Compare and contrast

Photosynthesis in Nature

carbon

eat

(attach)

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

energy

Energy

photo → light

hetero → not light

Carbon

auto → fix/attach carbon

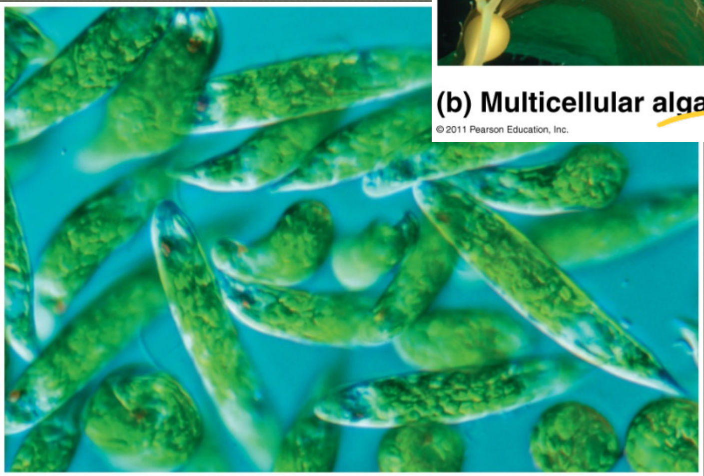
chemo — get carbon from food.

Photoautotrophs

became chloroplast

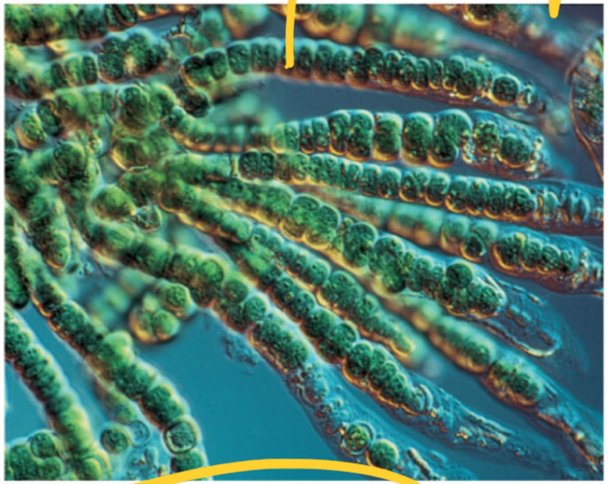
(a) Plants

(b) Multicellular alga



(c) Unicellular protists

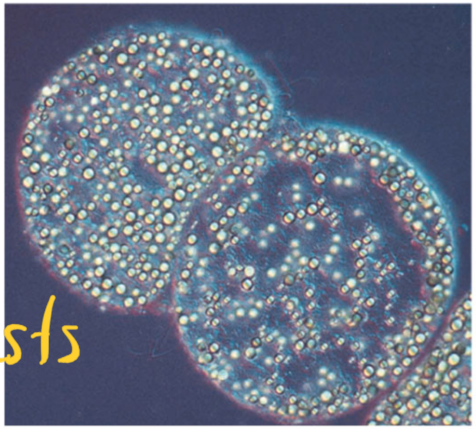
10 μm



(d) Cyanobacteria

40 μm

Endosymbiotic where chloroplasts came from.

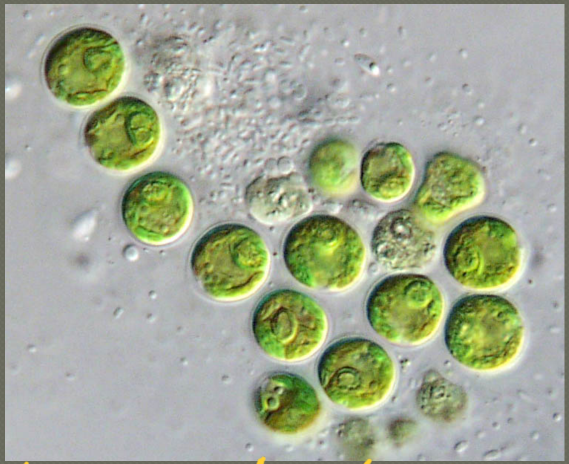


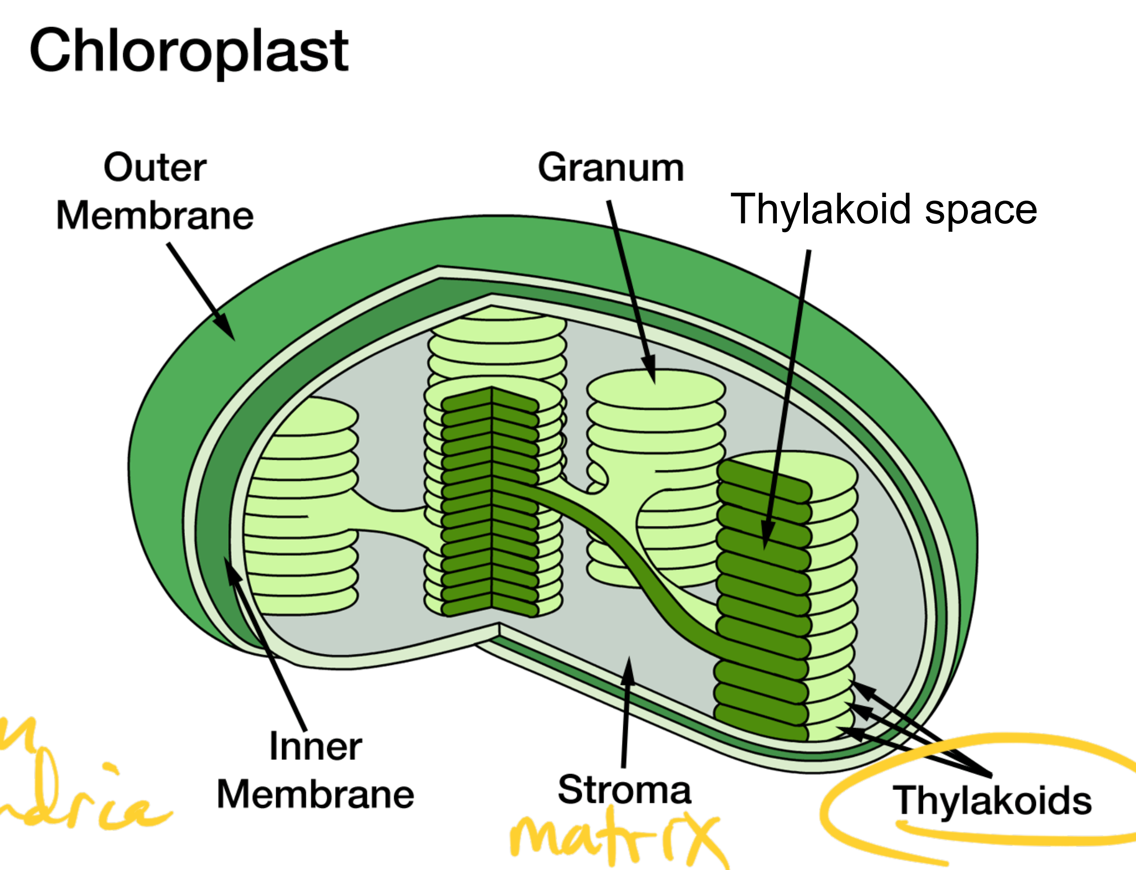
(e) Purple sulfur bacteria

1 μm

Photosynthesis: Converts light energy to chemical energy of food

- Chloroplasts: sites of photosynthesis in plants



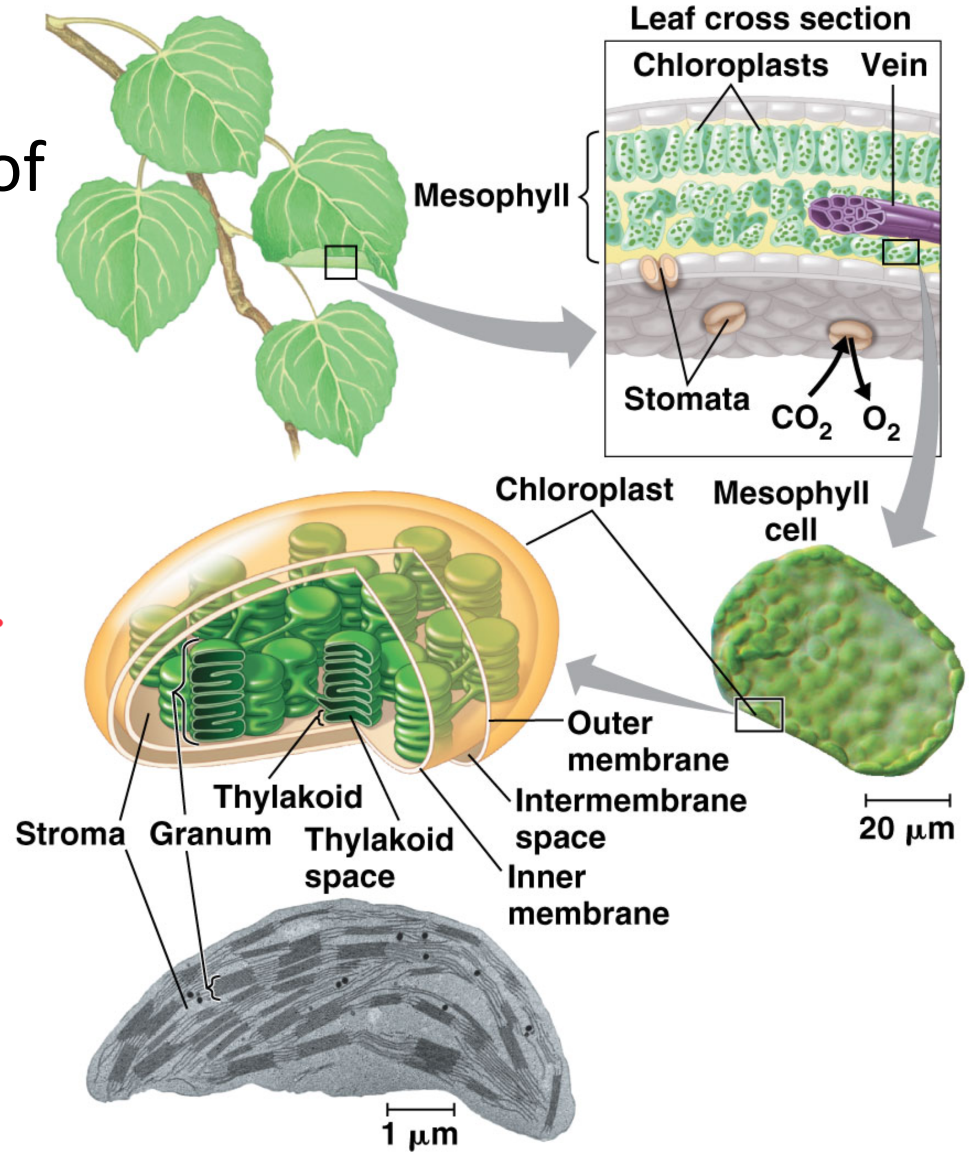


chloroplast is an inverted mitochondria


the chloroplast
crabby patties
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



Photosynthesis

reverse of cellular respiration

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

Anabolic, absorbs energy +ΔG nonspontaneous

Redox Reaction:

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

smaller molecules ⟶ larger/complex molecules

Remember: OILRIG

Oxidation: lose e-

Reduction: gain e-

Photosynthesis

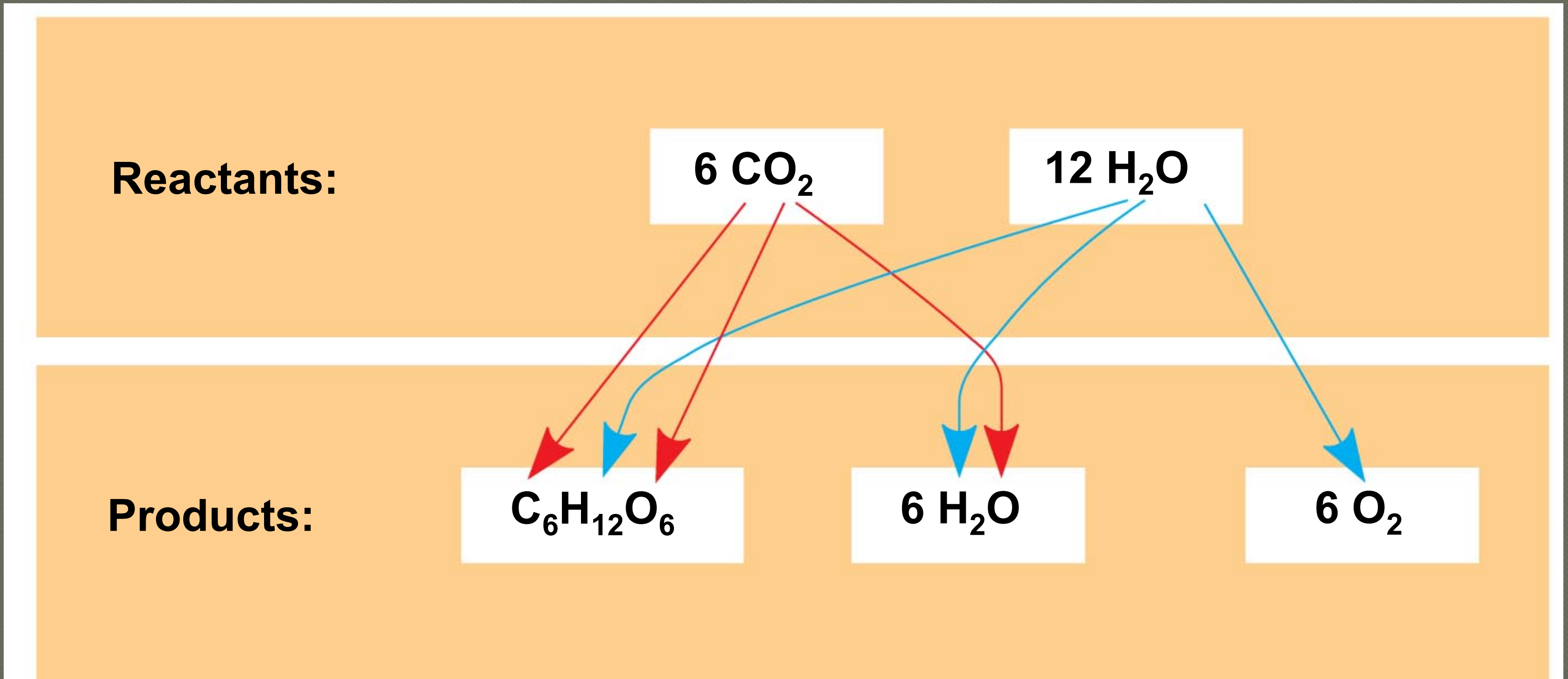
1) Light Phase
Electron Transport Chain (redox)

2.) Building sugar
Dark Phase

Tracking atoms through photosynthesis

Involves the OEC oxygen evolving complex

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

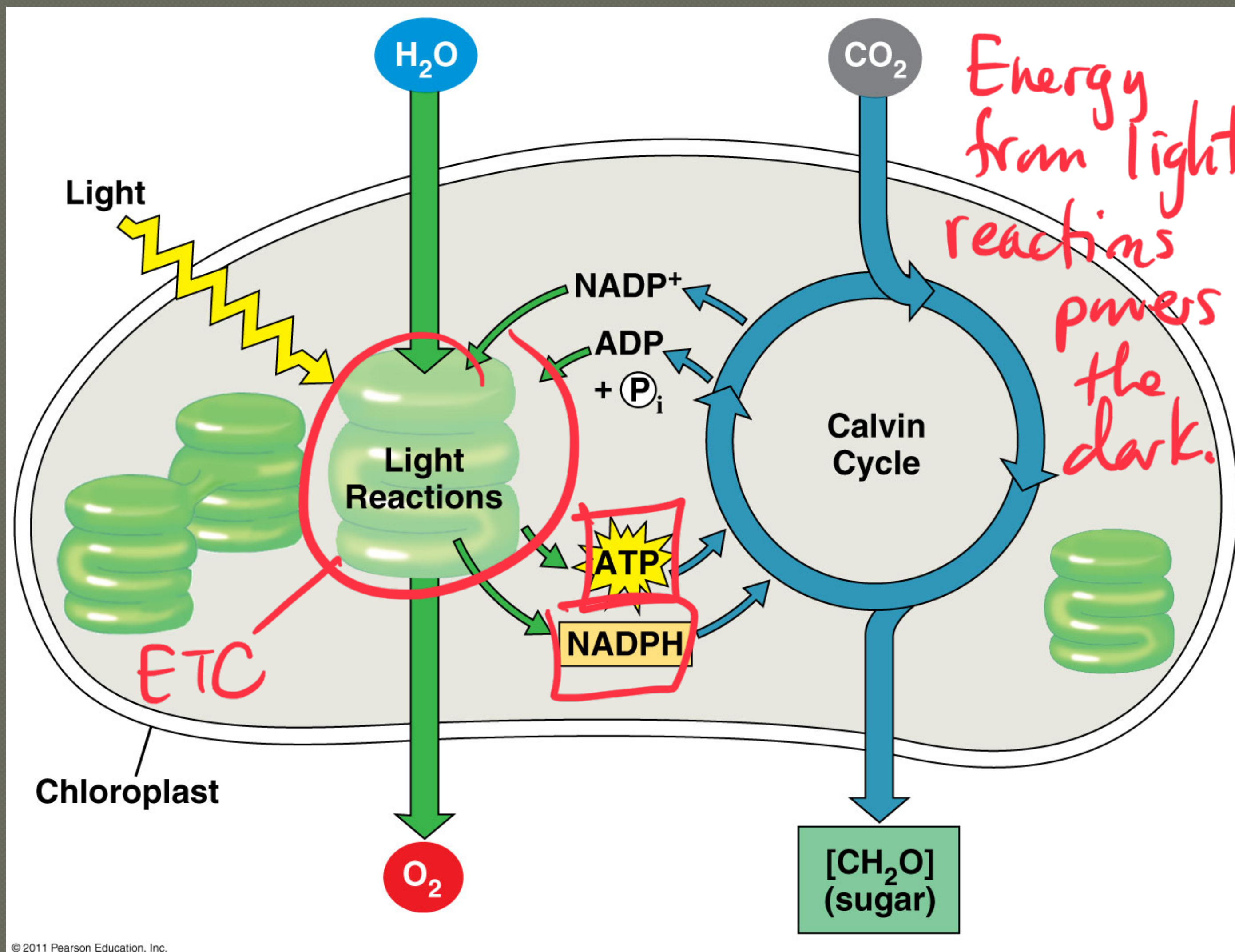


catabolic Dark

Photosynthesis = Light Reactions + Calvin Cycle

"photo" "synthesis"

anabolic



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

speed of light → $3 * 10^8$ m/s

$\lambda = 1/f$

Nature of sunlight

- Light = Energy = electromagnetic radiation

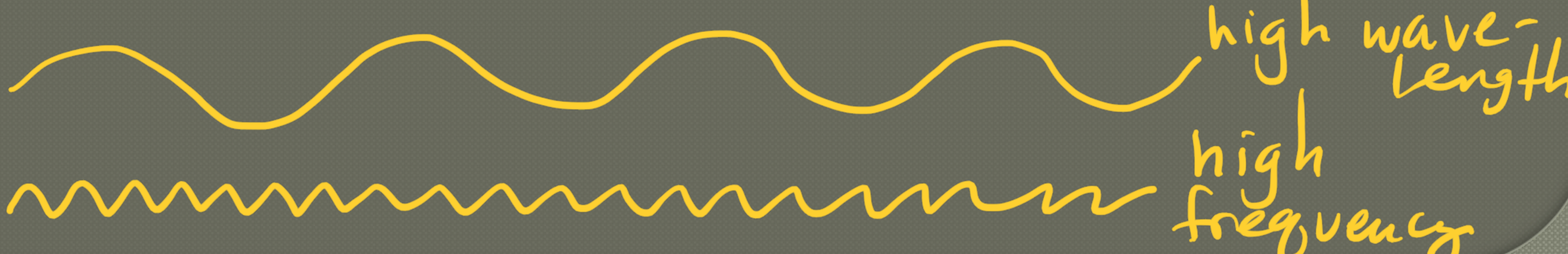
Higher frequency → greater the energy

frequency & wavelength are inversely related

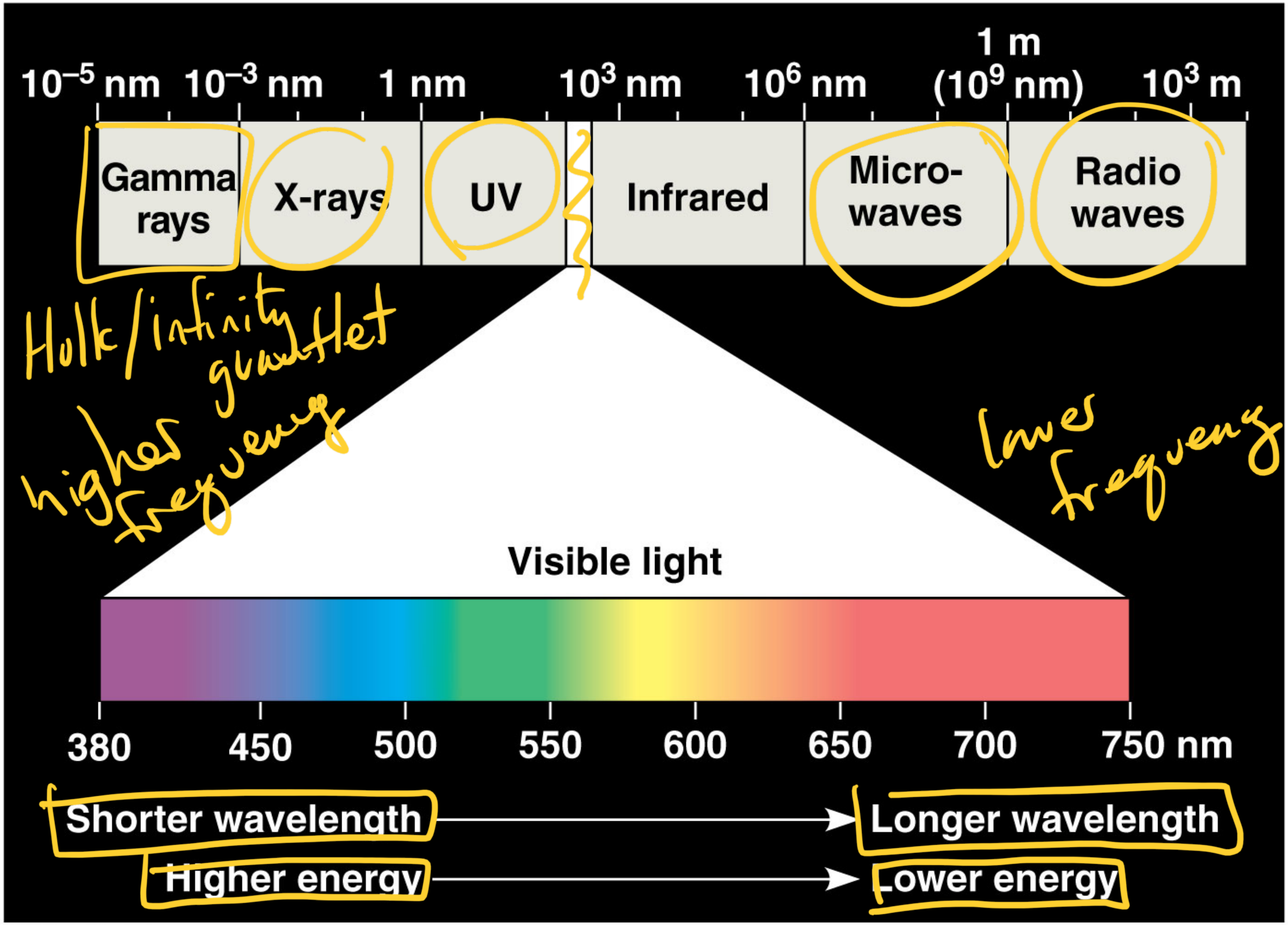
- Shorter wavelength (λ): higher E

higher frequency

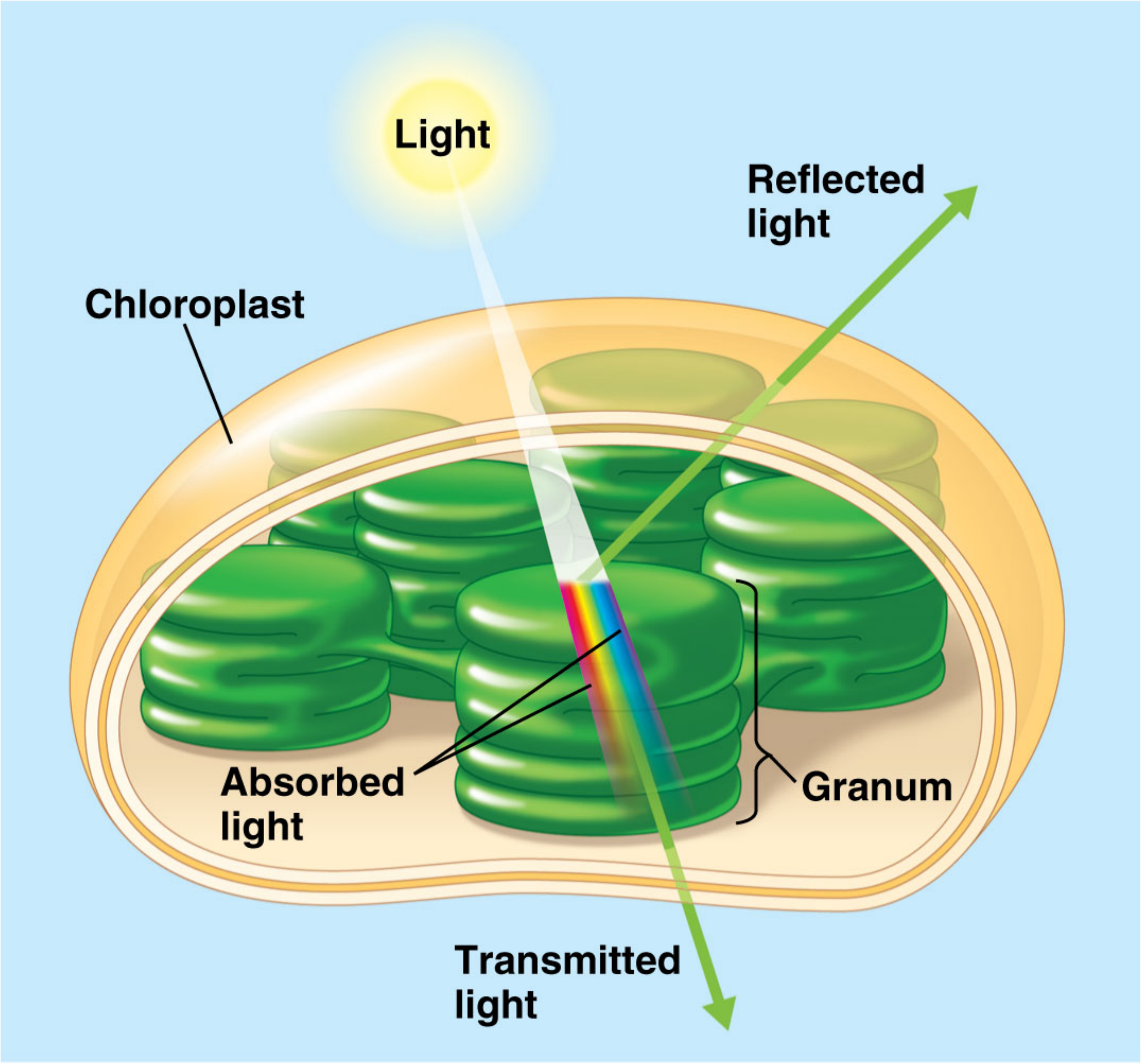
- Visible light - detected by human eye
- Light: reflected, transmitted or absorbed



Electromagnetic Spectrum



Interaction of light with chloroplasts

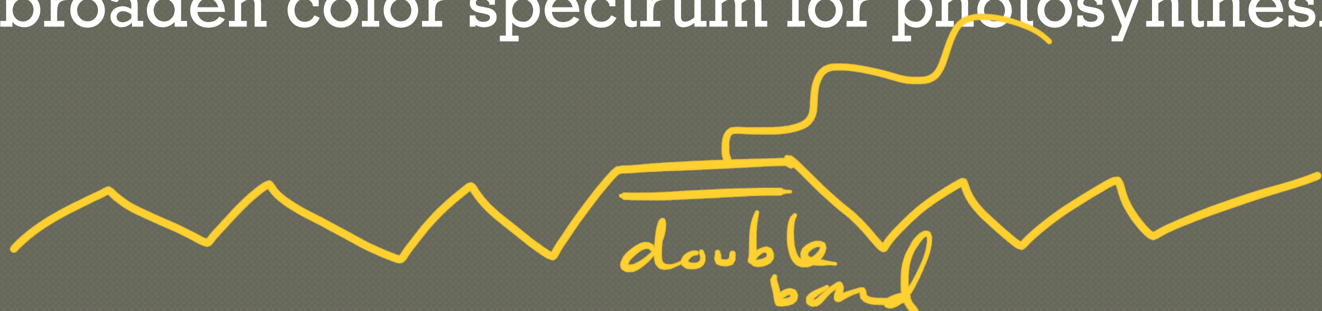


Photosynthetic pigments

- Pigments absorb different λ of light
- chlorophyll – absorb violet-blue/red light, reflect green

  absorb different colors

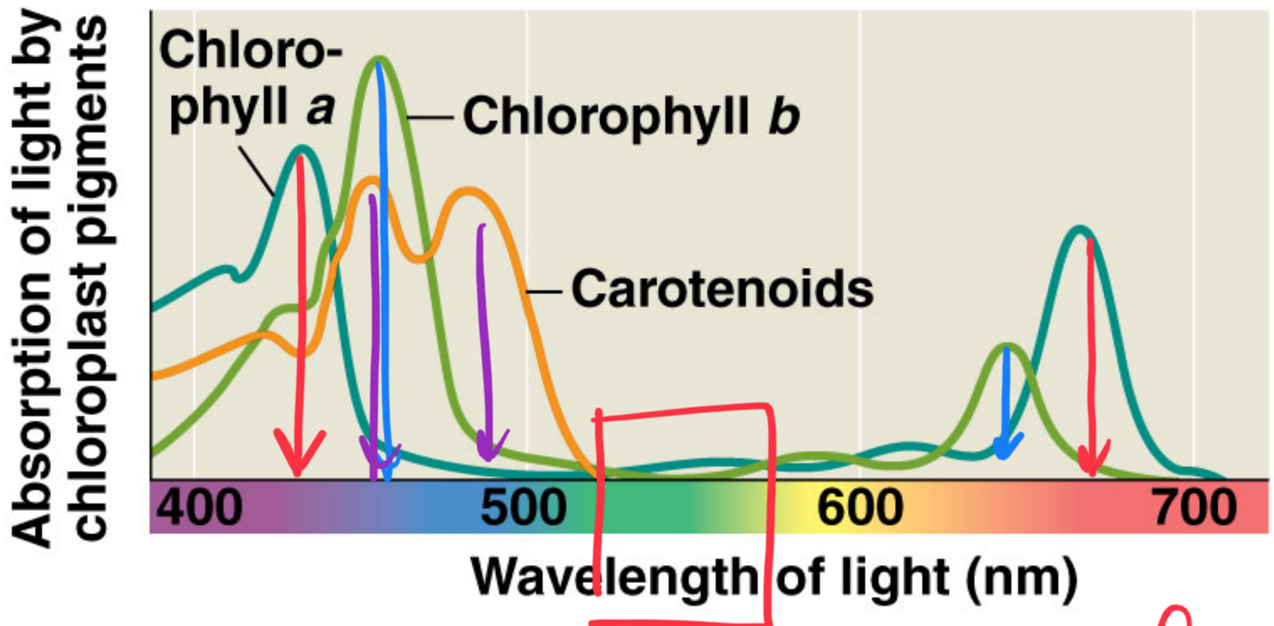
  - **chlorophyll a** (blue-green): light reaction, converts solar to chemical E
  - **chlorophyll b** (yellow-green): conveys E to chlorophyll a
  - **carotenoids** (yellow, orange): photoprotection, broaden color spectrum for photosynthesis



chlorophyll a - purple, orange/red
chlorophyll b - blue, orange

RESULTS

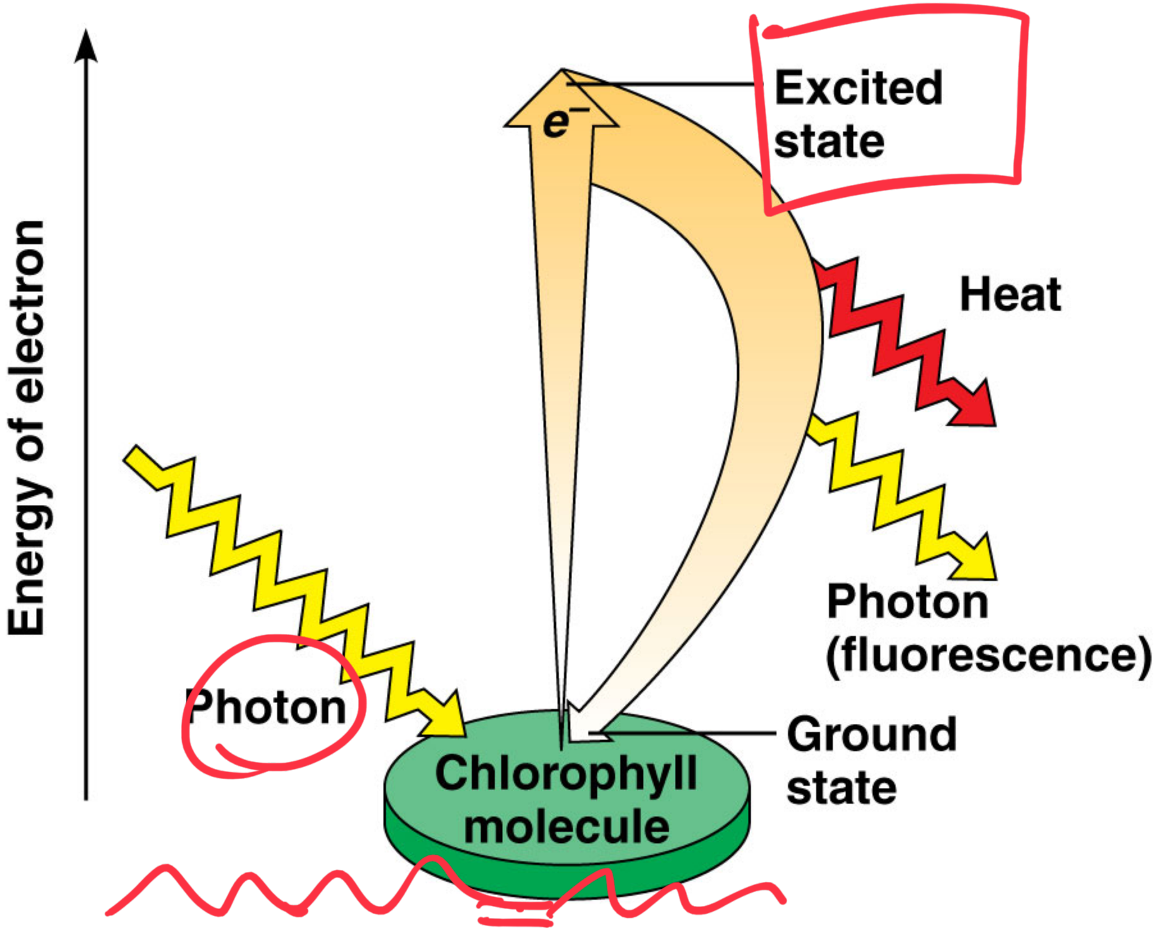
carotenoid
blue,



(a) Absorption spectra

no green is absorbed
green is reflected back

Electrons in chlorophyll molecules are excited by absorption of light

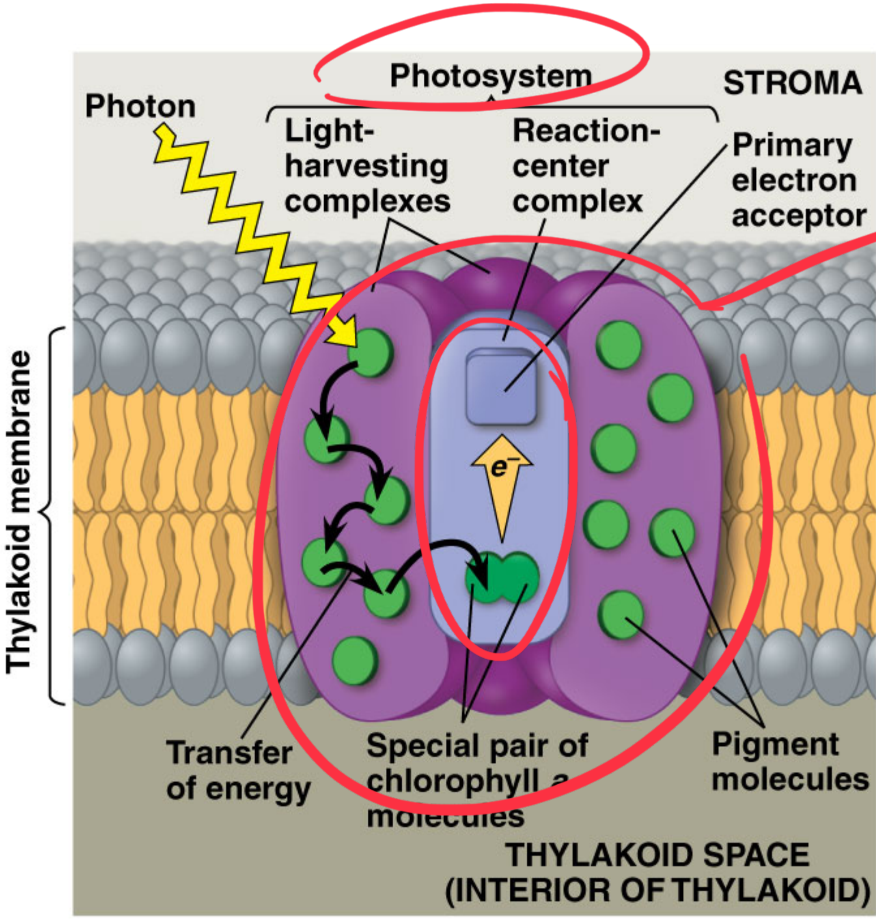


(a) Excitation of isolated chlorophyll molecule

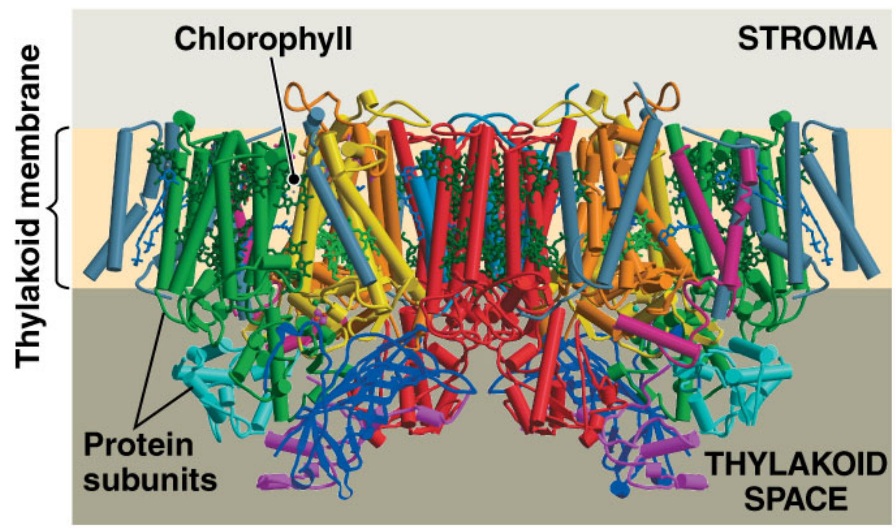
(b) Fluorescence

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

antenna
dish
protein
electron excitation



(a) How a photosystem harvests light



(b) Structure of photosystem II

Light Reactions

Two routes for electron flow:

A. Linear (noncyclic) electron flow

B. Cyclic electron flow

2 types

linear → if water

cyclical

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

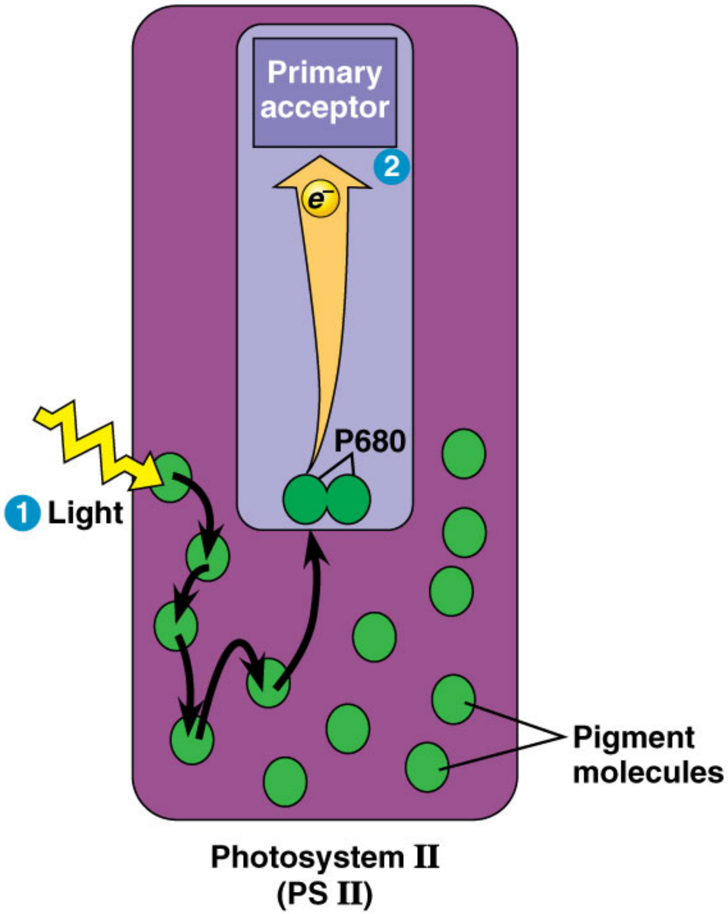
- Redox reaction → e- transfer
- e- prevented from losing E (drop to ground state)

4. **H_2O is split** to replace e- → **O_2 formed**

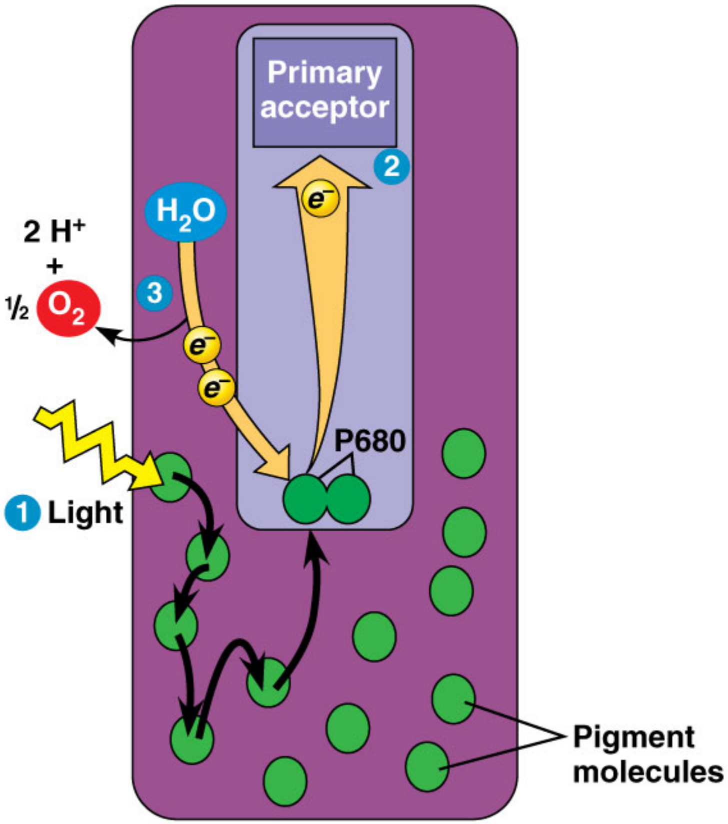
You do not need to know steps!

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

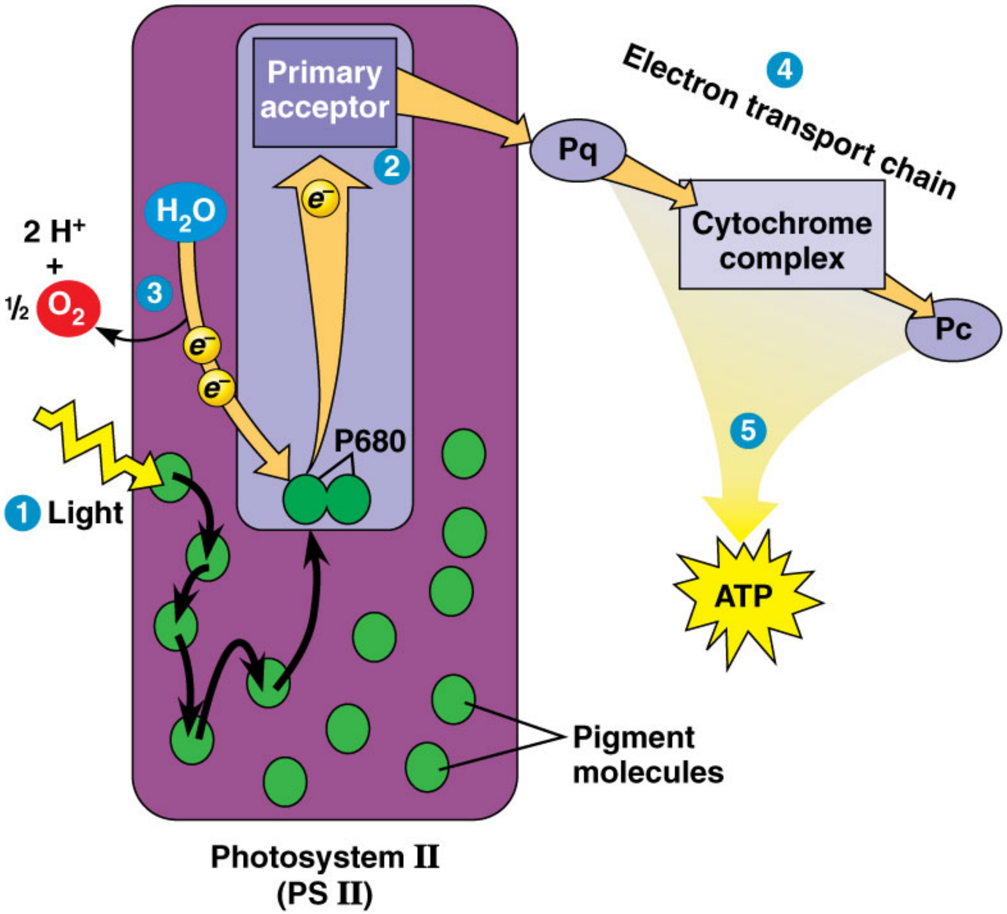
MAIN IDEA: *Use solar E to generate ATP & NADPH to provide E for Calvin cycle*

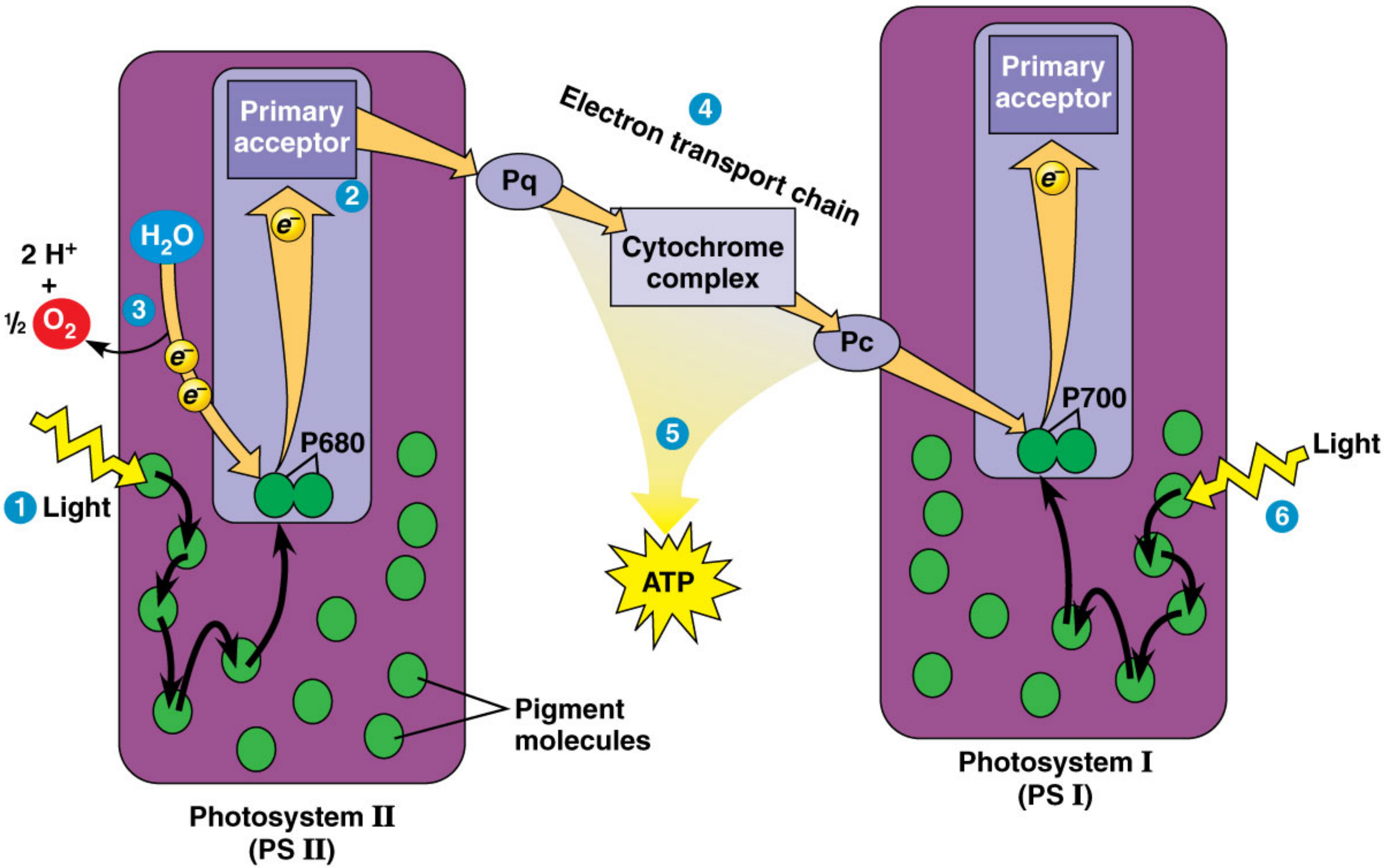


Primary acceptor
2
e⁻
P680
1 Light
Pigment molecules
Photosystem II (PS II)



Photosystem II
(PS II)

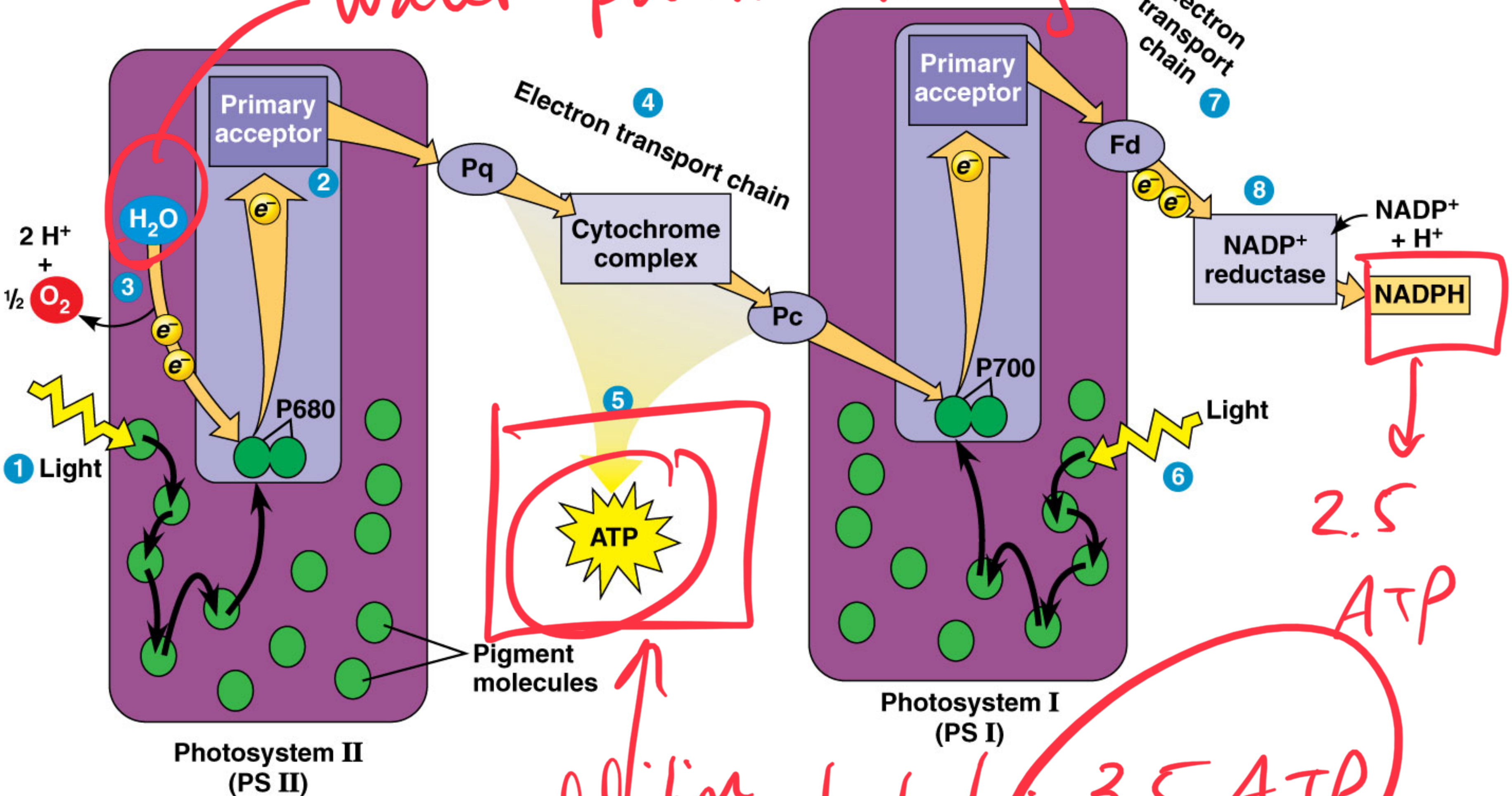

Primary acceptor
2
e⁻
H_2O
2 H^+
+
½ O_2
3
e⁻
e⁻
P680
1 Light
4
Electron transport chain
Pq
Cytochrome complex
Pc
5
ATP
Pigment molecules
Photosystem II (PS II)



Primary acceptor
Pq
Electron transport chain
4
Primary acceptor
2
e^-
H_2O
2 H^+
+
½ O_2
3
e^-
e^-
Cytochrome complex
Pc
e^-
P700
P680
5
Light
1 Light
6
ATP
Pigment molecules
Photosystem I (PS I)
Photosystem II (PS II)

Linear → parent's money

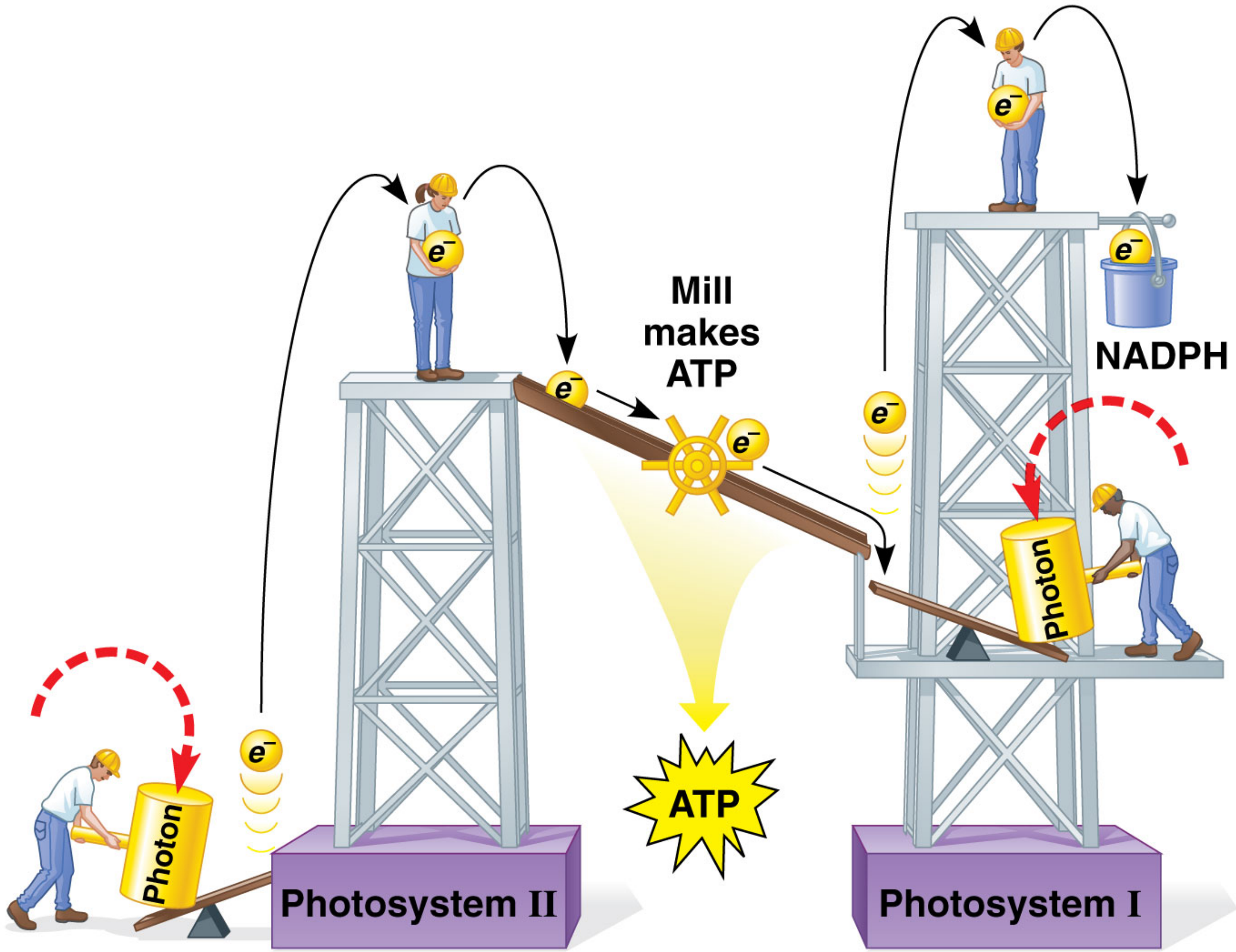
water = parent's money = electrons



2.5 ATP

in addition

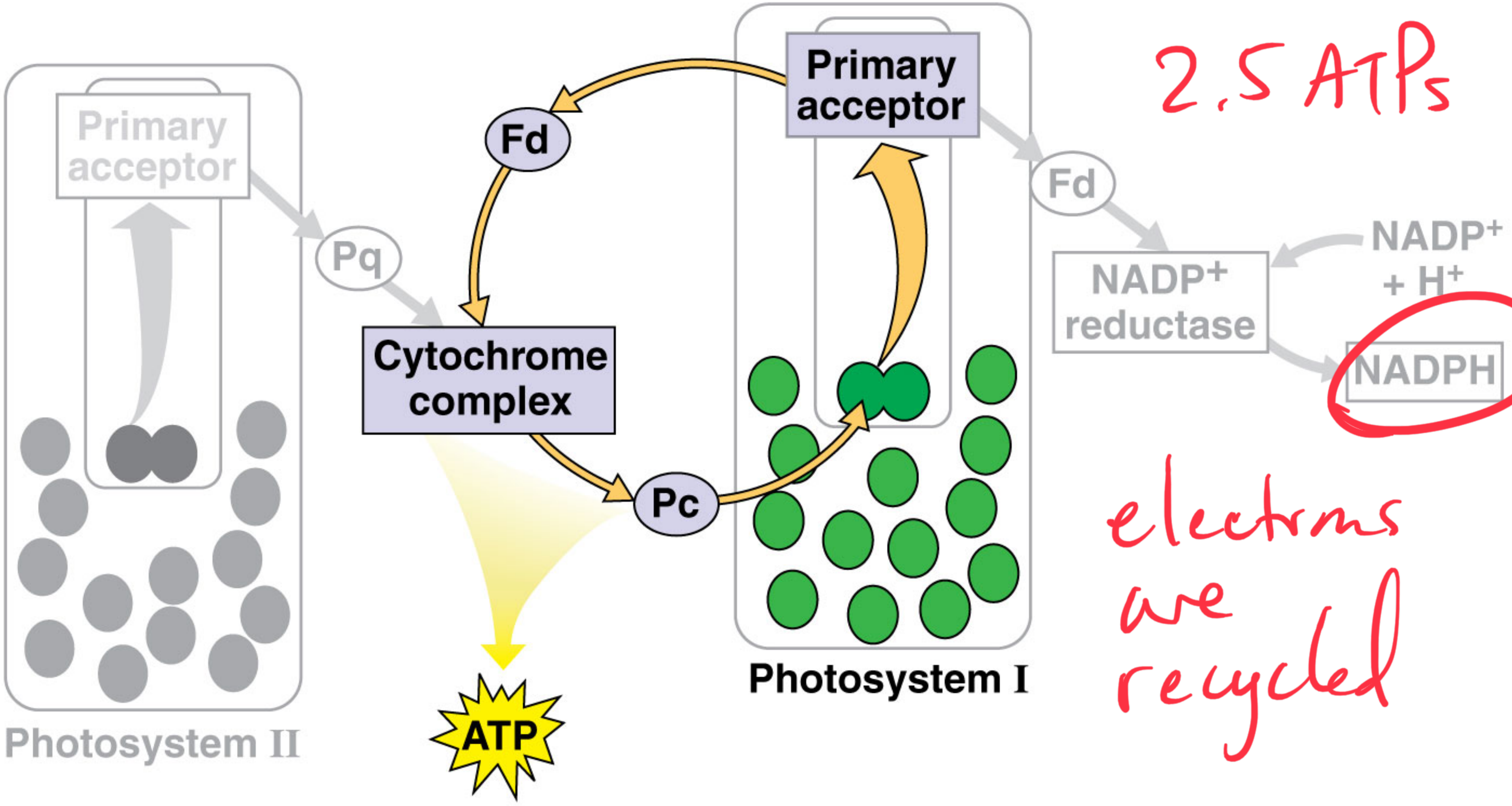
total: 3.5 ATP



Mechanical analogy for the light reactions

Your money → not outside electrons

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

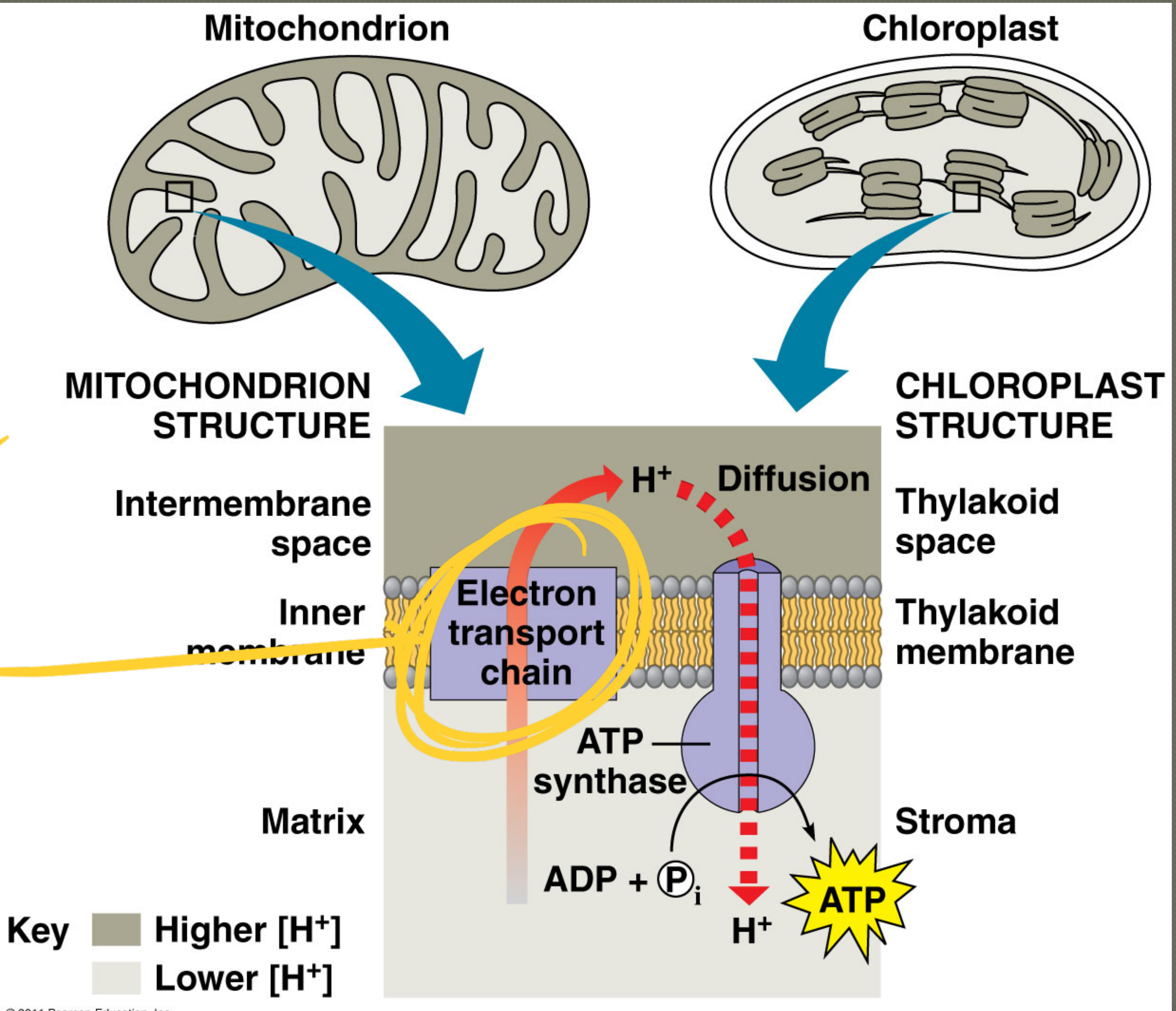


2.5 ATPs

electrons are recycled

Both respiration and photosynthesis use chemiosmosis to generate ATP

Electron transport chain



Proton motive force generated by:

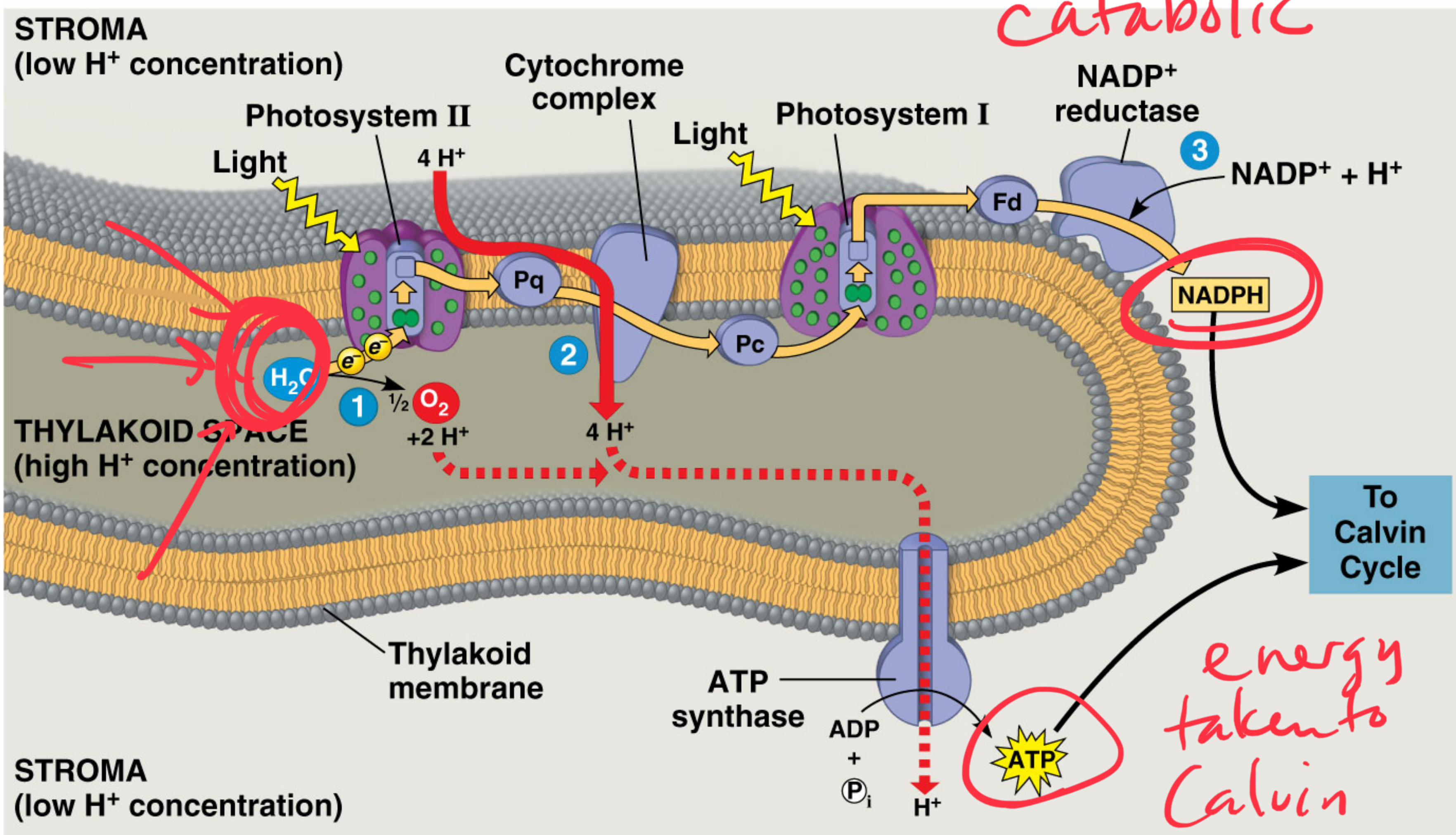
(1) H^+ from water

(2) H^+ pumped across by cytochrome

(3) Removal of H^+ from stroma when $NADP^+$ is reduced

Linear (Because of water)

catabolic



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

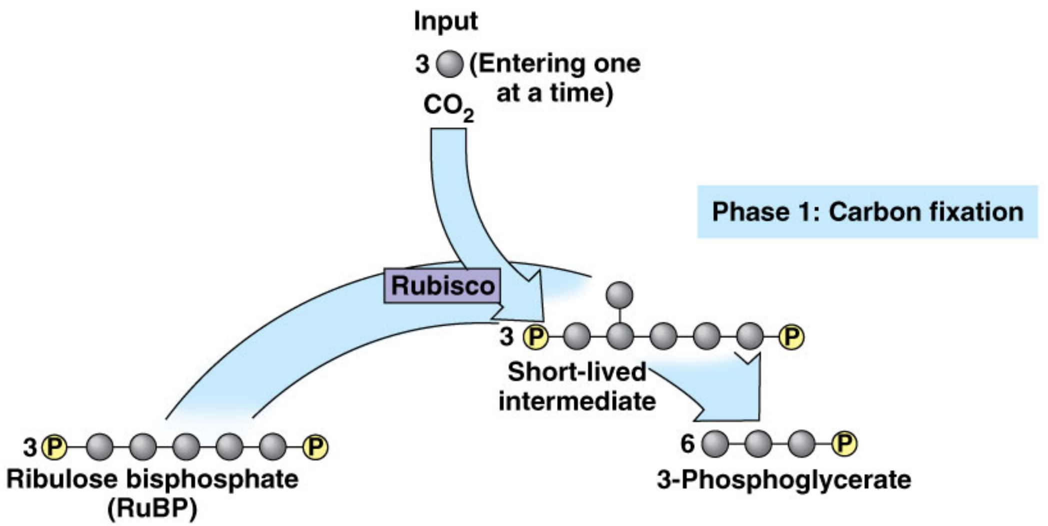
Dark Reaction

Anabolic

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

Three phases:

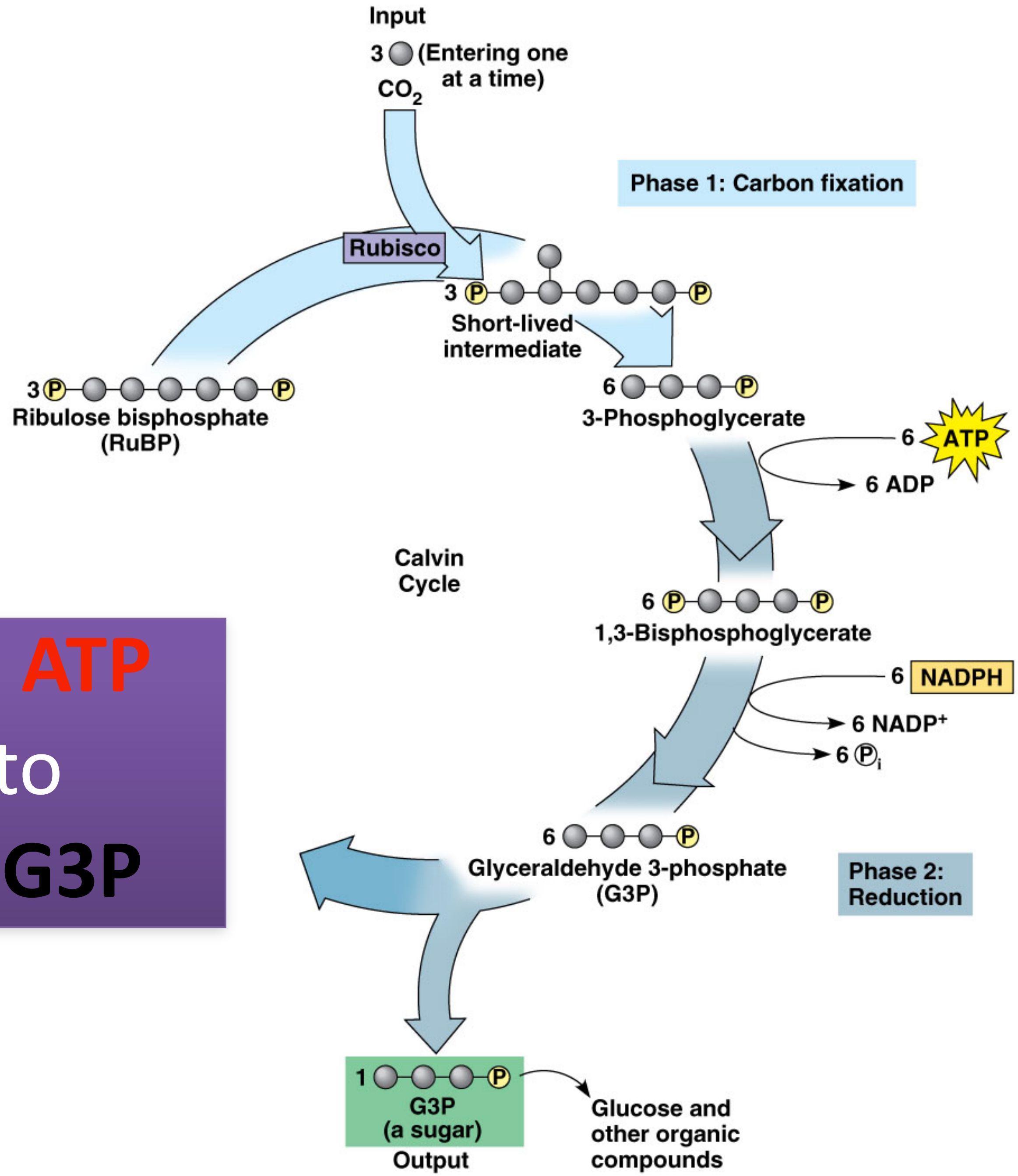
1. Carbon fixation ← "autotroph"
2. Reduction
3. Regeneration of RuBP (CO_2 acceptor)



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

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

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



Get 32 ATP from glucose

It takes 48 ATP to make glucose

Enzymes facilitate 100,000 – 1,000,000 reactions per second

more of Rubisco enzyme than any other enzyme

3 rxns/second

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