ATP** to regenerate RuBP (5 C sugar)

Supporting a biosphere

- On global scale, photosynthesis is the most important process for the continuation of life on Earth
  - each year photosynthesis…
    - captures 121 billion tons of CO_2
    - synthesizes 160 billion tons of carbohydrate
  - heterotrophs are dependent on plants as food source for fuel & raw materials

The poetic perspective…

- All the solid material of every plant was built by sunlight out of thin air
- All the solid material of every animal was built from plant material

air

sun

Then all the plants, cats, dogs, elephants & people … are really particles of air woven together by strands of sunlight!

BioFlix: Photosynthesis
Calvin Cycle

- https://video.search.yahoo.com/yhs/search;_ylt=AwrEeSV0sy9cLTgAM6EnnIlQ;_ylu=X3oDMTByMjB0aG5zBGNvbG8DYmYxBHBvcwMxBHZ0aWQDBHNlYwNzYw--?p=bioflix+photosynthesis&fr=yhs-mozilla-004&hspart=mozilla&hsimp=yhs-004#id=4&vid=5e07661af4ef8ab17f9720b48841dd97&action=view

Resume at 4:38

Practice Worksheet

1. Use your notes to complete both sides of the worksheet.

2. Raise your hand when you finish.

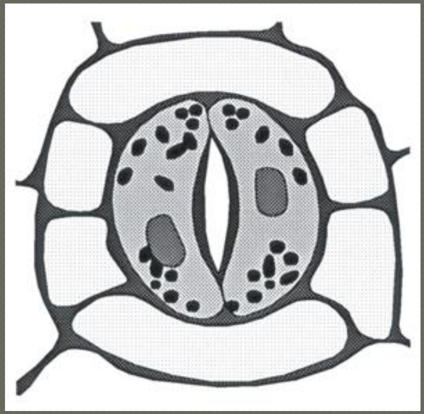
3 Classes of Plants

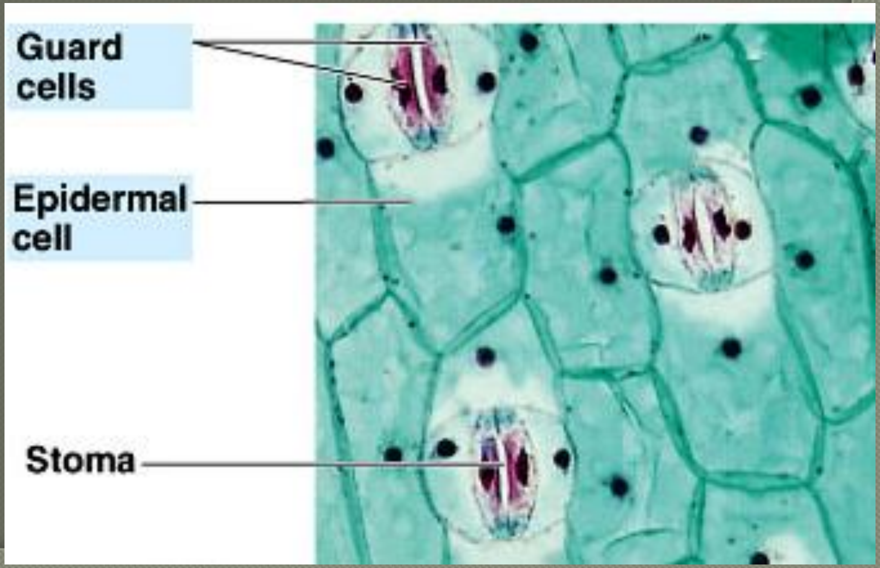
1. C_3 Plants: regular everyday plants
   A. they open their stomata during the day to take in CO_2 and release O_2.
   B. they go through the light and dark reactions normally because they are not exposed to extremely hot conditions.

C_3 Problem

- On hot or dry days
  - stomates close to conserve water
  - guard cells
    - gain H_2O = stomates open
    - lose H_2O = stomates close
  - adaptation to living on land, but…

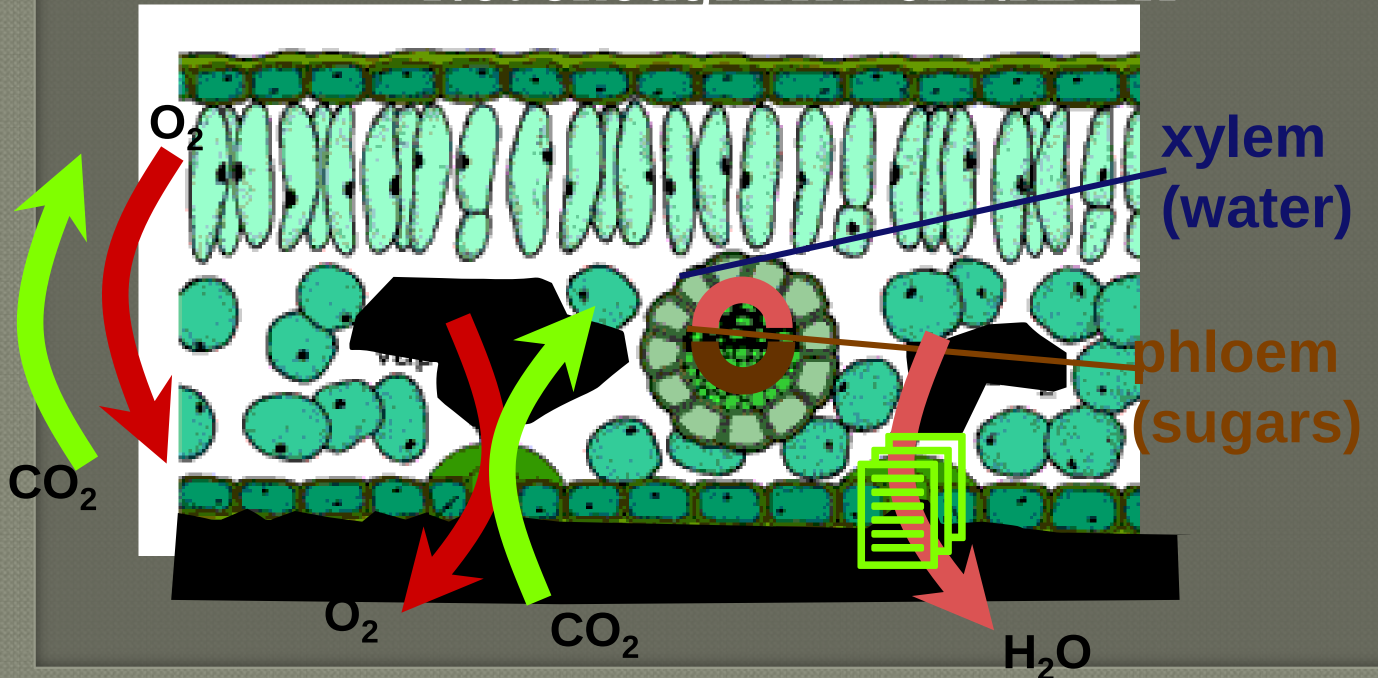
    creates PROBLEMS!





When stomates close…

- Closed stomates lead to…
  - O_2 build up → from light reactions
  - CO_2 is depleted → in Calvin cycle
    - causes problems in Calvin Cycle
    - Not enough ATP or NADPH



The Problem of Photorespiration

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

3 Classes of Plants

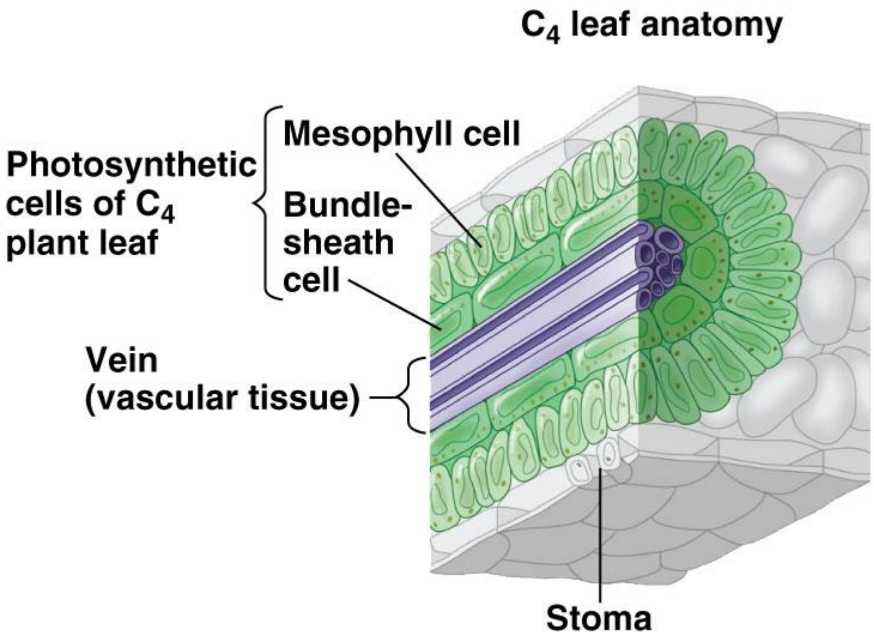
2. C_4 Plants: adapted to hot, dry environments
   A. have 2 separate cells, mesophyll cells and bundle sheath cells.
   B. Use spatial separation of light & dark rxns to combat photorespiration, which is when the plants breakdown glucose to form CO2 instead building glucose from CO2 and releasing O2.

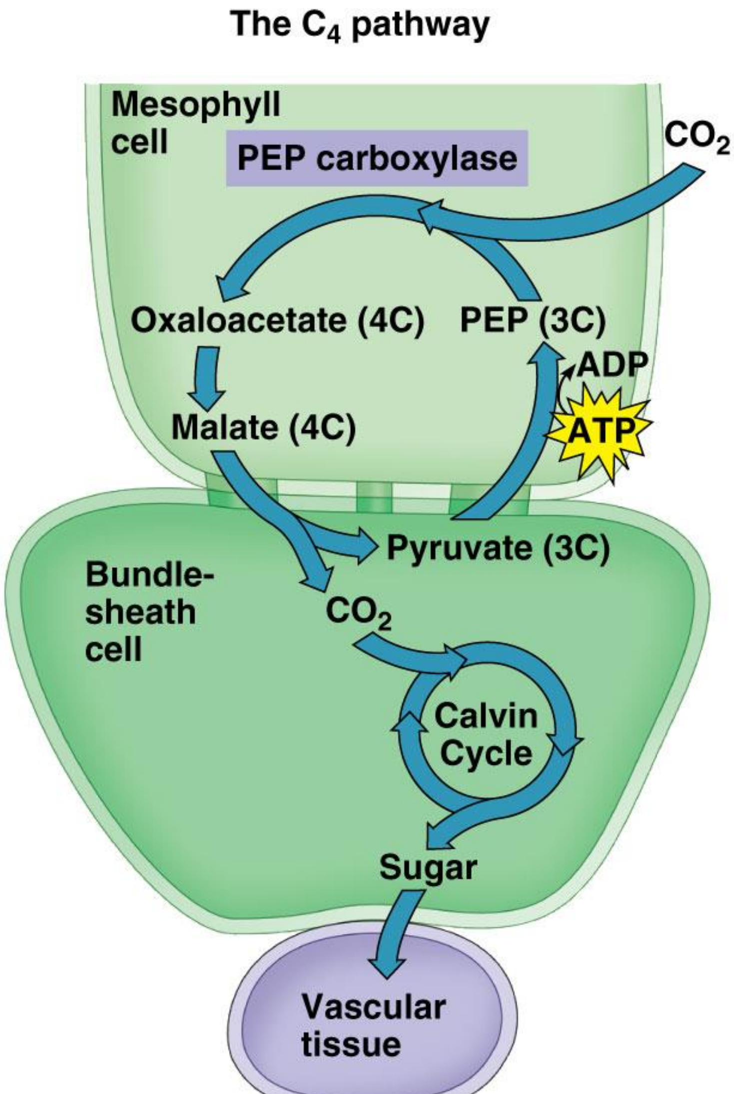
3. CAM Plants: adapted to hot, dry environments
   A. have only one cell,
   B. they open their stomata at night and close them during the day.
   C. the CO2 they take in at night is incorporated into 4 carbon compounds (organic acids) and is sent off to the Calvin cycle during the day to make glucose.

Evolutionary Adaptations

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
   - 2 stages of photosynthesis are PHYSICALLY (spatialy) separated
   - ↓photorespiration, ↑sugar production

C_4 Leaf Anatomy

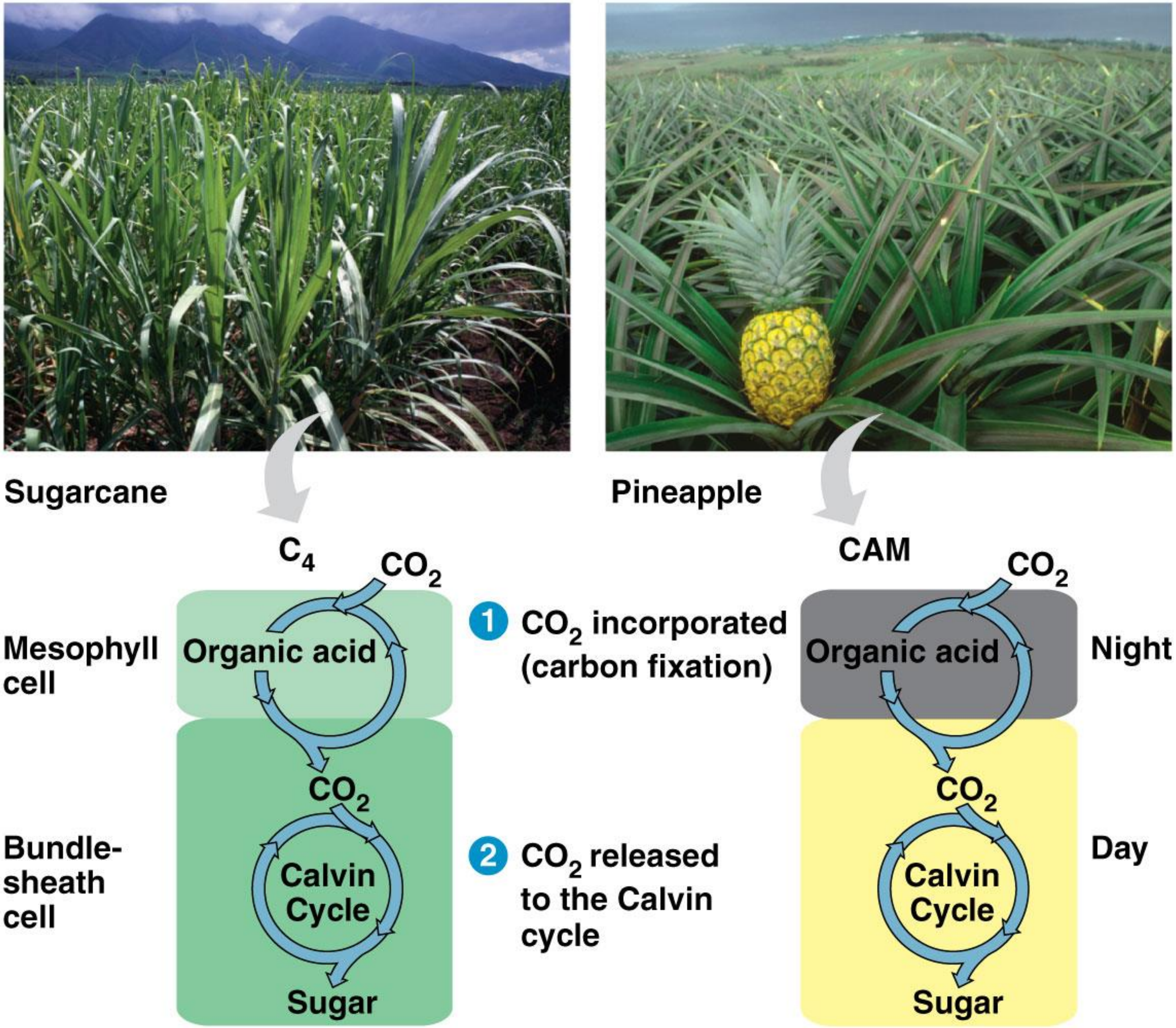






3. **CAM Plants**:

- *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
- 2 stages of photosynthesis are TEMPORALLY separated



(a) Spatial separation of steps

(b) Temporal separation of steps

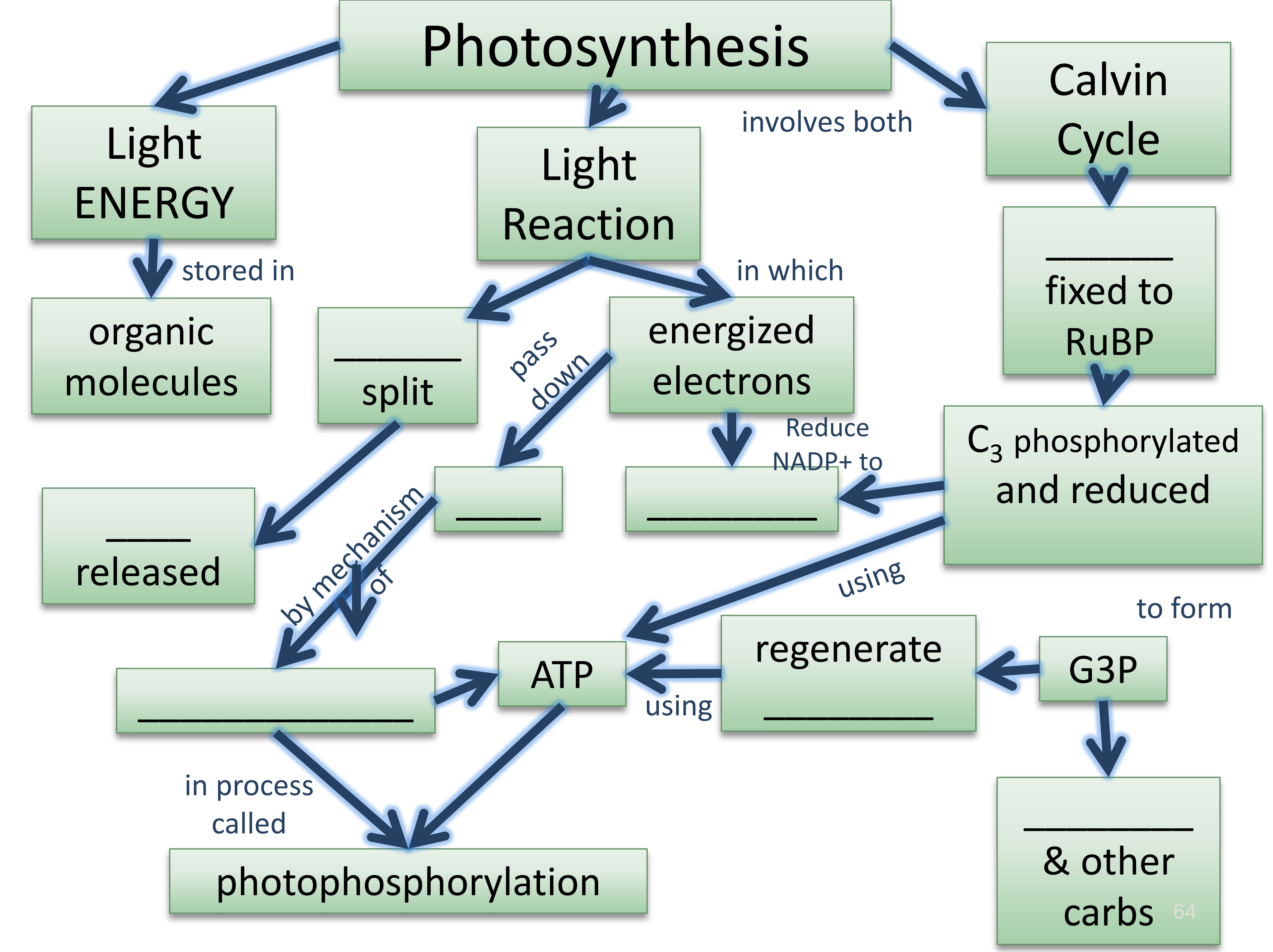
Comparison

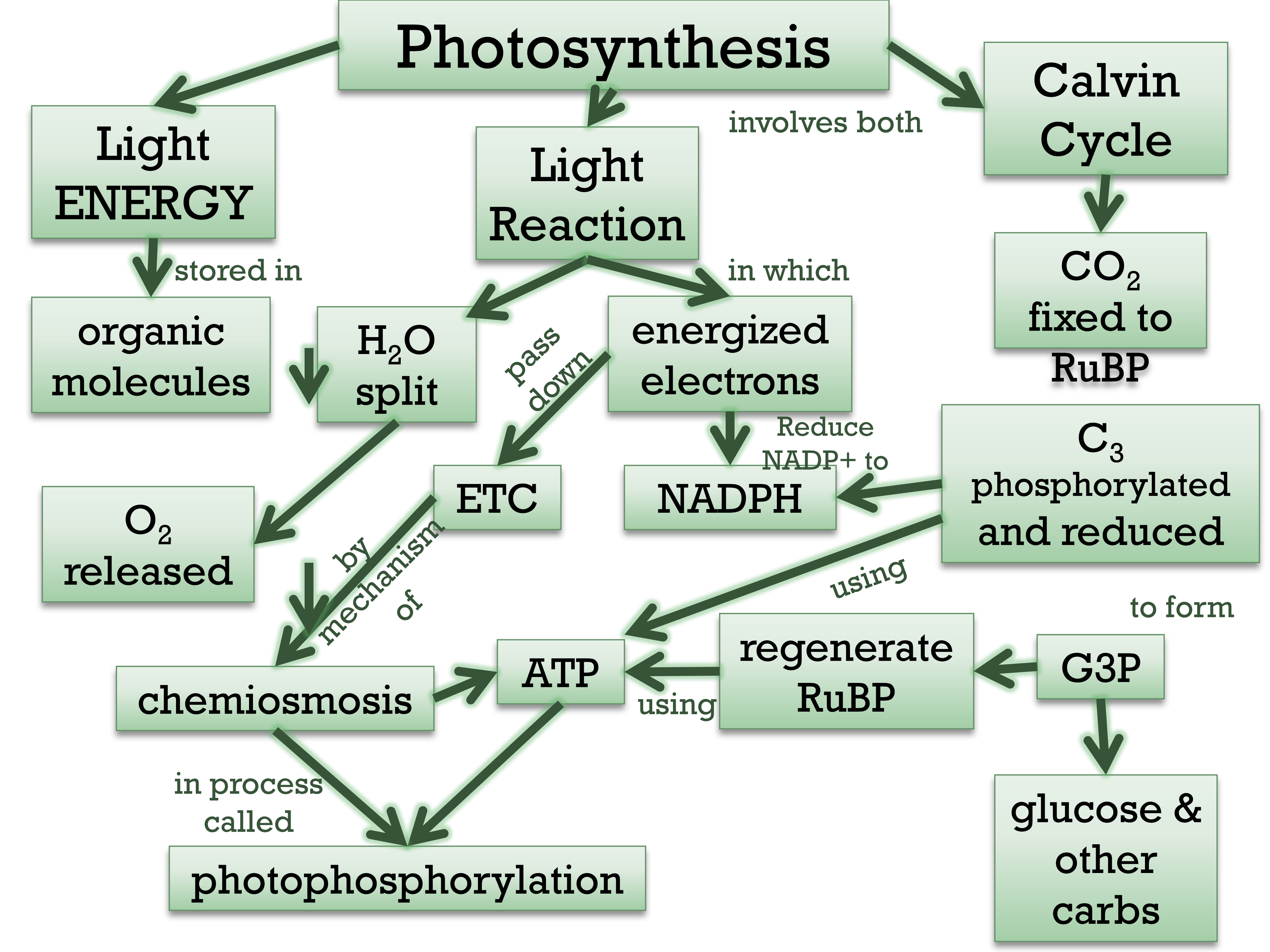
C_3	C_4	CAM
C fixation & Calvin together	C fixation & Calvin in different *CELLS*	C fixation & Calvin at different *TIMES*
Rubisco	PEP carboxylase	Organic acid

Importance of Photosynthesis

Plant:	• Make glucose for respiration • Make cellulose for cell wall
Global:	• O_2 Production (for aerobic respiration) • Food source for heterotrophs

Review of Photosynthesis


Photosynthesis
Light ENERGY
stored in
organic molecules
Light Reaction
involves both
Calvin Cycle
in which
______ split
pass down
energized electrons
______ fixed to RuBP
____ released
____
Reduce NADP+ to
____
C$_3$ phosphorylated and reduced
by mechanism of
using
to form
____
ATP
using
regenerate _________
G3P
in process called
photophosphorylation
________ & other carbs


Photosynthesis
Light ENERGY
stored in
organic molecules
Light Reaction
H2O split
O2 released
in which
energized electrons
pass down
ETC
by mechanism of
chemiosmosis
ATP
in process called
photophosphorylation
Reduce NADP+ to
NADPH
involves both
Calvin Cycle
CO2 fixed to RuBP
C3 phosphorylated and reduced
using
regenerate RuBP
using
G3P
to form
glucose & other carbs

Procedure: Video

- Brad Williamson: "Sinking Leaf Disks Lab" at www.kabt.org

Part 2: Designing & Conducting Your Own Investigation

Class Generated Table: "Variables Affecting Rate of Photosynthesis"

Environmental Variables	Plant or Leaf Variables	Method Variables
Temp.	Type of leaf/plant	Bicarb. Concen. (CO_2)
Amt/strength of light	Size of leaf	Amt. soap
pH	Health of leaf	Size/shape of leaf disk
Bicarb. Concen. (CO_2)	Part of leaf	
Color of light	C3 vs. C4 plant	
salinity	Stomata density	

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