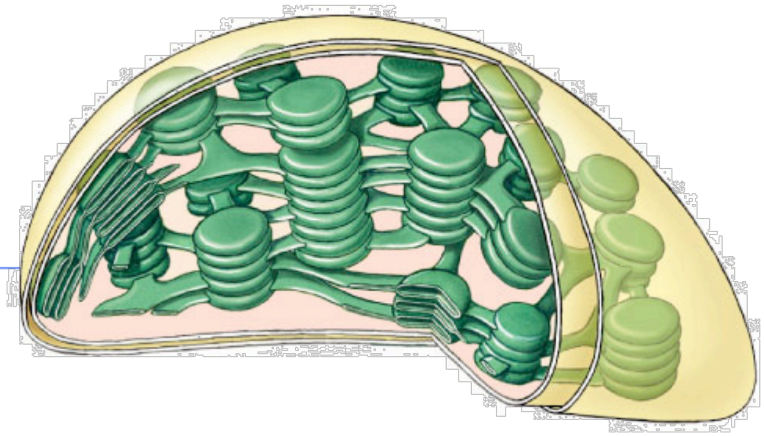
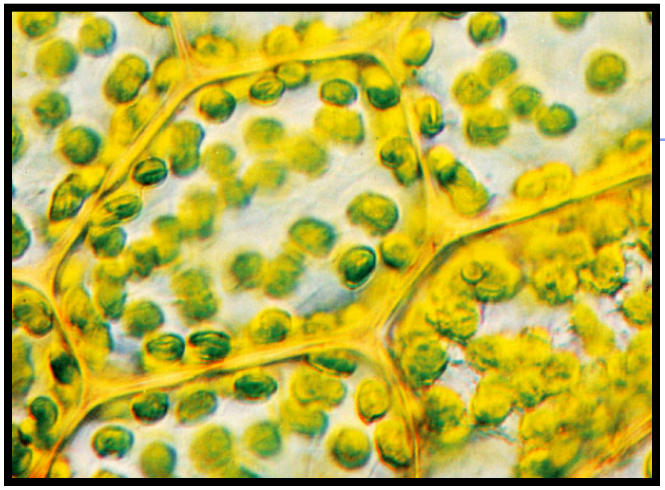


Ch.10 Photosynthesis:

Life from Light & Air



Energy needs of life

- All life needs a constant input of energy
  - Chemoheterotrophs (Ex: Animals)
    - Get their carbon from organic compounds
    - Get their energy from the organic compounds made by others *("Hetero" = other; "Trophos" = feed)*
      - consume nutrients = other organisms = organic molecules
    - Release the energy in molecules through respiration

consumers

  - Photoautotrophs (Plants)
    - Get their energy from the sun *("Auto" = self ; "Trophos" = feed)*
      - convert energy of sunlight into chemical energy
    - get the carbon to build organic molecules (CHO) from CO_2
      - store energy & synthesize sugars through photosynthesis = the conversion of light energy to the chemical energy stored in sugar and other organic molecules.

producers

How are they connected?

Heterotrophs: <u>DEPENDENT</u> on autotrophs for carbon, energy, & O_2!

obtaining energy & making organic molecules from ingesting organic molecules

glucose + oxygen → carbon dioxide + water + energy

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

oxidation = exergonic

Autotrophs

obtaining energy & making organic molecules from light energy & CO_2

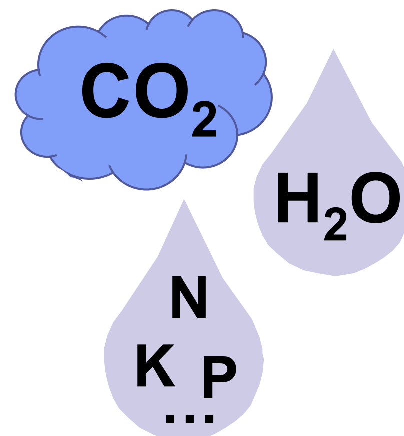
carbon dioxide + water + energy → glucose + oxygen

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

reduction = endergonic

What does it mean to be a plant

- Need to…
  - collect light energy
    - transform it into chemical energy
  - store light energy
    - in a stable form to be moved around the plant or stored for later use
  - need to get building block atoms from the environment
    - C, H, O, N, P, K, S, Mg
  - produce all organic molecules needed for growth
    - carbohydrates, proteins, lipids, nucleic acids



Plant structure

- Obtaining raw materials:
  - Sunlight
    - leaves = solar energy collectors
  - CO_2
    - Enters through stomates = microscopic pores in leaves that allow for efficient gas exchange
  - H_2O
    - uptake from roots
  - Nutrients
    - N, P, K, S, Mg, Fe and more obtained as ions or polyatomic ions
    - uptake from roots

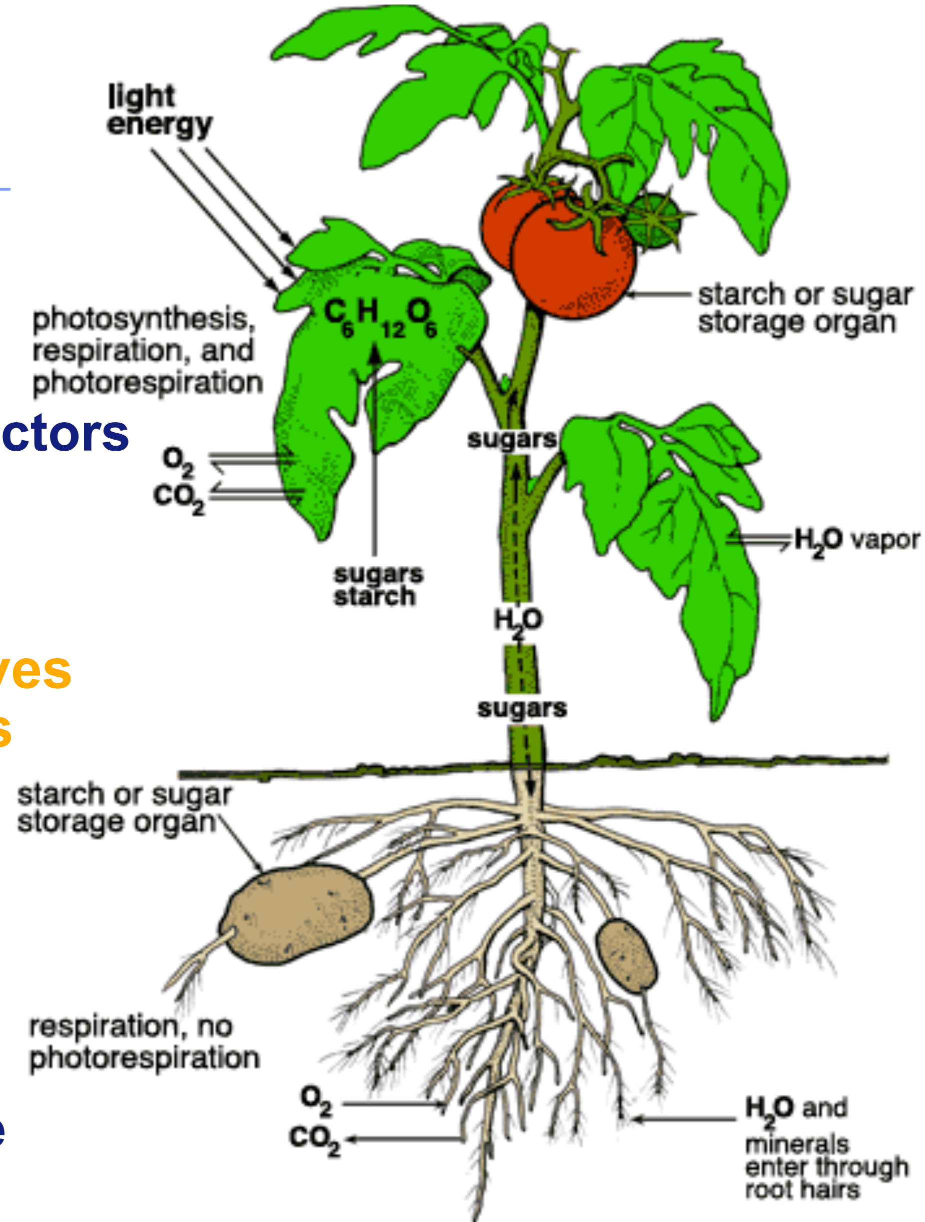


Figure 24. Photosynthesis, respiration, leaf water exchange, and translocation of sugar (photosynthate) in a plant.

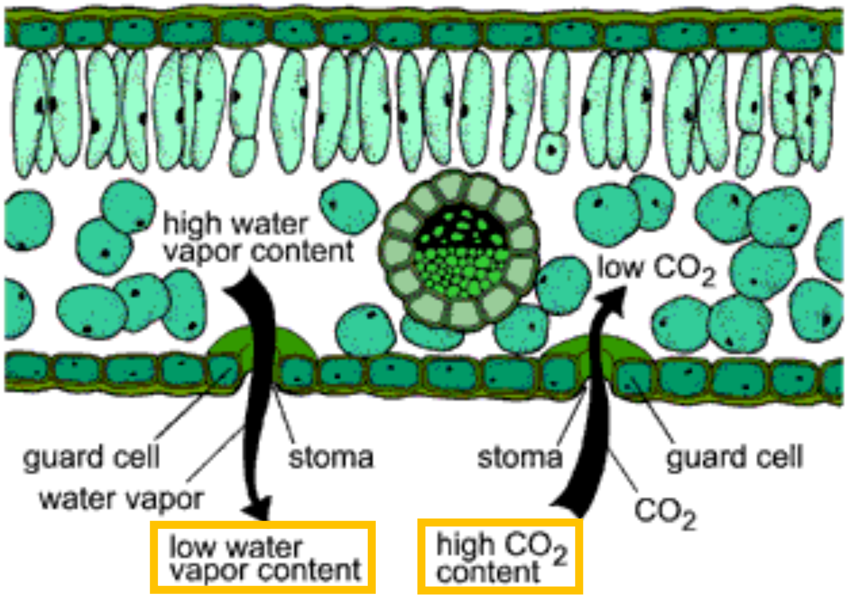
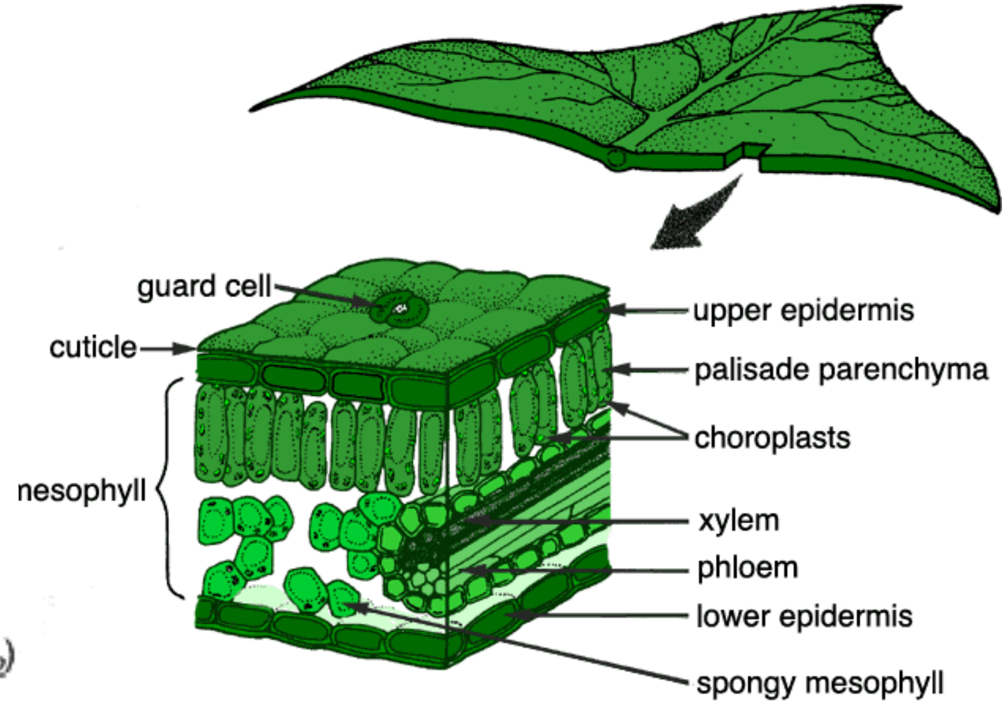
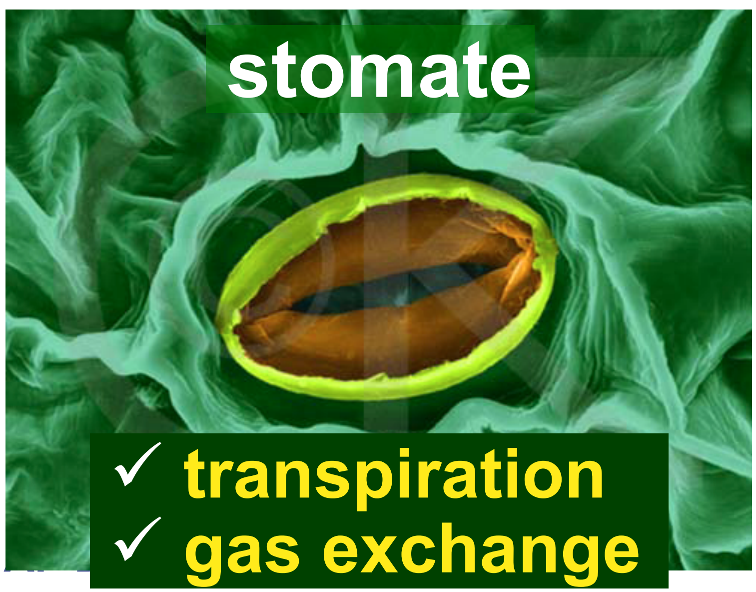
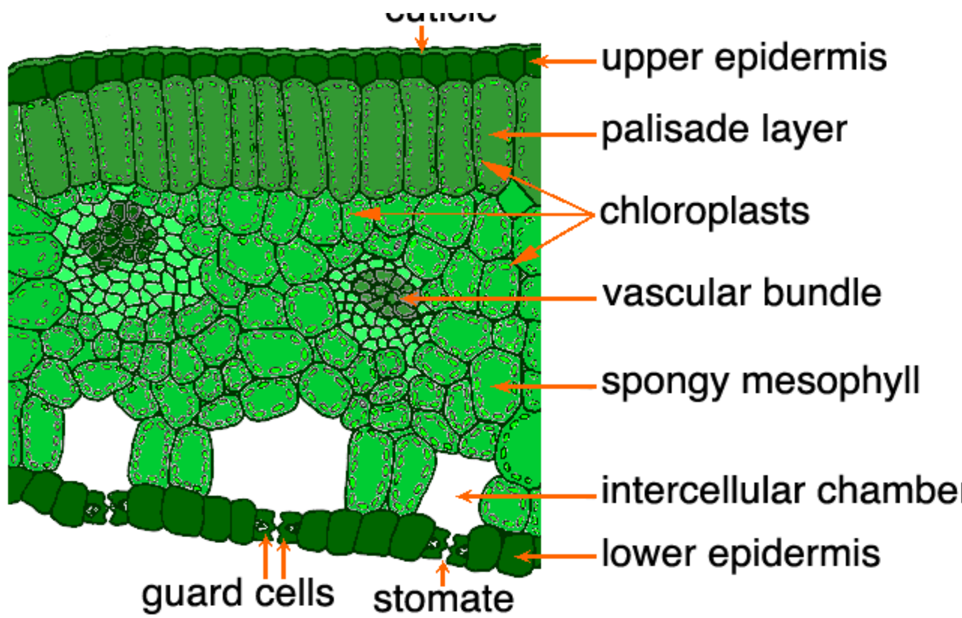


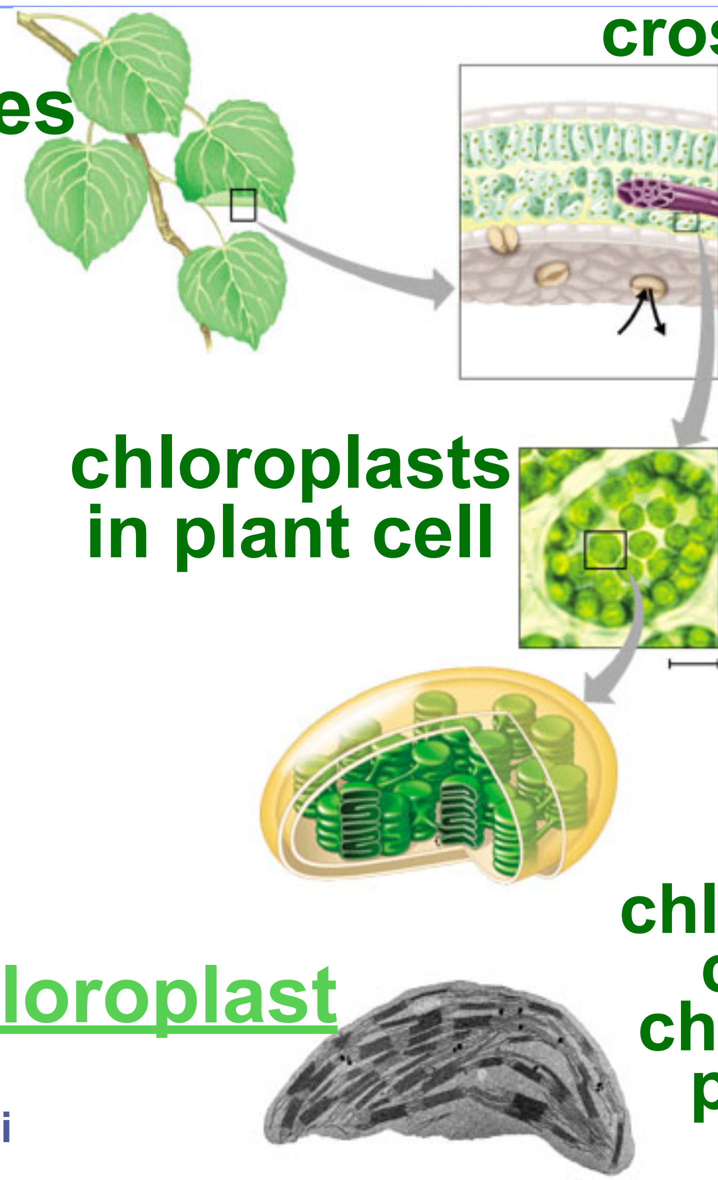
Figure 25. Stomata open to allow carbon dioxide (CO_2) to enter a leaf and water vapor to leave.

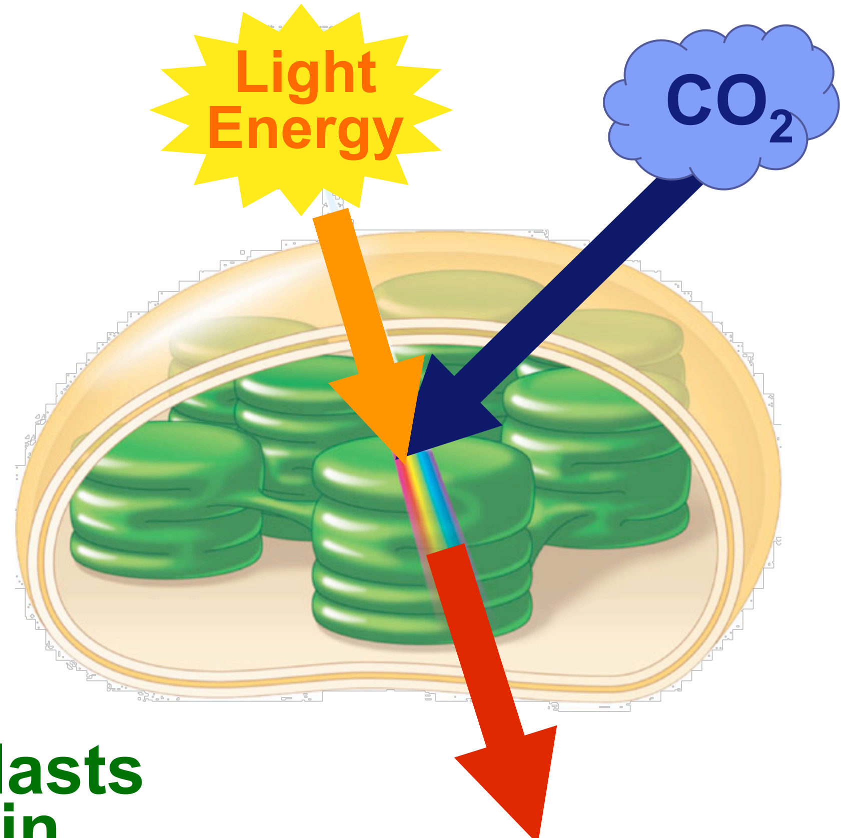






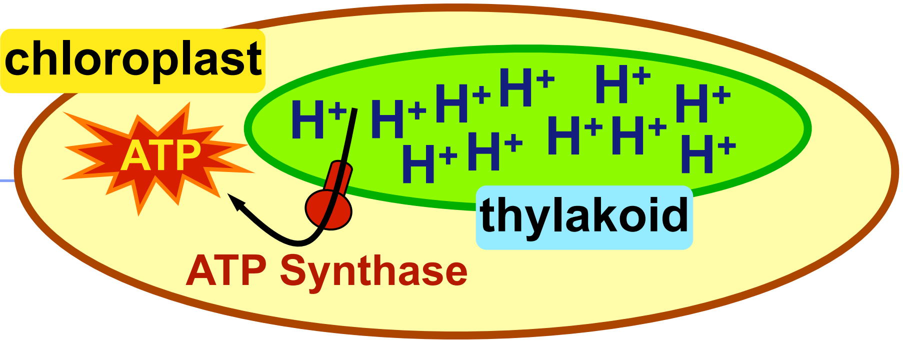
Chloroplasts *- the organelles of photosynthesis in Eukaryotes*

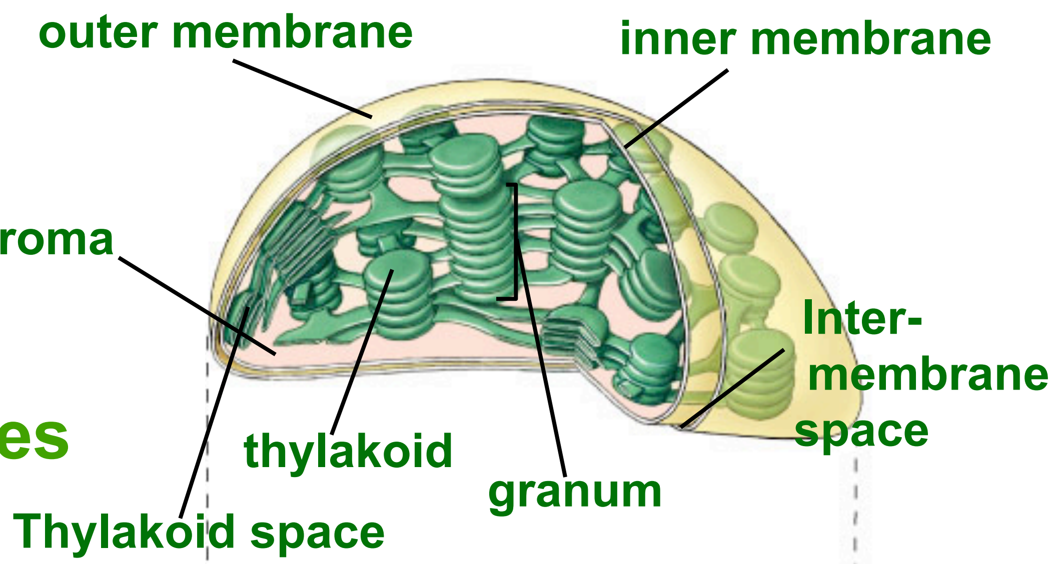


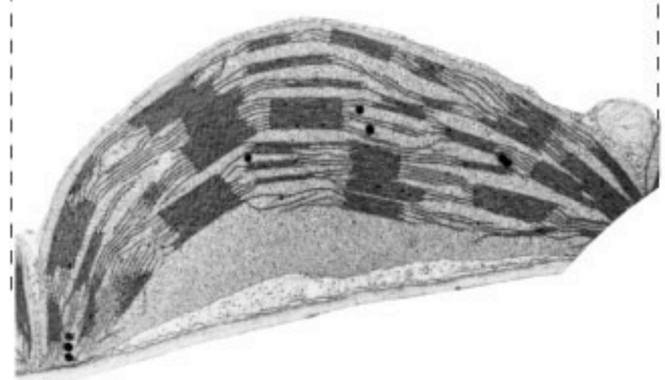


Plant structure

- Chloroplasts have...
  - double membrane
  - stroma
    - fluid-filled interior
  - thylakoid sacs
  - grana stacks
- Thylakoid membranes contain...
  - chlorophyll molecules
  - electron transport chains
  - ATP synthases
    - H^+ gradient is built up between the thylakoid space and the stroma

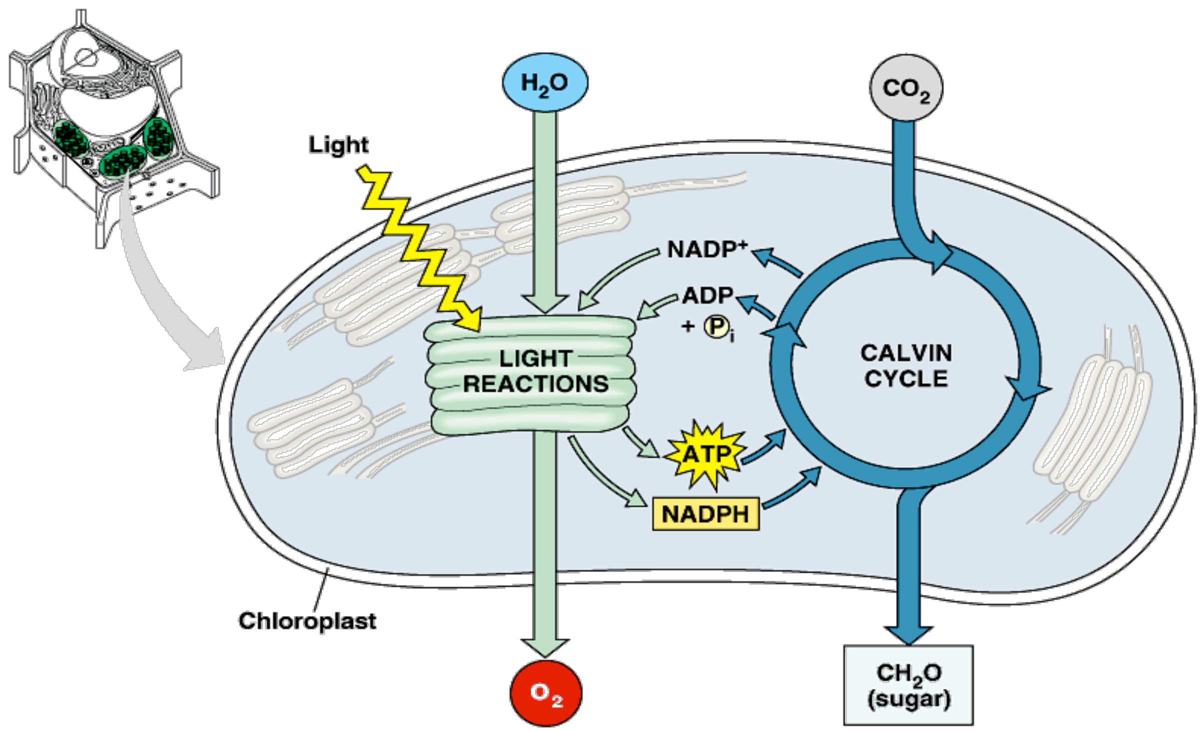




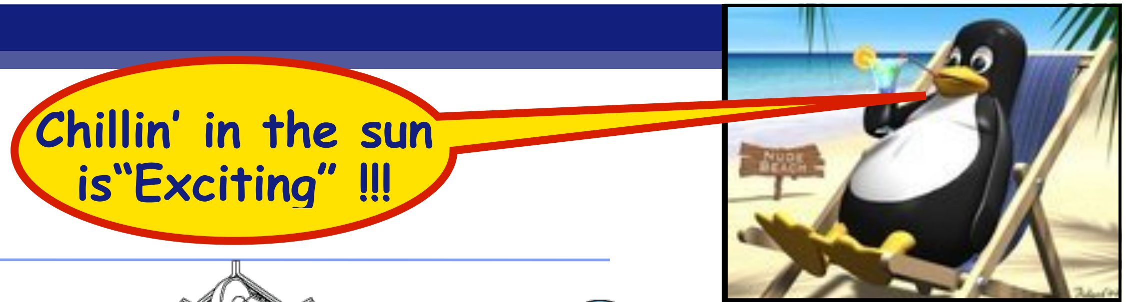


Photosynthesis

- Involves <u>redox reactions</u> but in the reverse order of cellular respiration
- <u>Water is split</u> instead of made
- <u>Electrons are transferred</u> along with hydrogen ions from the water to <u>carbon dioxides</u>, *reducing* them to sugar
- Process <u>requires energy</u> since electrons increase in potential energy starting off as low in potential energy & turning into high energy electrons
  - Energy comes form light



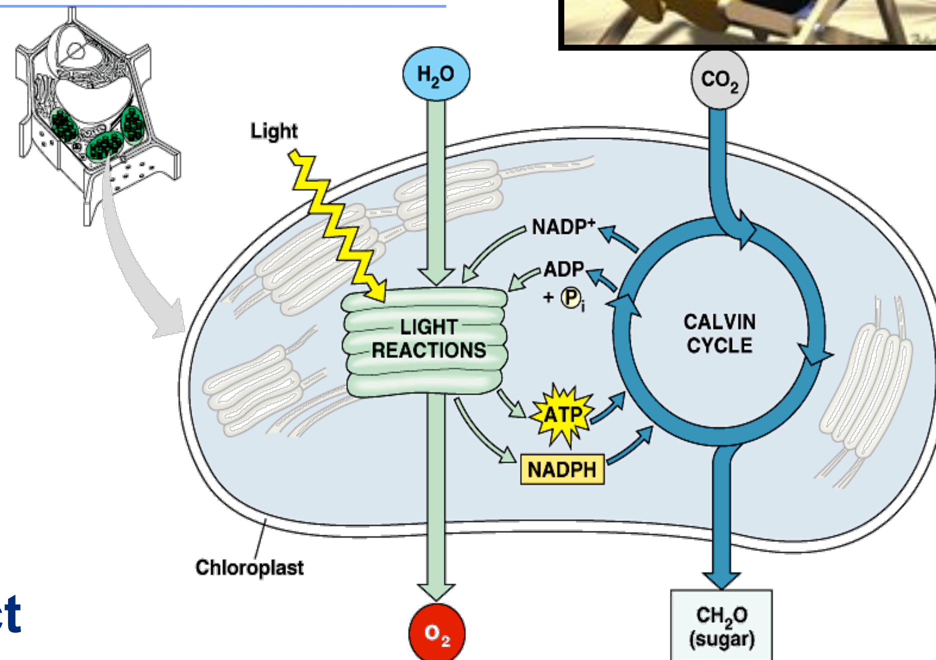
Two Stages of Photosynthesis:



1. Light reactions

(PHOTO PART)

- light-dependent reactions
  - In Thylakoids
- energy conversion reactions
  - convert solar energy to chemical energy
- Water is split
- O_2 released as waste product
- Reduced NADPH produced
- ATP made by through chemiosmosis, referred to here as photophosphorylation *(similar to oxidative phosphorylation in cellular respiration)*
- NO SUGAR MADE!!!
  - Only radiant energy collected

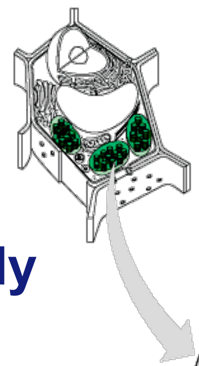


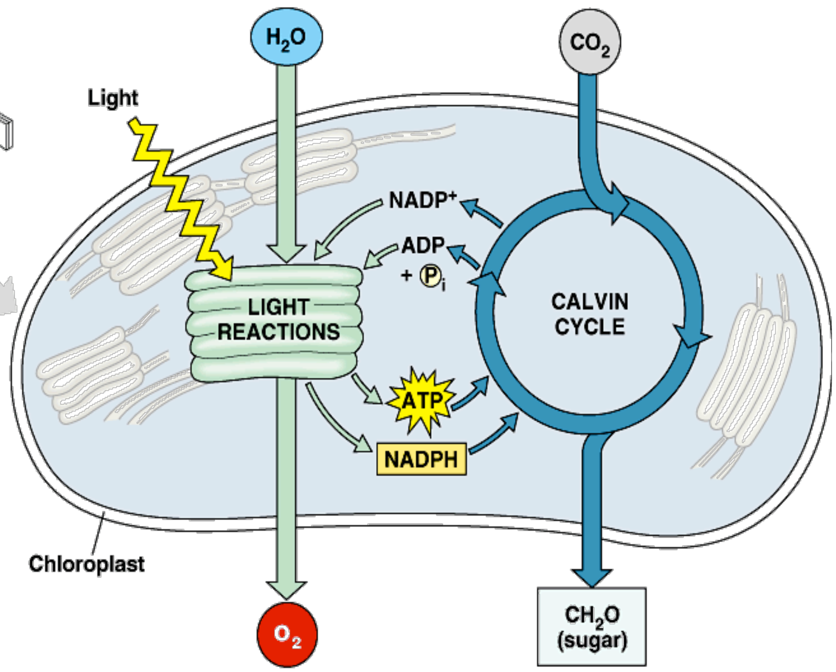
Two Stages of Photosynthesis:

2. Calvin cycle

(SYNTHESIS PART)

- light-independent reactions
  - In Stroma
- sugar building reactions
  - Incorporates CO_2 into organic molecules already present in chloroplast = carbon fixation
  - Uses chemical energy & high electrons (from ATP & NADPH) to reduce fixed CO_2 & synthesize $C_6H_{12}O_6$

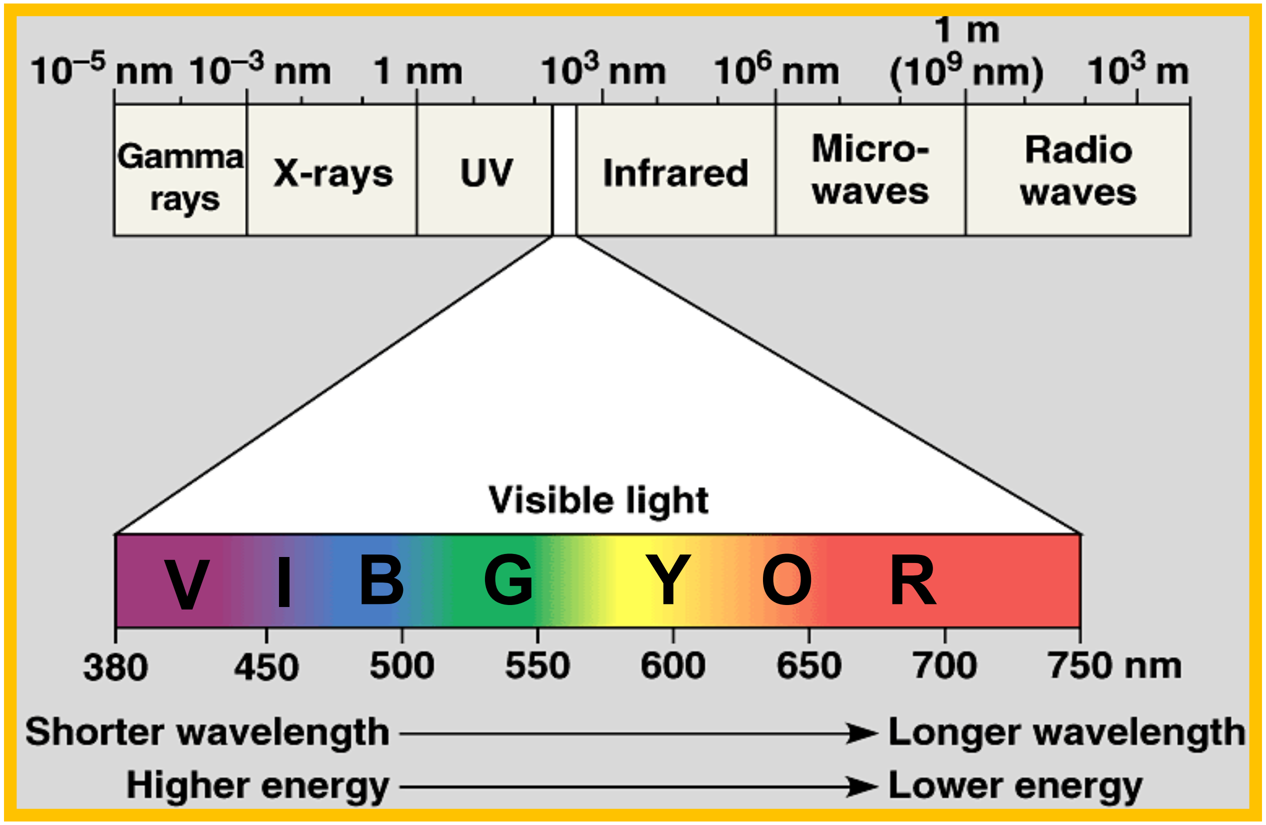




- Does not require light **DIRECTLY** but this phase of photosynthesis relies on the products of light reactions **INDIRECTLY** so the Calvin-Benson Cycle usually occurs during the daytime.

A Look at Light = Electromagnetic Energy

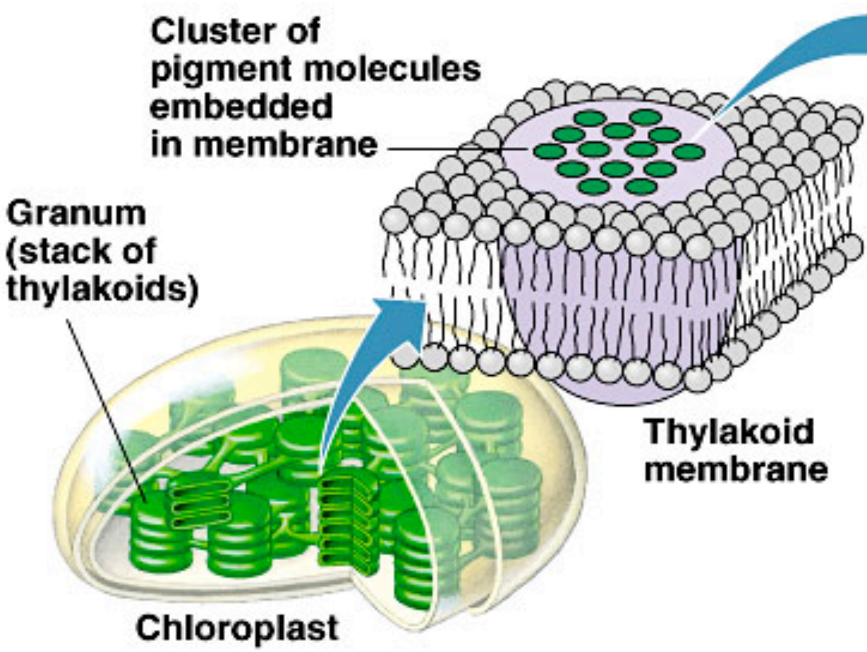
- Entire range of radiation = Electromagnetic spectrum
- Visible light = waves of 380 nm to 750 nm in wavelength, which appears as a spectrum of color to the human eye

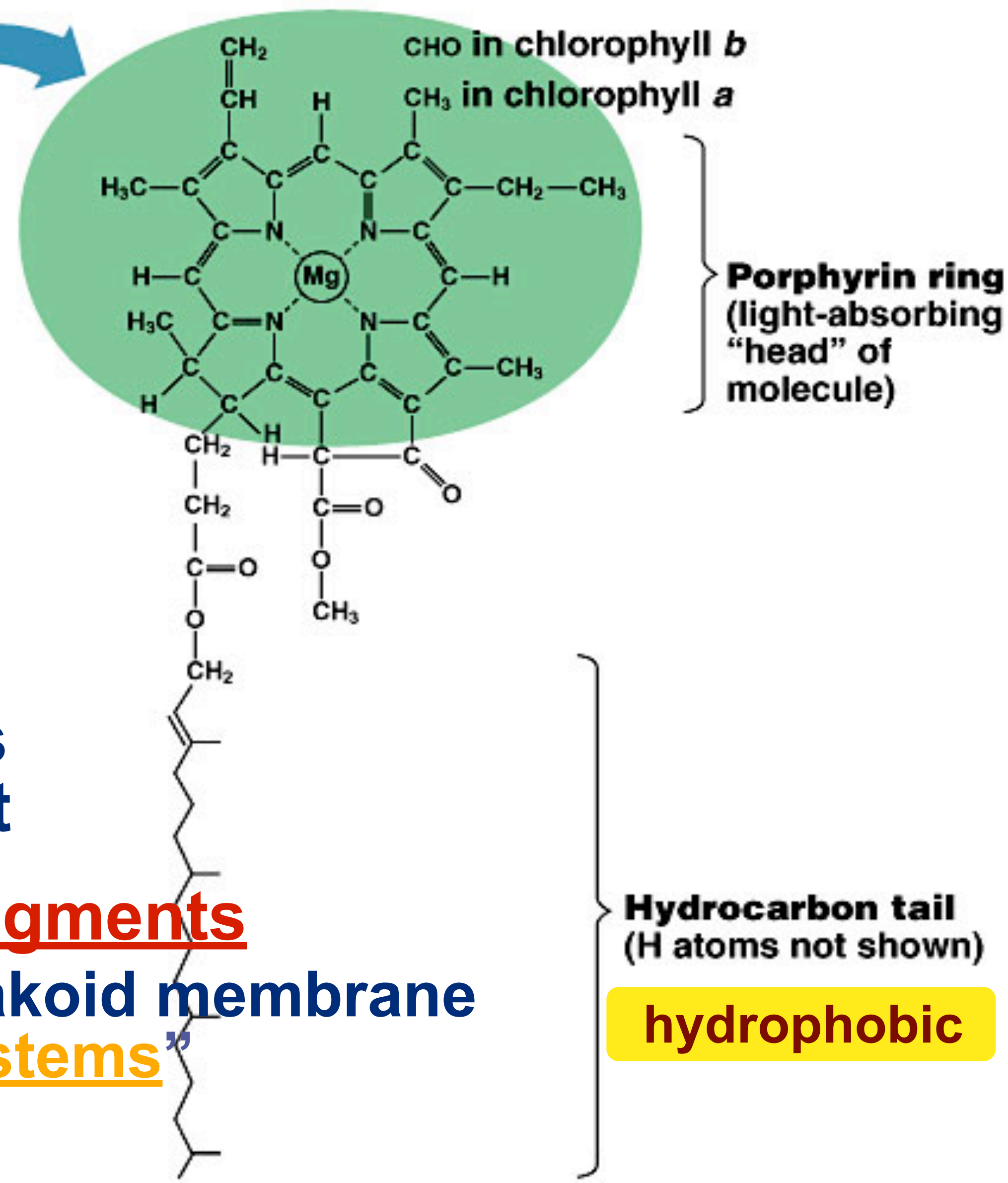


- Visible light drives photosynthesis!

Photosynthetic Pigments

hydrophilic

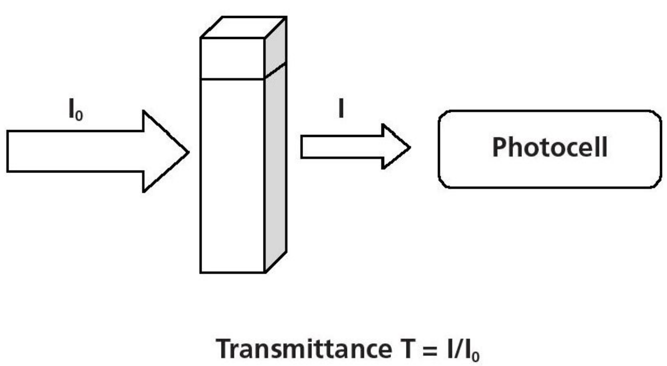


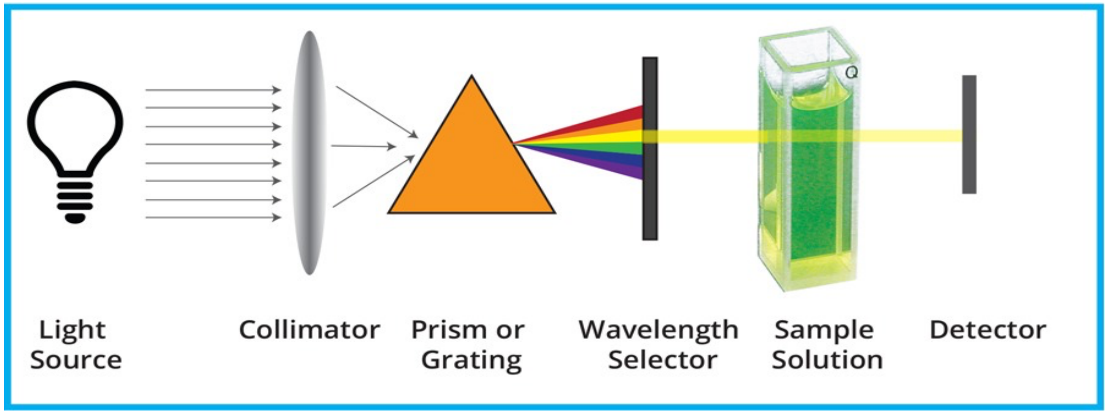


- Pigments = substances that absorb visible light
- Chlorophylls & other pigments
  - are embedded in thylakoid membrane
  - arranged in "photosystems"

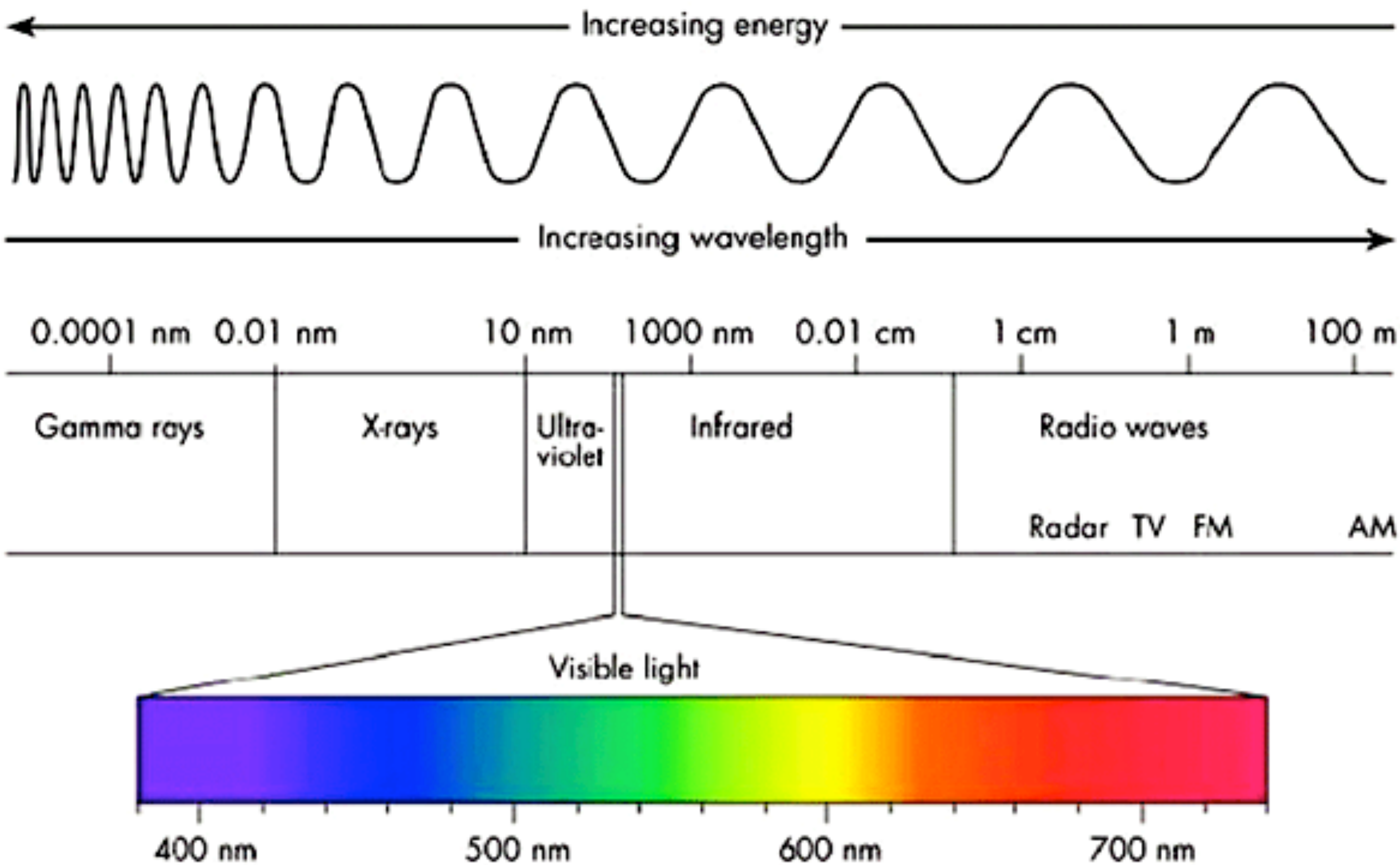
Measuring the Absorbance of Light Energy

- A spectrophotometer is an instrument used to measure the amount of light energy of a particular wavelength absorbed as it passes through a sample solution.
  - By knowing which wavelength of lights certain solutes absorb, you also know which wavelength of light energy are transmitted (and not absorbed)
- Spectrophotometers can have a variable wavelength selector that allows the instrument to transmit light within a specific and narrow range of wavelengths (i.e., 340–950 nm).
  - Different compounds in solution absorb light at different wavelengths.
    - The instrument indirectly measures the amount of light absorbed by that sample by comparing the initial intensity of light reaching the sample (I_0) with the light detected by a photocell as it exits the sample (I). The ratio of the 2 readings is referred to as the transmittance of light through the sample
    - When light interacts with a substance, certain wavelengths may be absorbed by the substance, while other wavelengths may be transmitted or reflected.
    - The intensity of a solution's color measures of the amount of dissolved material.

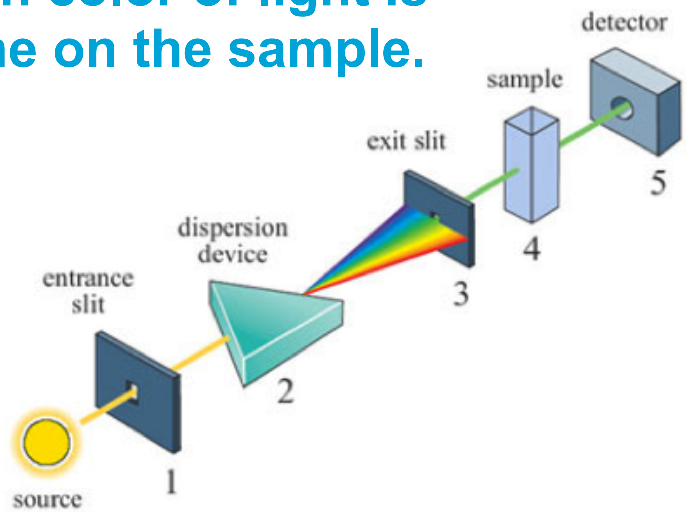


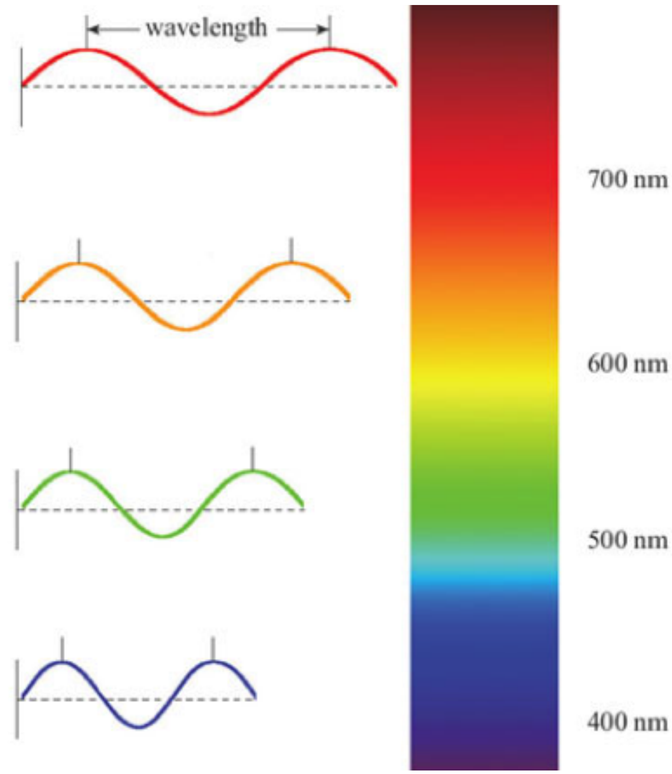


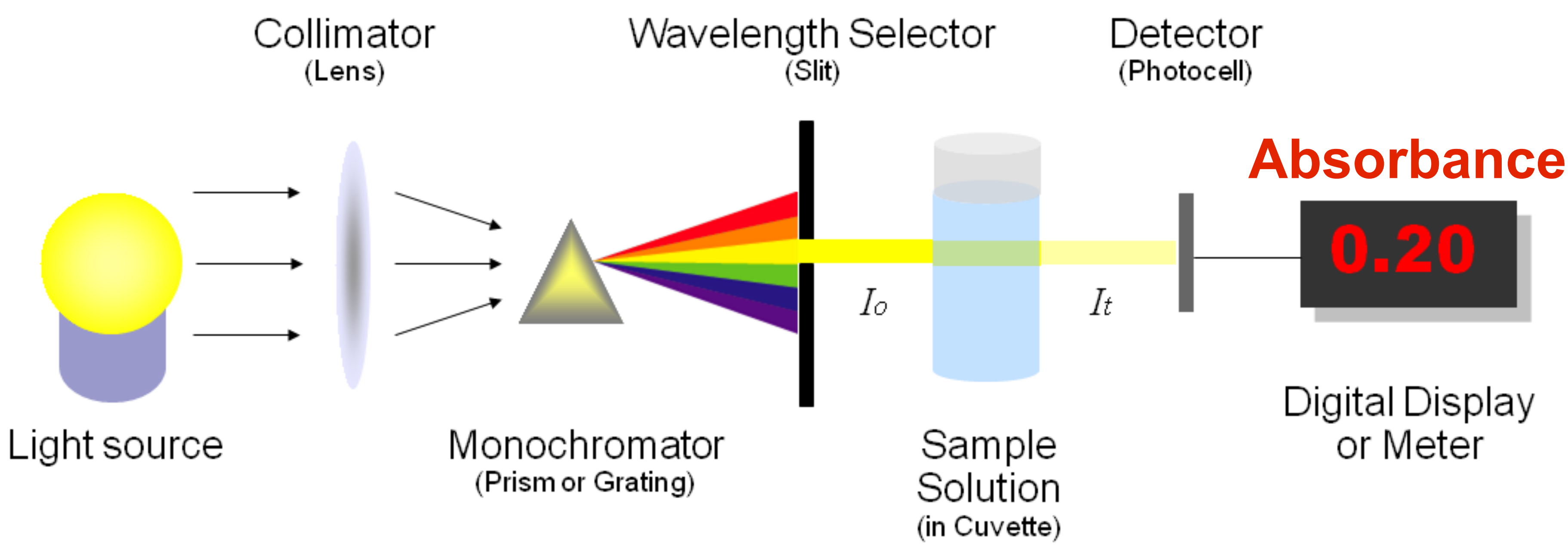
Spectrophotometers measure the amount of a particular visible light energy absorbed (or transmitted) as it passes through a sample solution.



- **The scientist selects which color of light is shone on the sample.**

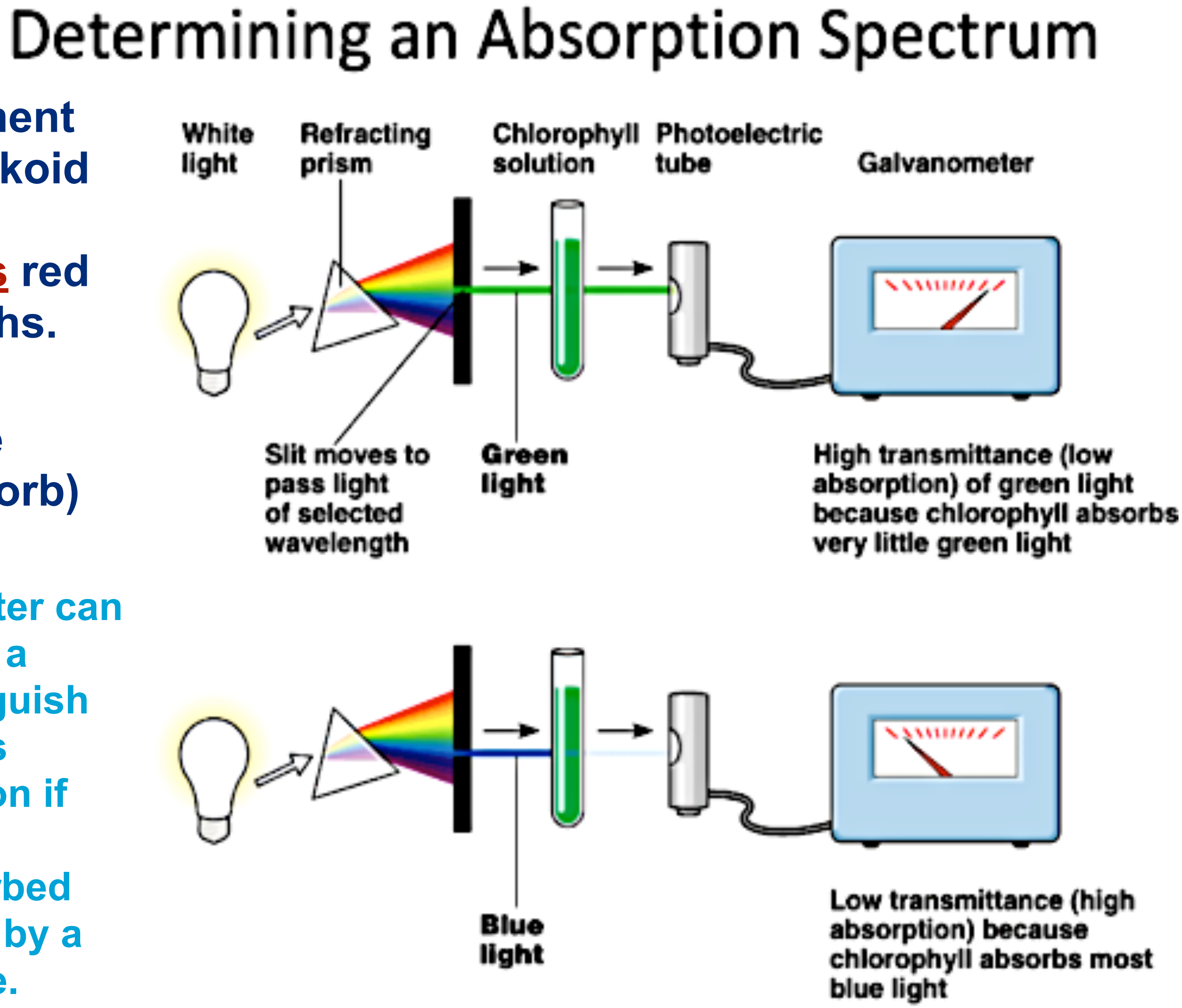






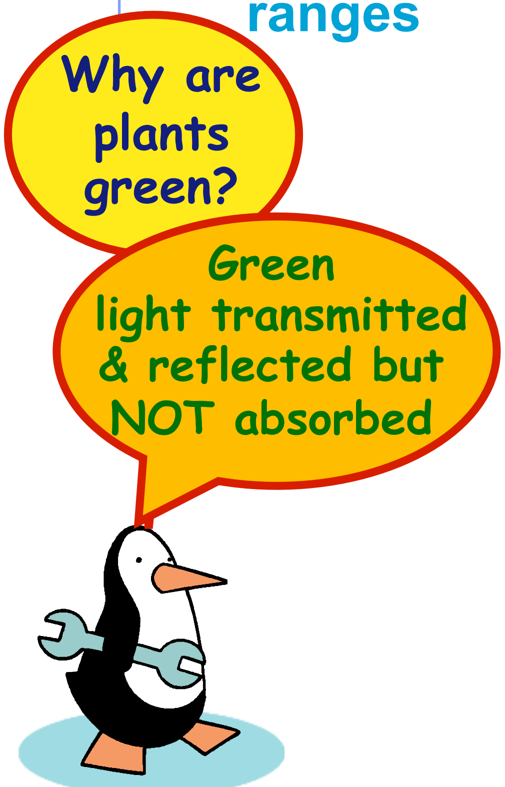
Light Absorption Abilities can be Used to Identify the Type & Amount of Substance Present in a solution

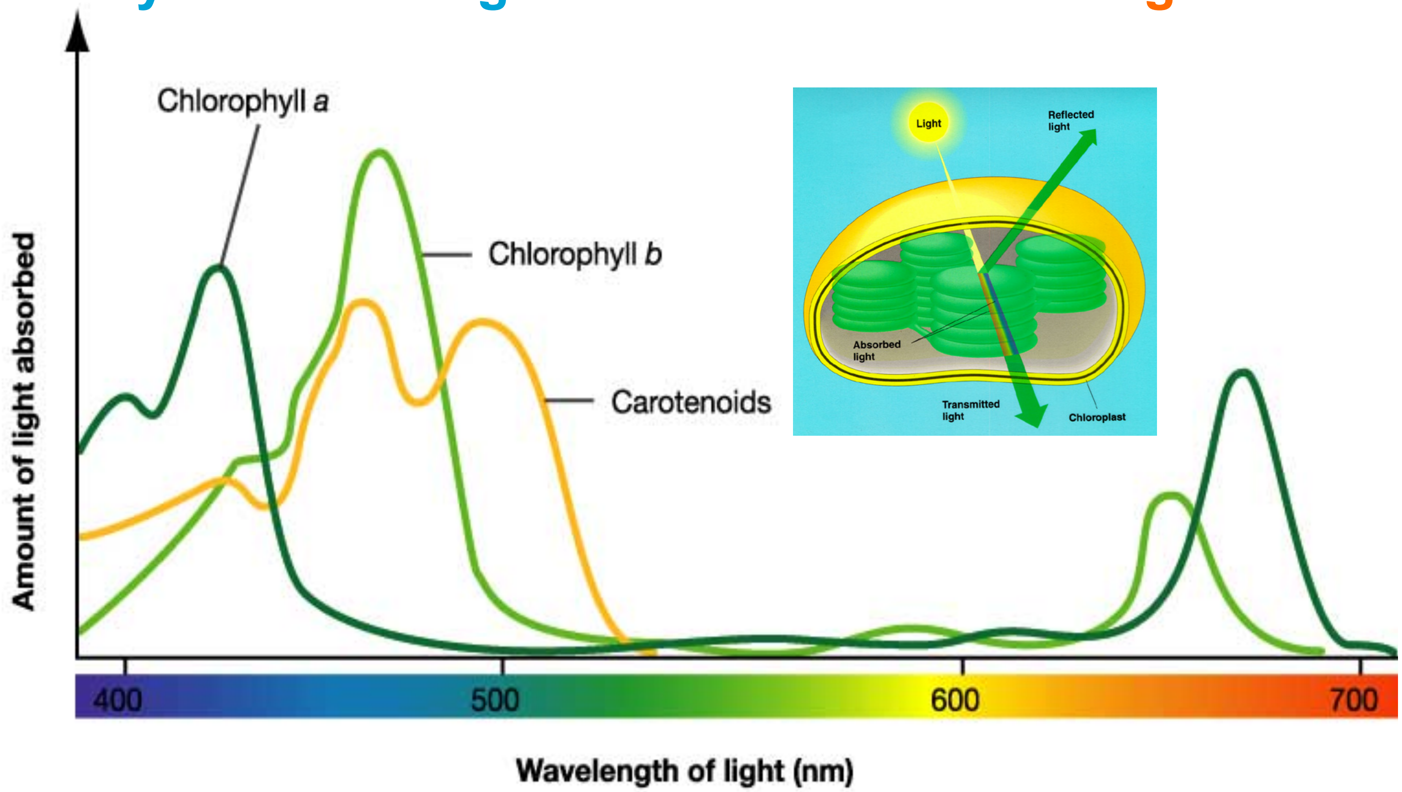
- **The chlorophyll pigment molecule in the thylakoid membranes of chloroplasts absorbs red and violet wavelengths.**
- **However, the same chlorophyll molecule transmits (fail to absorb) green wavelengths.**
    - **A spectrophotometer can be used to identify a molecule or distinguish between molecules present in a solution if one knows the wavelengths absorbed and/or transmitted by a particular molecule.**



Absorption spectra *- graph of light absorbed by pigment vs wavelength*

- **Photosynthesis gets energy by absorbing energy from wavelengths of light**
  - **ONLY absorbed light energy can be harnessed to do work**
- **Different pigments absorb different wavelengths of light energy**
  - **Cholorphylls & accessory pigments result in most light energy used for photosynthesis being in the violet-blue to orange-red ranges**

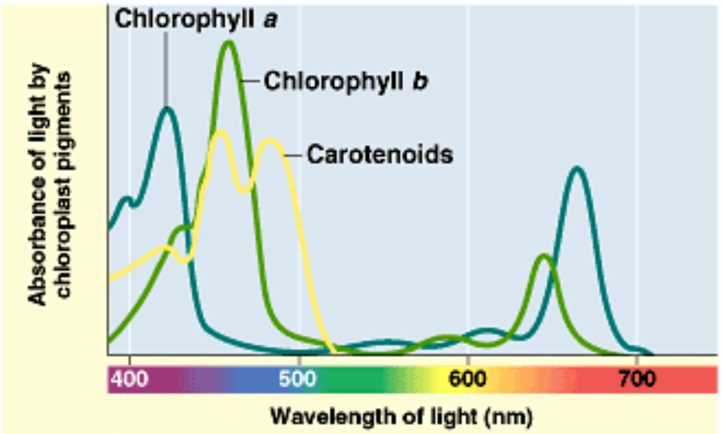




Photosynthetic pigments

- **Chlorophyll *a***
  participates directly in the light reactions of photosynthesis
  - Blue-green colored pigment:
    - absorbs red & blue wavelengths best & green wavelengths the least

- **Accessory "Helper" pigments** with different structures absorb light energy of different wavelengths than chlorophyll a
  - Selective Advantage of accessory pigments?
    - Help broaden the spectrum of light energy that can be absorbed for photosynthesis

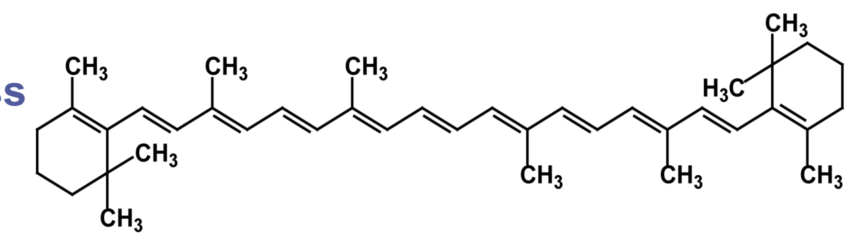


Accessory Pigments

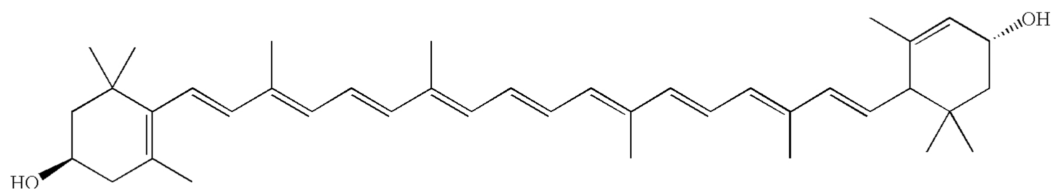
- **chlorophyll b**: absorbed slightly different red and blue light
  - Yellow-green colored pigment

- **Carotenoids**: yellow-orange pigments
  - Absorb mostly violet and blue-green light
    - Important in photoprotection: absorb and dissipate excessive light energy that can damage chlorophyll a and interact with oxygen causing forming damaging O free radicals

- Carotenes - hydrocarbon class
  - Orange hued pigments

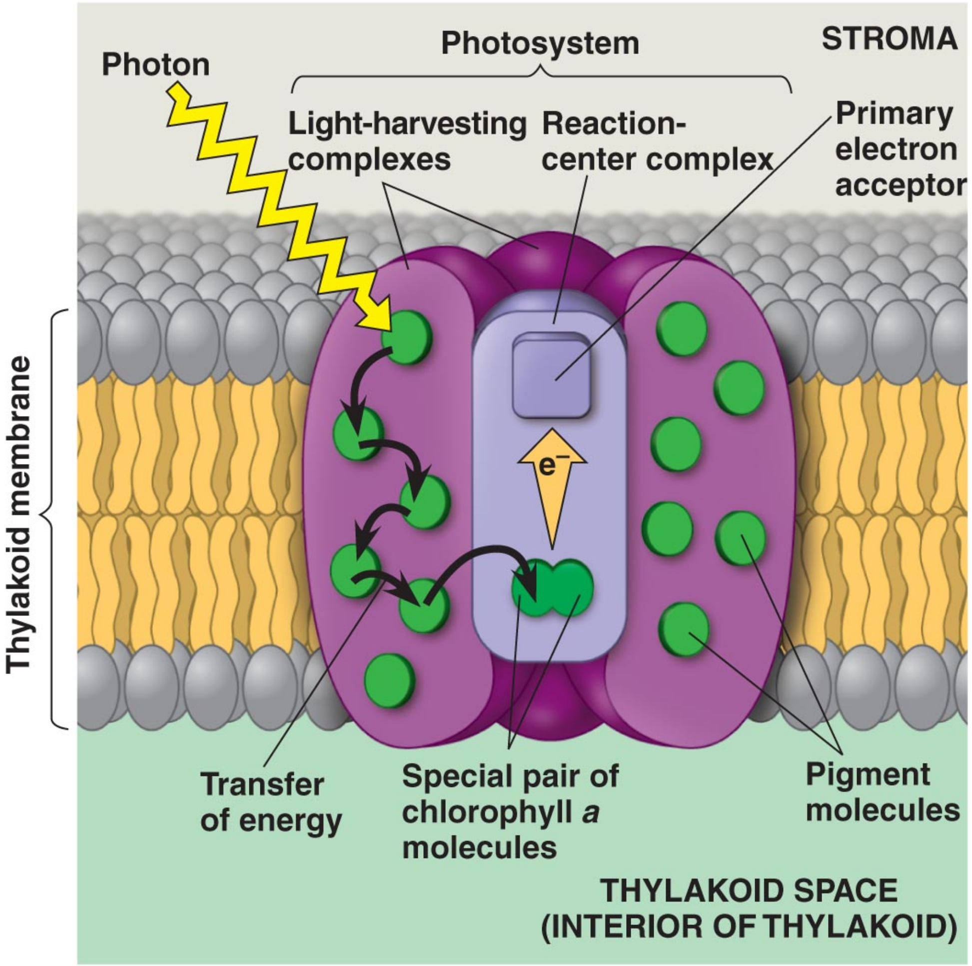


- Xanthophylls - oxygenated alcohol class
  - yellow hued



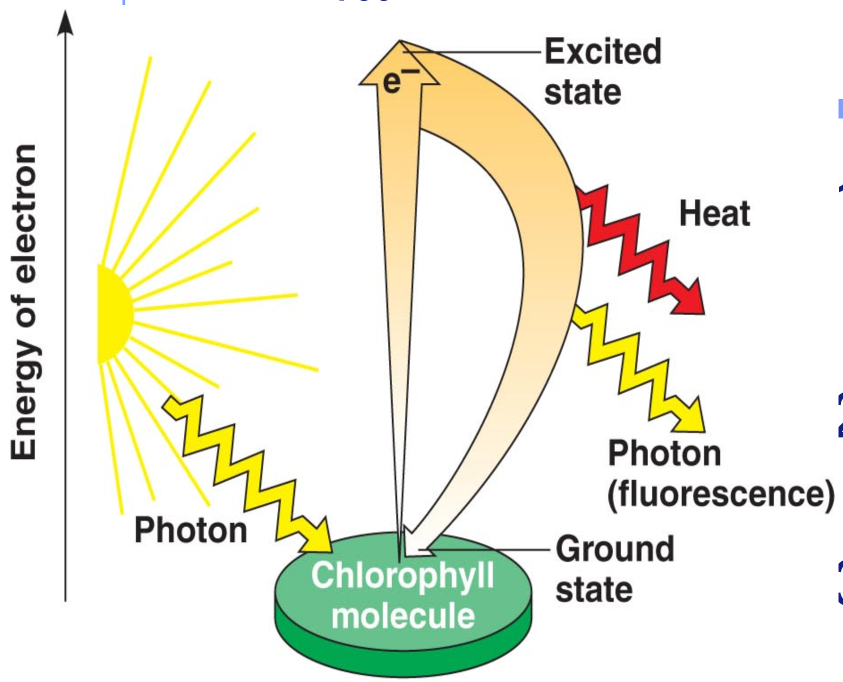
Photosystems of photosynthesis

- 2 types of photosystems in thylakoid membrane: Photosystem II & I
  - collections of chlorophyll, small organic molecules, and proteins
  - act as light energy-gathering molecules
- Photosystem Components:
  - **Reaction-center Complex:**
    - special pair of chlorophyll *a* molecules
    - a primary electron acceptor capable of becoming reduced
  - **Light-Harvesting Complex:**
    - Pigment molecules (chlorophyll a, b, carotenoids) bound to proteins
      - *Used to harvest light energy over large surface area & portion of the spectrum*
      - *Transfers energy from light to reaction center complex*



Transferring energy through photosystems by exciting electrons through light

- **Photosystem II**
  - chlorophyll *a* at the center
  - P_{680} = absorbs 680nm wavelength red light
- **Photosystem I**
  - chlorophyll *a* at center
  - P_{700} = absorbs 700nm wavelength red light



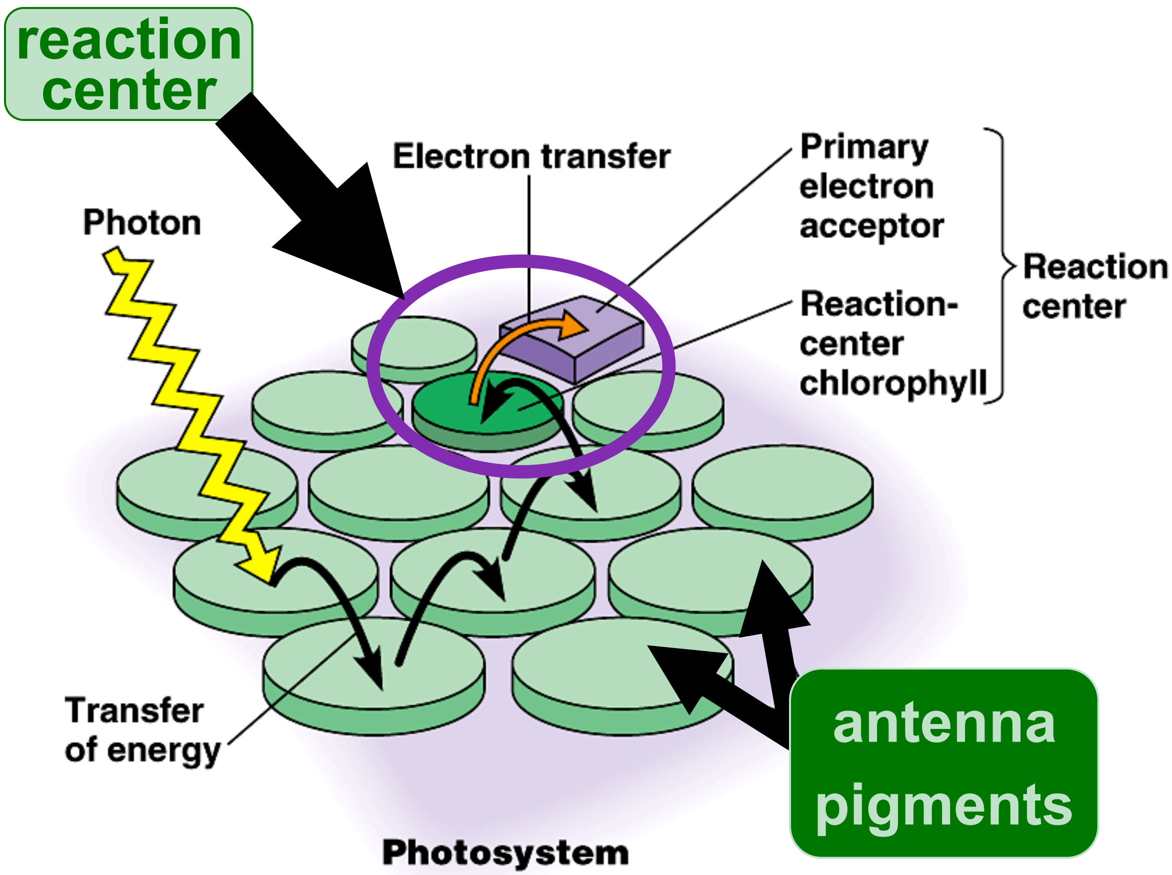
(a) Excitation of isolated chlorophyll molecule

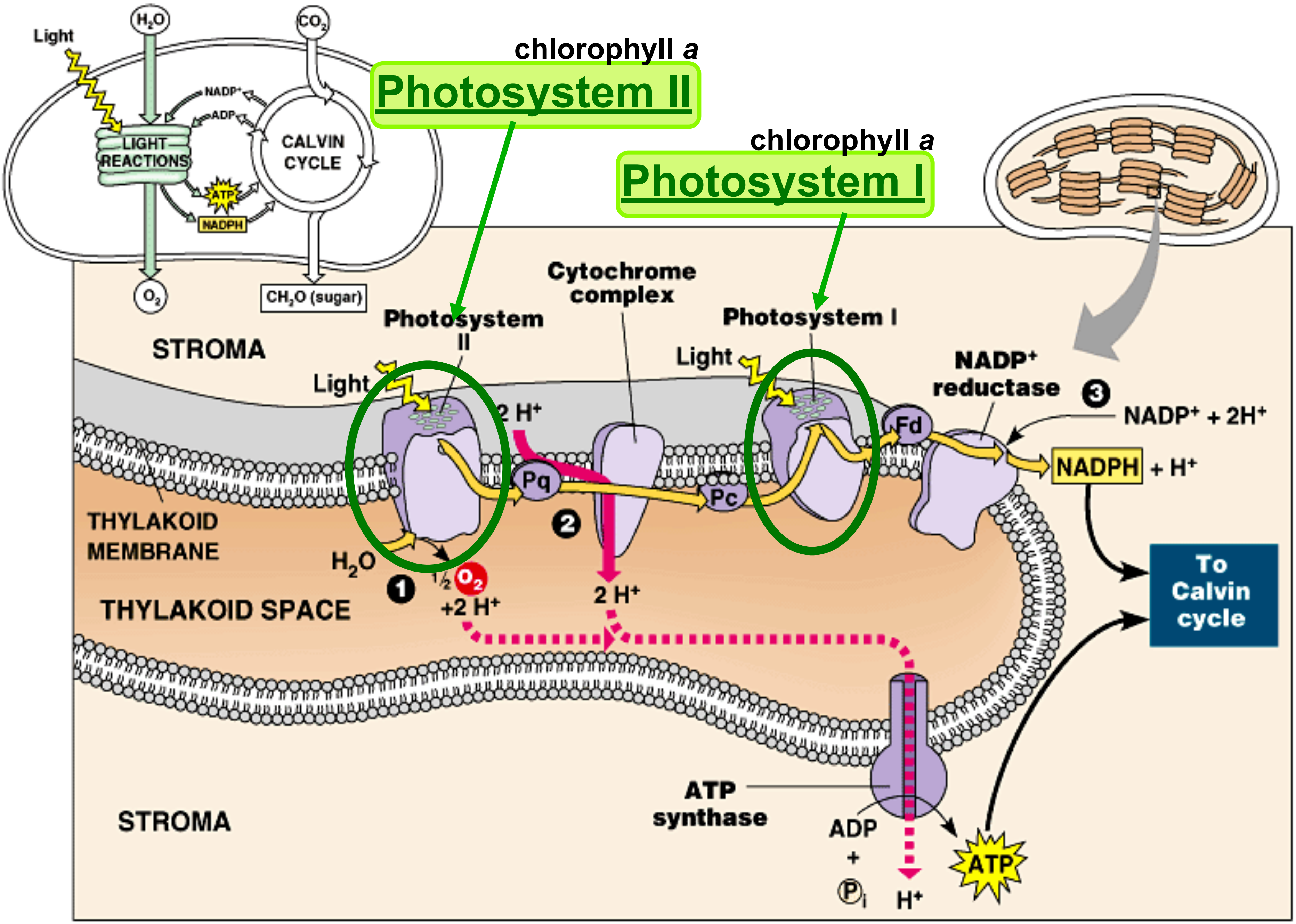
- **Starting the light reaction:**

1. Photons are absorbed by clusters of pigment molecules (in the light harvesting or antenna complex) in the thylakoid membrane.
2. When any antenna pigment absorbs a photon, electrons are excited, and move to a higher energy level in an atom.
3. As electrons fall back to their ground state, the energy released excites the next electron in a neighboring molecule's atom

Photosystem Functioning

- ENERGY is transferred all the way to a particular pair of chlorophyll *a* molecules in the the reaction center.
- In the reaction center, a primary electron acceptor REMOVES 2 excited electrons from a pair of reaction center chlorophyll a.
- The electrons then proceed to an ELECTRON TRANSPORT CHAIN

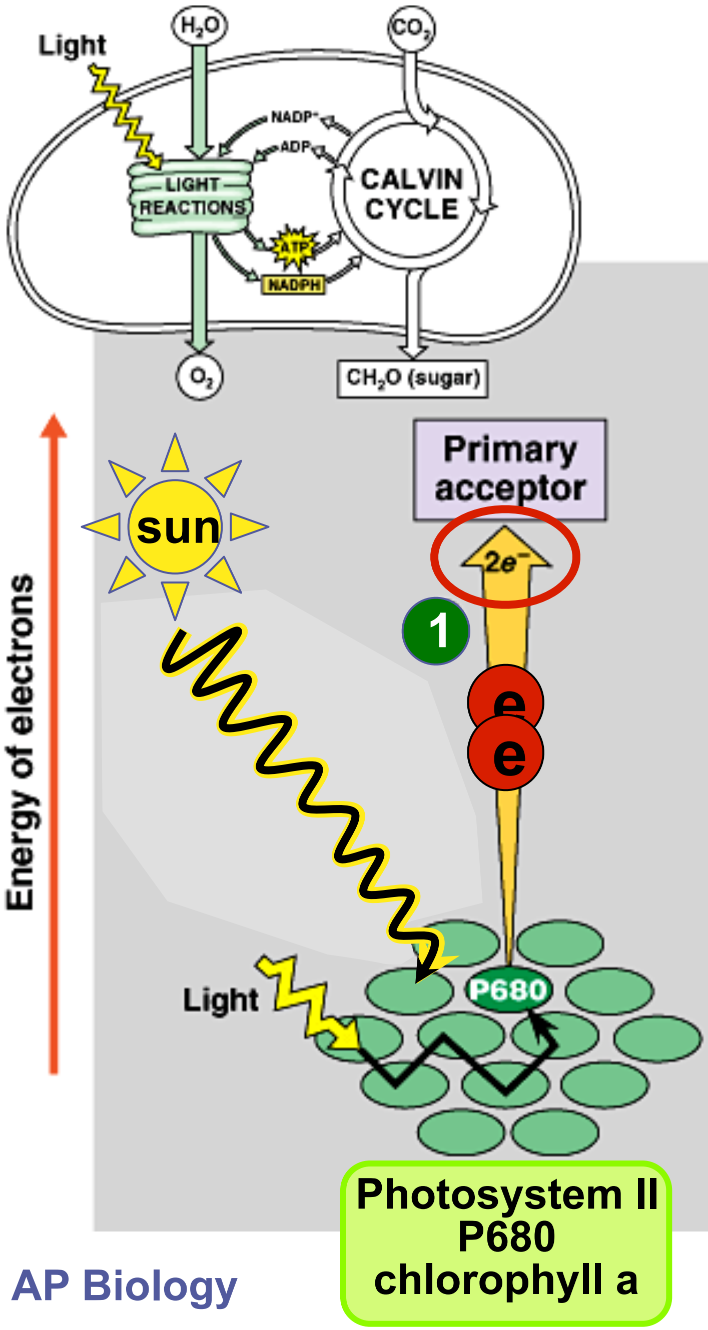




chlorophyll a
Photosystem II
chlorophyll a
Photosystem I
Light
H_2O
CO_2
$NADP^+$
ADP
LIGHT REACTIONS
CALVIN CYCLE
ATP
NADPH
O_2
CH_2O (sugar)
Cytochrome complex
Photosystem II
Photosystem I
STROMA
Light
Light
NADP⁺ reductase
3
$NADP^+ + 2H^+$
2 H⁺
Fd
Pq
Pc
NADPH + H⁺
2
THYLAKOID MEMBRANE
H_2O
1
½ O_2
+2 H⁺
2 H⁺
THYLAKOID SPACE
To Calvin cycle
ATP synthase
STROMA
ADP + Ⓟi
H⁺
ATP

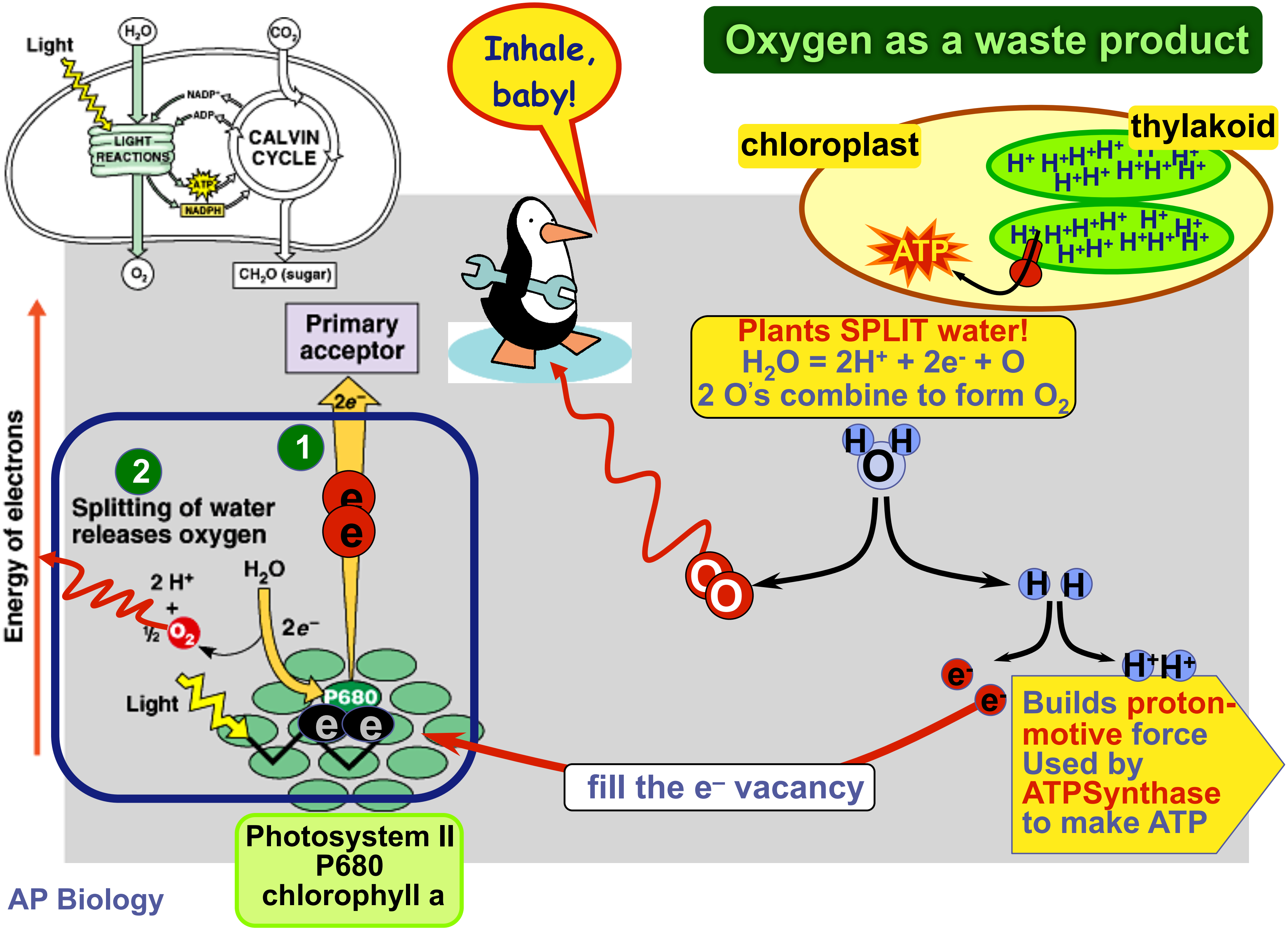
Linear electron flow =

e- move from photosystems through ETC's in thylakoid membrane

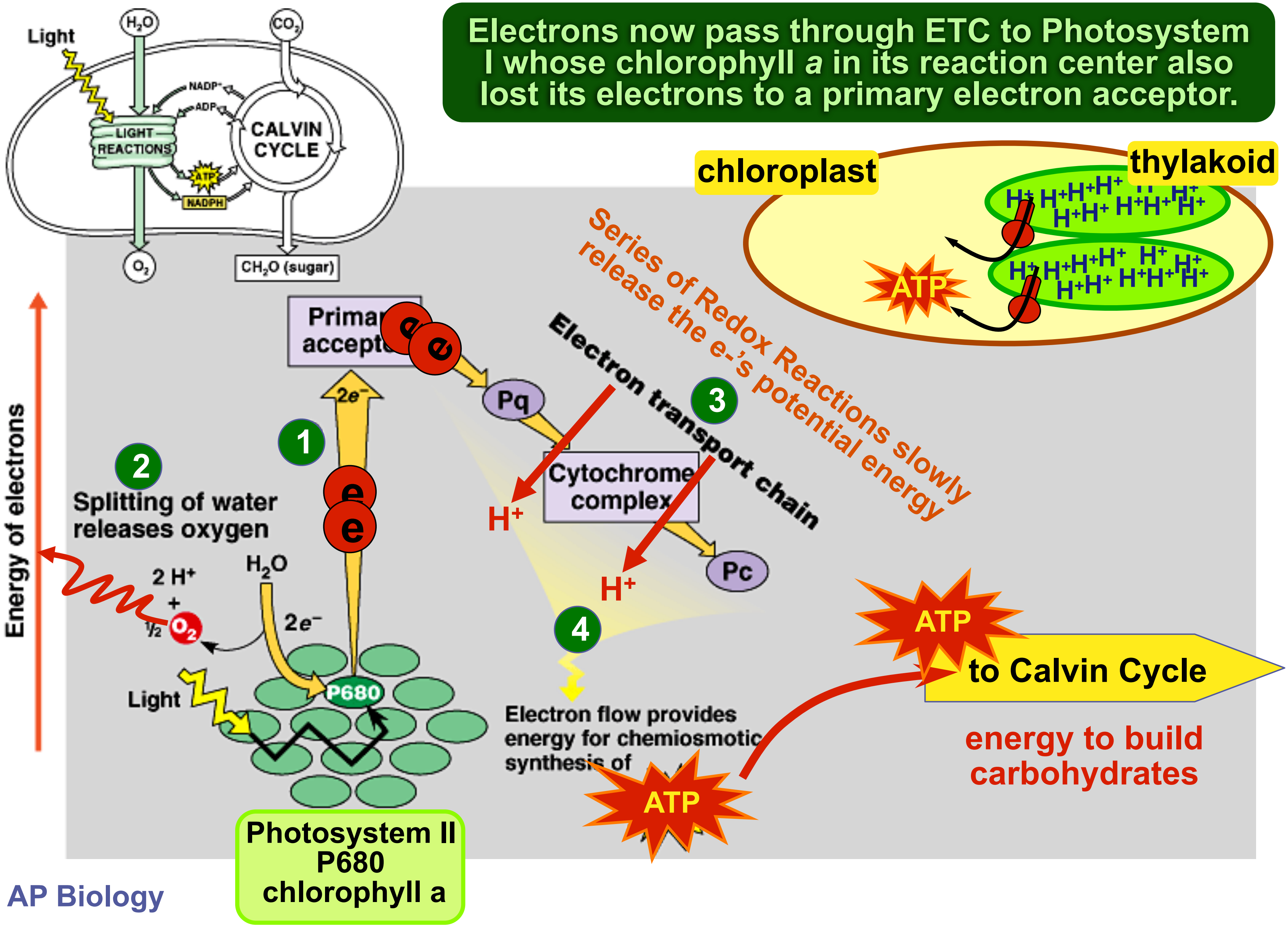


- Photon strikes pigment
- Energy passed through light-harvesting (antenna) complex to reaction center
- Two chlorophyll a electrons excited and are **REMOVED** by a primary electron acceptor *(gets reduced)*
- P680 oxidized to **P680+**

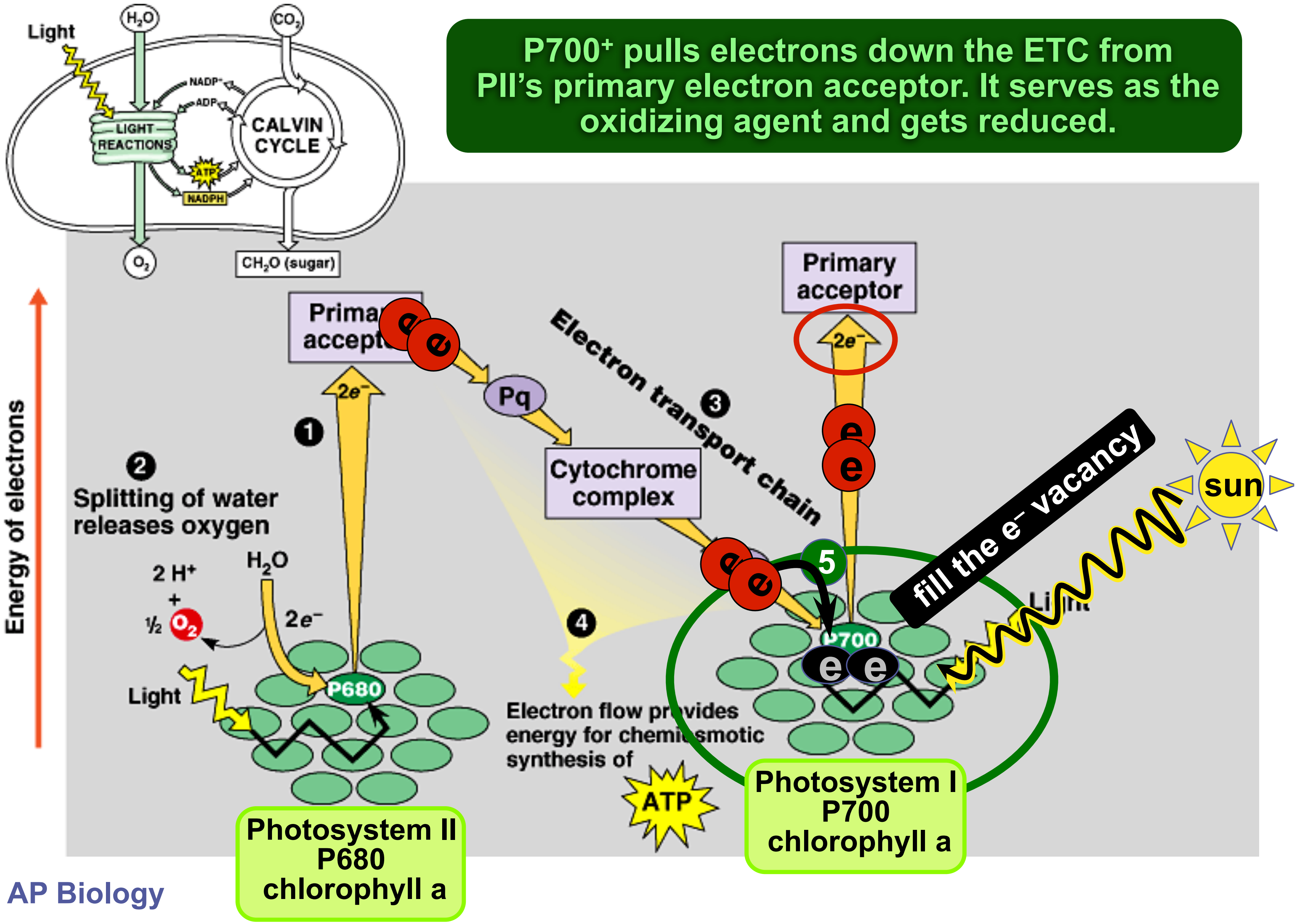
Oxygen as a waste product



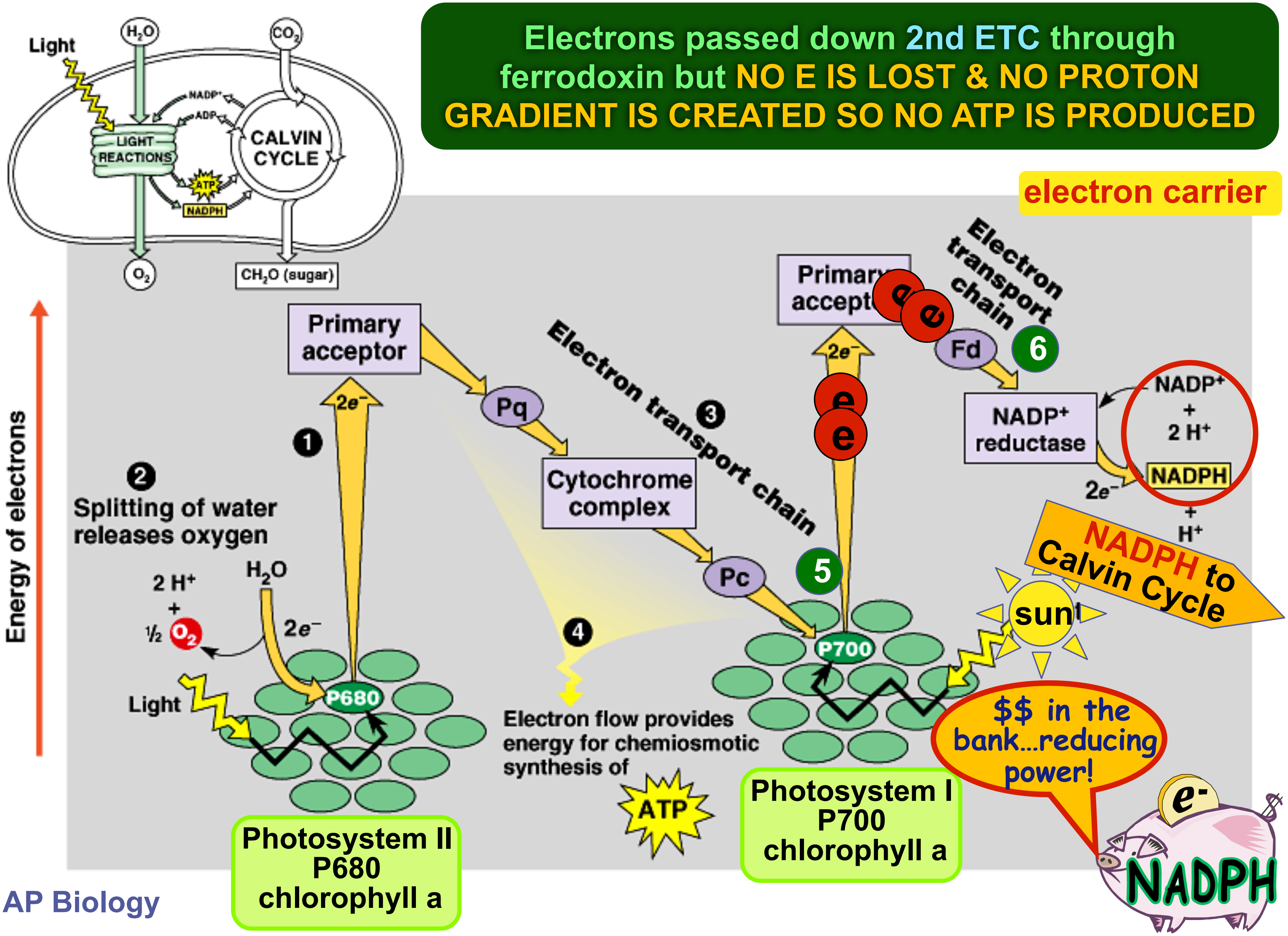
Electrons now pass through ETC to Photosystem I whose chlorophyll *a* in its reaction center also lost its electrons to a primary electron acceptor.



P700+ pulls electrons down the ETC from PII's primary electron acceptor. It serves as the oxidizing agent and gets reduced.

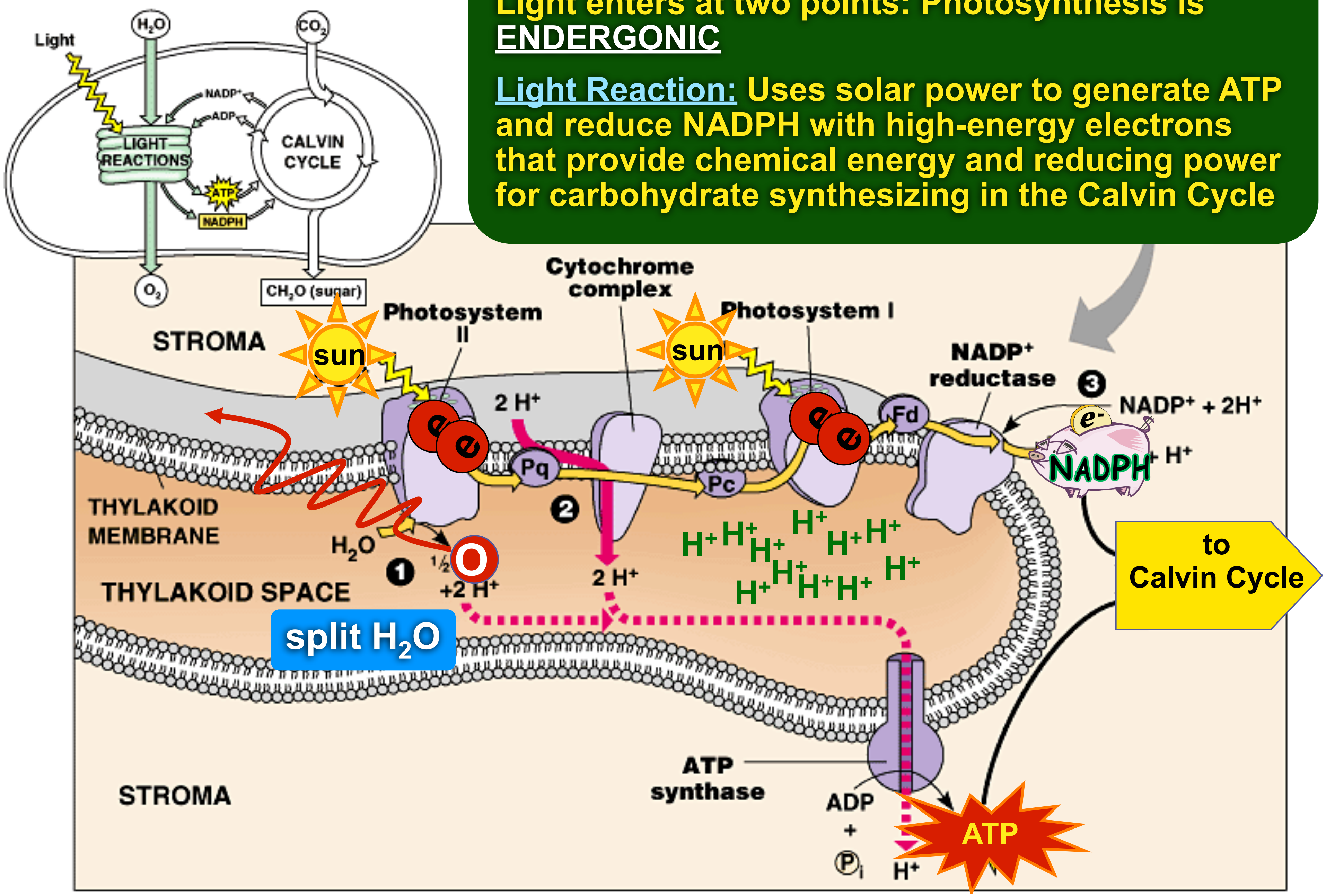


Electrons passed down 2nd ETC through ferrodoxin but NO E IS LOST & NO PROTON GRADIENT IS CREATED SO NO ATP IS PRODUCED



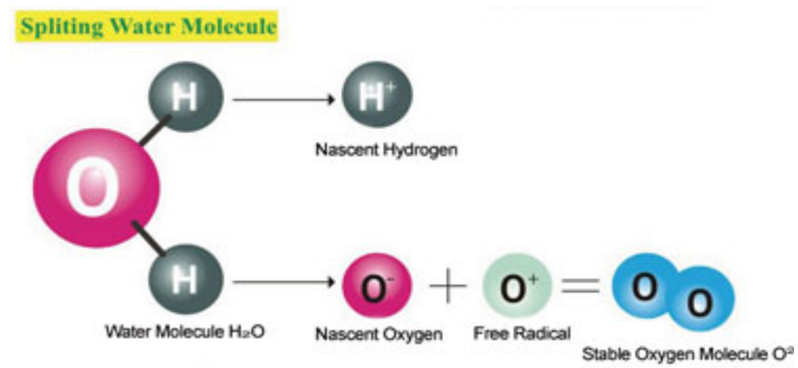
Light enters at two points: Photosynthesis is <u>ENDERGONIC</u>

<u>Light Reaction:</u> Uses solar power to generate ATP and reduce NADPH with high-energy electrons that provide chemical energy and reducing power for carbohydrate synthesizing in the Calvin Cycle



ETC of Photosynthesis

- ETC uses light energy to produce
  - ATP & reduced NADPH
    - go to Calvin cycle
- PS II absorbs light
  - excited electron passes from chlorophyll *a* to "primary electron acceptor"
  - need to replace electron in chlorophyll
  - enzyme extracts electrons from H_2O & supplies them to chlorophyll *a*
    - splits H_2O
    - O combines with another to form O_2
    - O_2 released to atmosphere
      - and we breathe easier (or at all) !!!



O_2 origin debate: From water or carbon dioxide

- **Where did the O_2 come from?**
  - radioactive tracer added to molecules = O_{18}

Experiment 1

$$6CO_2 + 6H_2\mathbf{O} + \text{light energy} \rightarrow C_6H_{12}O_6 + 6\mathbf{O}_2$$

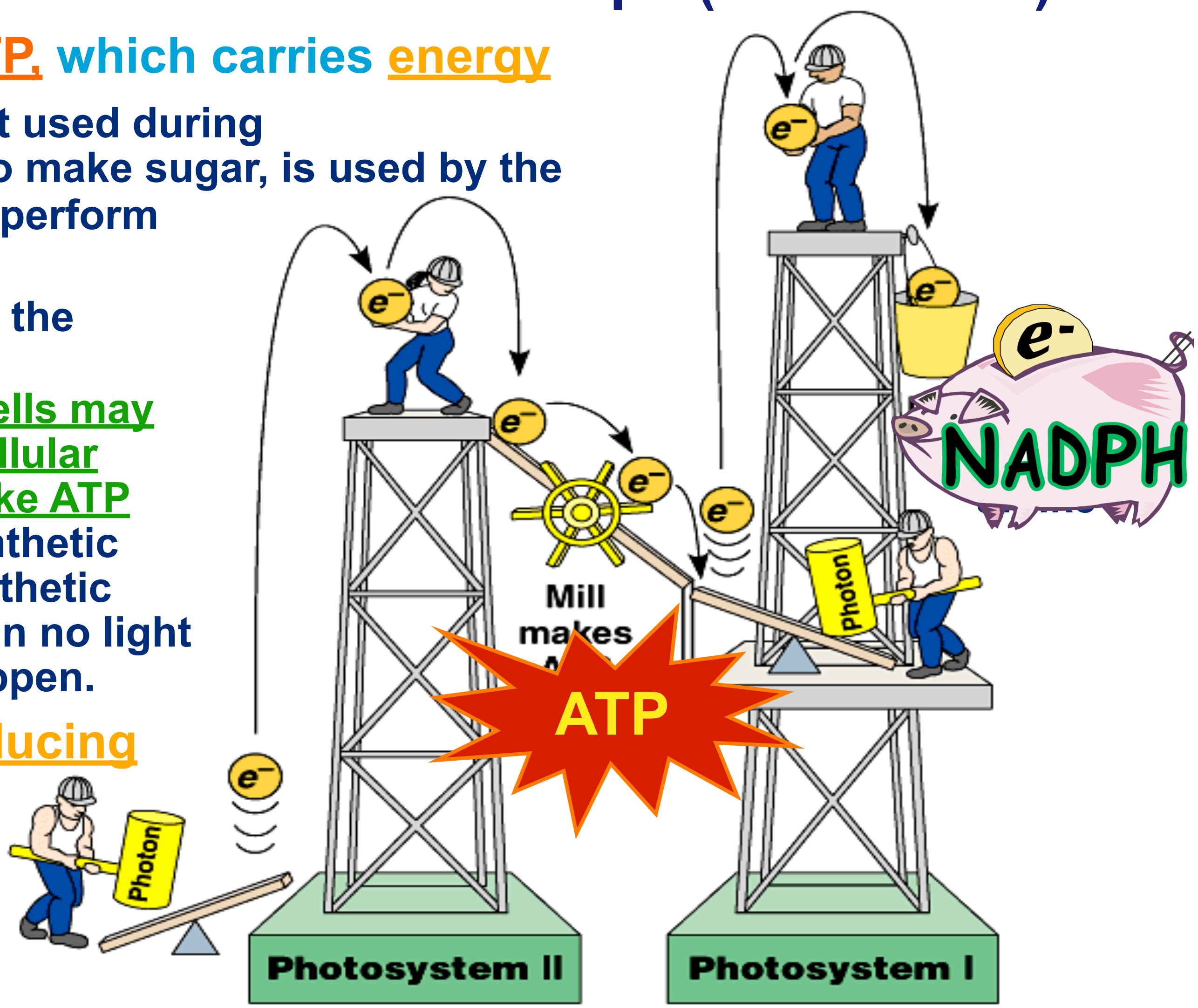
Experiment 2

$$6C\mathbf{O}_2 + 6H_2O + \text{light energy} \rightarrow C_6H_{12}\mathbf{O}_6 + 6O_2$$

Proved O_2 came from H_2O not CO_2 = plants split H_2O!

Noncyclic Photophosphorylation - Linear Electron Flow

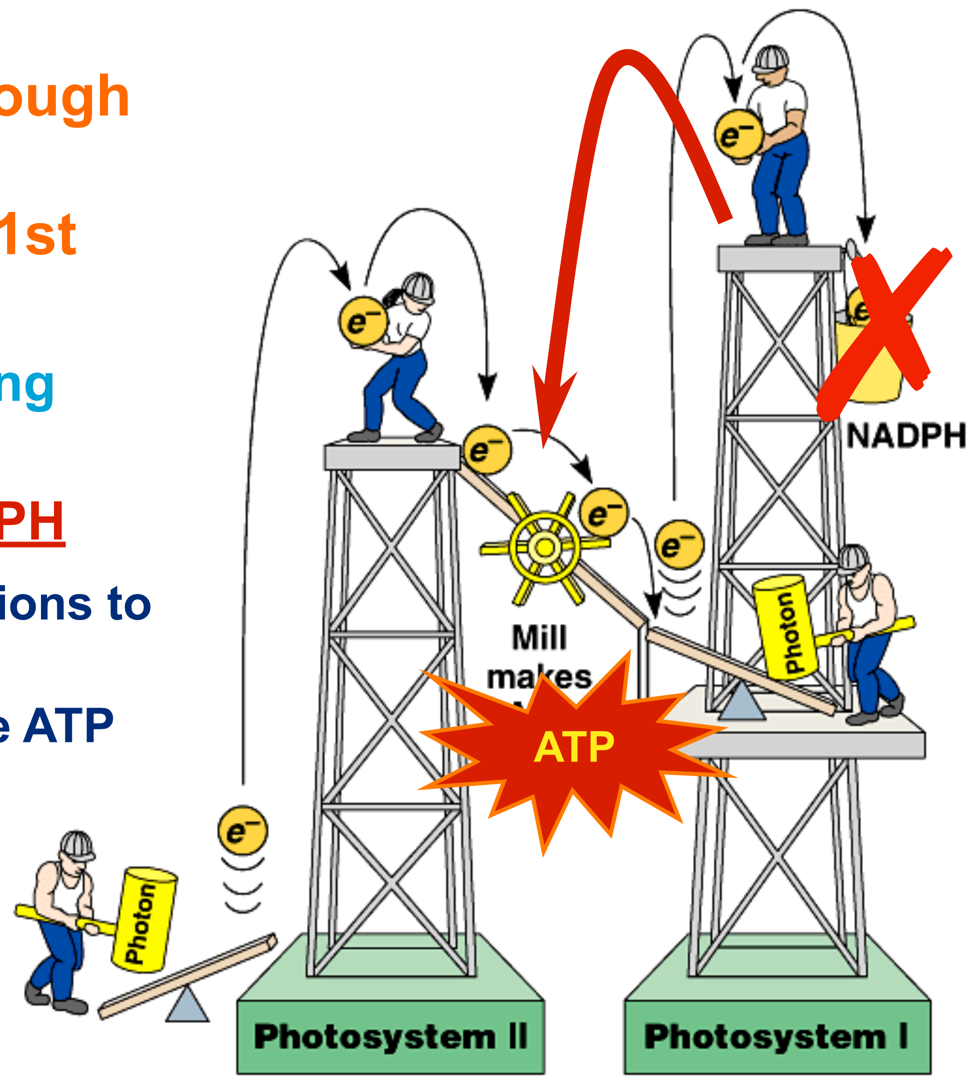
- Light reactions excite electrons in 2 steps (PS II & PS I)
  - PS II generates ATP, which carries energy
    - Any extra ATP not used during photosynthesis to make sugar, is used by the rest of the cell to perform other work.
    - Therefore, during the day time, the photosynthetic cells may not have to do cellular respiration to make ATP the non-photosynthetic cells or photosynthetic cells at night when no light reactions can happen.
  - PS I generates reducing power as NADPH, which carries high-energy electrons



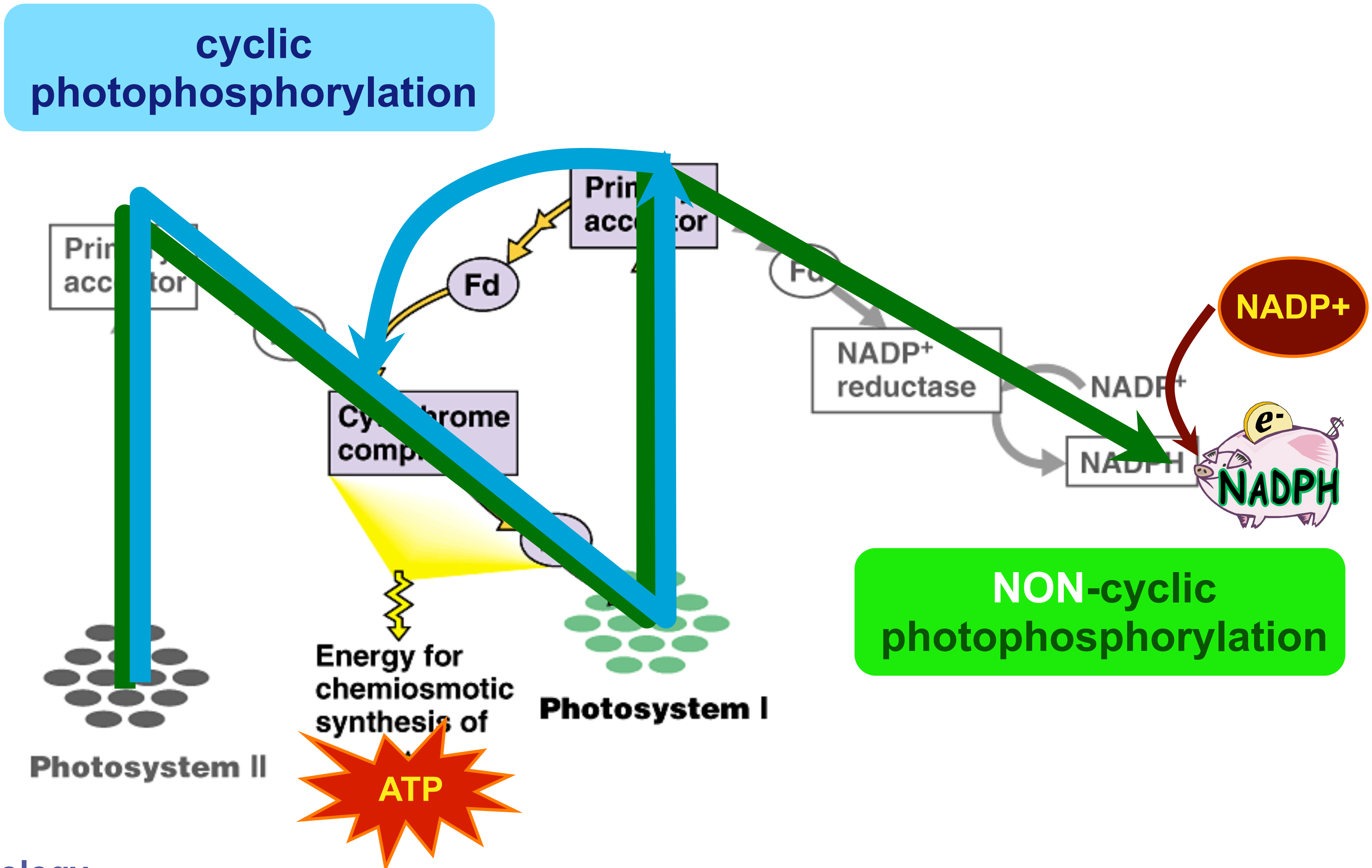
Cyclic photophosphorylation - Cyclic Electron Flow

- If PS I can't pass electron to NADP+, it cycles the e⁻'s through ferrodoxin back to back to cytochrome complex in the 1st ETC
  - Results in more ATP being made
  - Makes NO O_2 & NO NADPH
    - coordinates light reactions to Calvin cycle
    - Calvin cycle uses more ATP than NADPH
    - Photoprotective role

18 ATP + 12 NADPH → 1 $C_6H_{12}O_6$



Electron Flow - Cyclic versus Noncyclic



Photosynthesis summary

- Where did the energy for ATP or to convert low energy into high energy come from?
- Where did the electrons come from?
- Where did the H_2O come from?
- Where did the O_2 come from?
- Where did the O_2 go?
- Where did the H^+ come from?
- Where did the ATP come from?
- What will the ATP be used for?
- Where did the NADPH come from?
- What will the NADPH be used for?

…stay tuned for the Calvin cycle

Answer Key

Where did the energy for ATP or to convert low energy into high energy come from? *The sun.*

Where did the electrons come from? *The splitting of water molecules.*

Where did the H_2O come from? *The soil, absorbed into the plant by the roots*

Where did the O_2 come from? *The splitting of the water molecules.*

Where did the O_2 go? *Diffuses out of the chloroplasts and photosynthetic cell into the air.*

Where did the H^+ come from? *The splitting of the water molecule and the natural ionization of water molecules that sometimes occurs..*

Where did the ATP come from? *It was made by ATP Synthase in the thylakoid membranes through a process called photophosphorylation as part of the light reactions.*

What will the ATP be used for? *For building a high-energy organic sugar (and any extra ATP left over for cellular work int he restof the cell)*

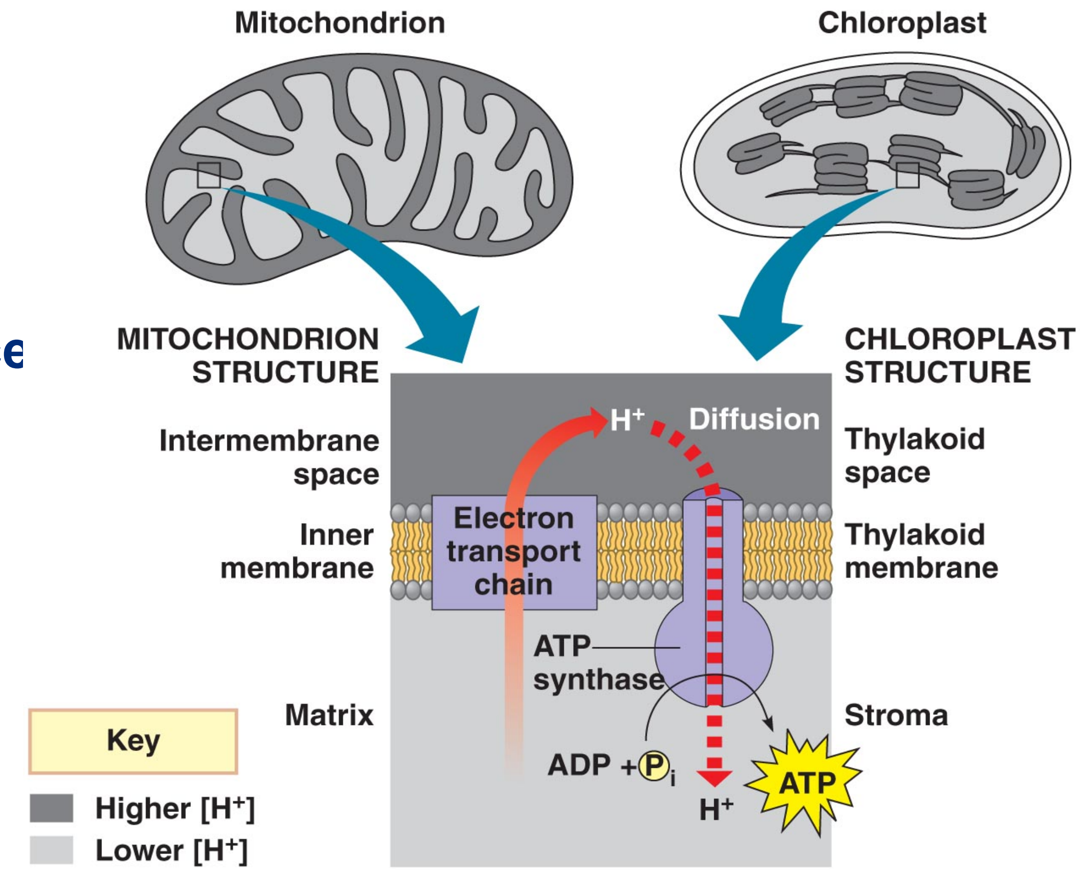
Where did the NADPH come from? *The electron carrier NADP+ was reduced with high-energy electrons by NADP+ Reductase*

What will the NADPH be used for? *The high-energy electrons it carries will be used to reduce inorganic carbon into organic sugars.*

Similarities between mitochondria and chloroplasts
(both organelles evolved from similar ancestors)

Chloroplasts and mitochondria generate ATP by the same mechanism: <u>CHEMIOSMOSIS</u>

- In both, ETC pump protons across the membrane as e-'s are passed through a series of carriers that get more and more electronegative.
- Transform redox energy into a proton-motive force with potential energy stored in the form of an H+ gradient across the membrane
- <u>ATP synthase complex:</u> couples diffusion of H+ down their gradient to phosphorylation of ADP



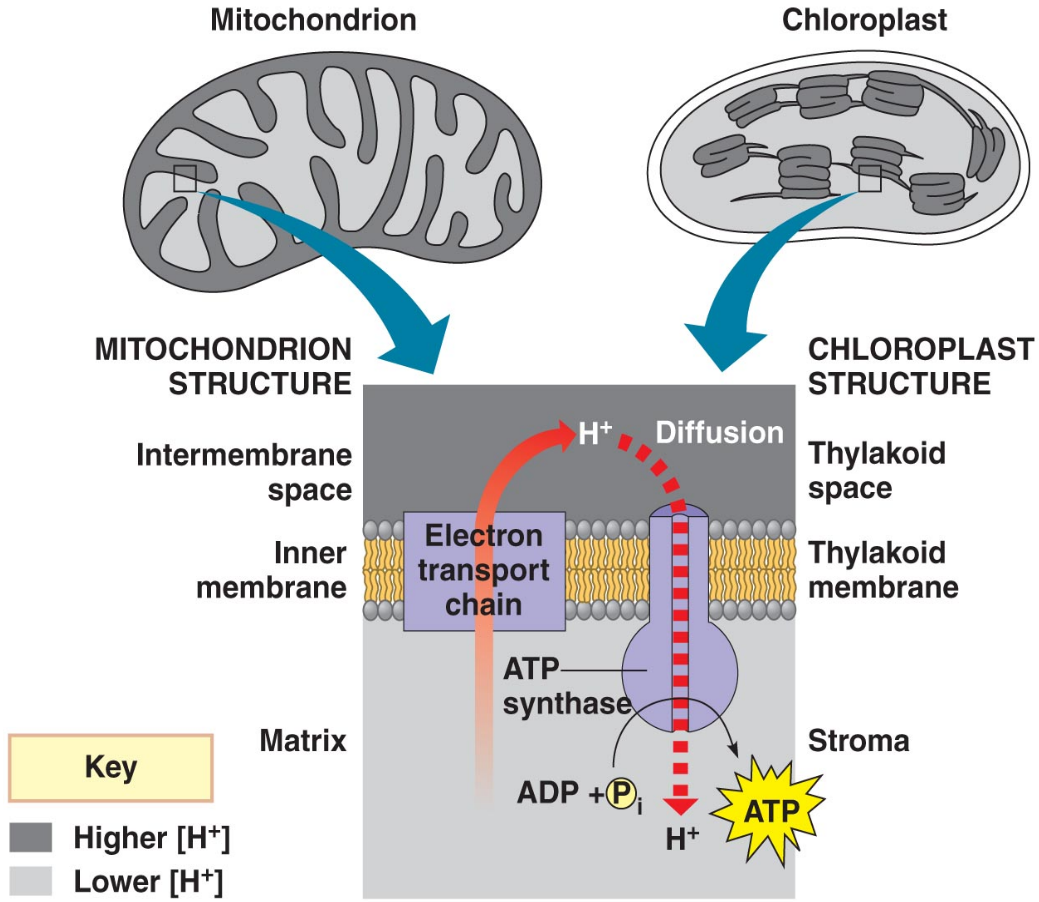
Differences between mitochondria and chloroplasts

Mitochondria

- Source of High Energy e-'s taken from organic molecule
- Transfer chemical energy from food molecules to ATP
- Pumps protons from matrix into intermembrane space
- ATP formed in the matrix

Chloroplasts

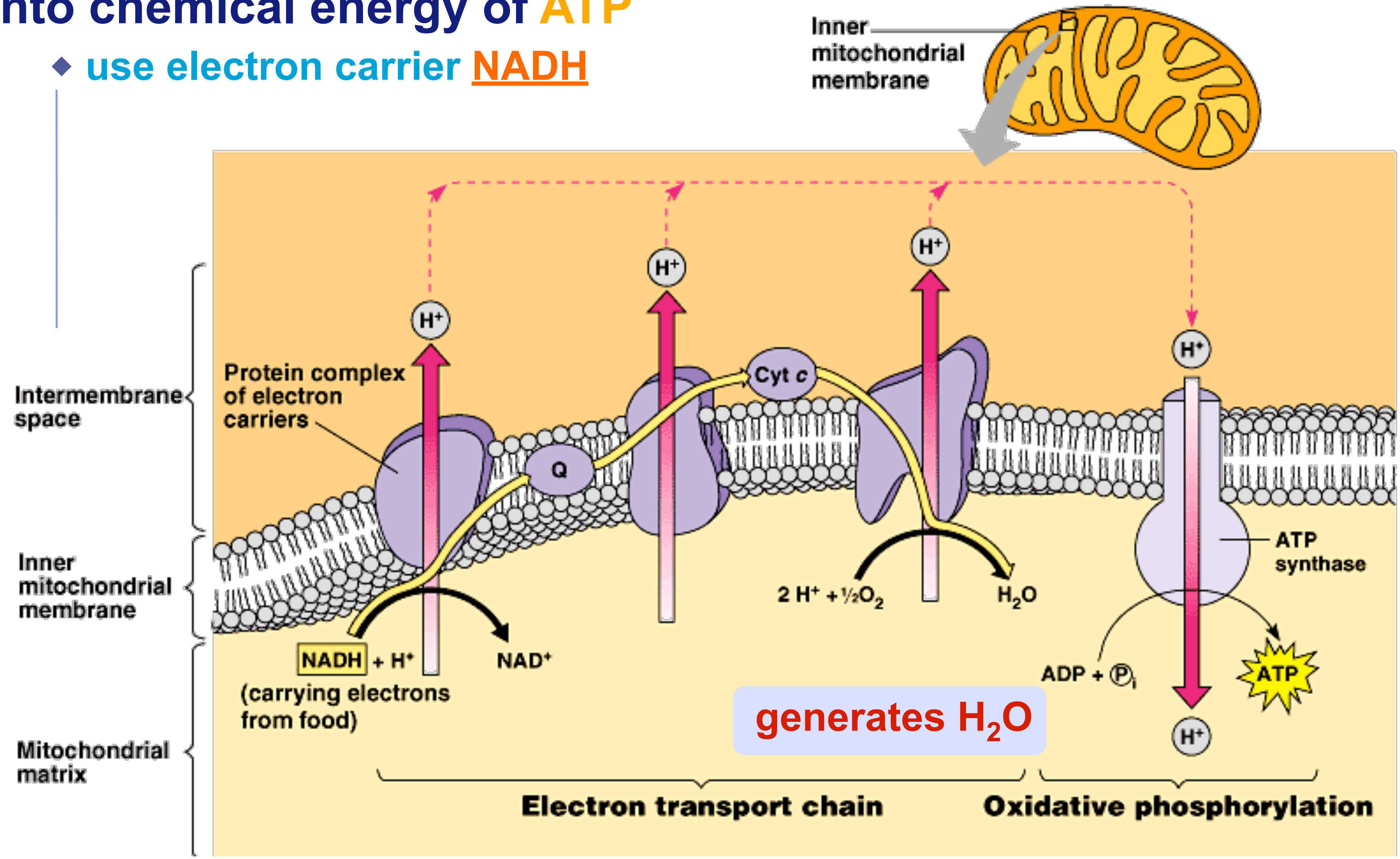
- Source of Low Energy e-'s is water
- Use light energy to drive the electrons to the top of ETC
- Transform light energy into chemical energy in ATP
- Pumps protons from stroma into the thylakoid space
- ATP formed in the stroma



ETC of Respiration

Mitochondria transfer chemical energy from food molecules into chemical energy of ATP

- use electron carrier NADH

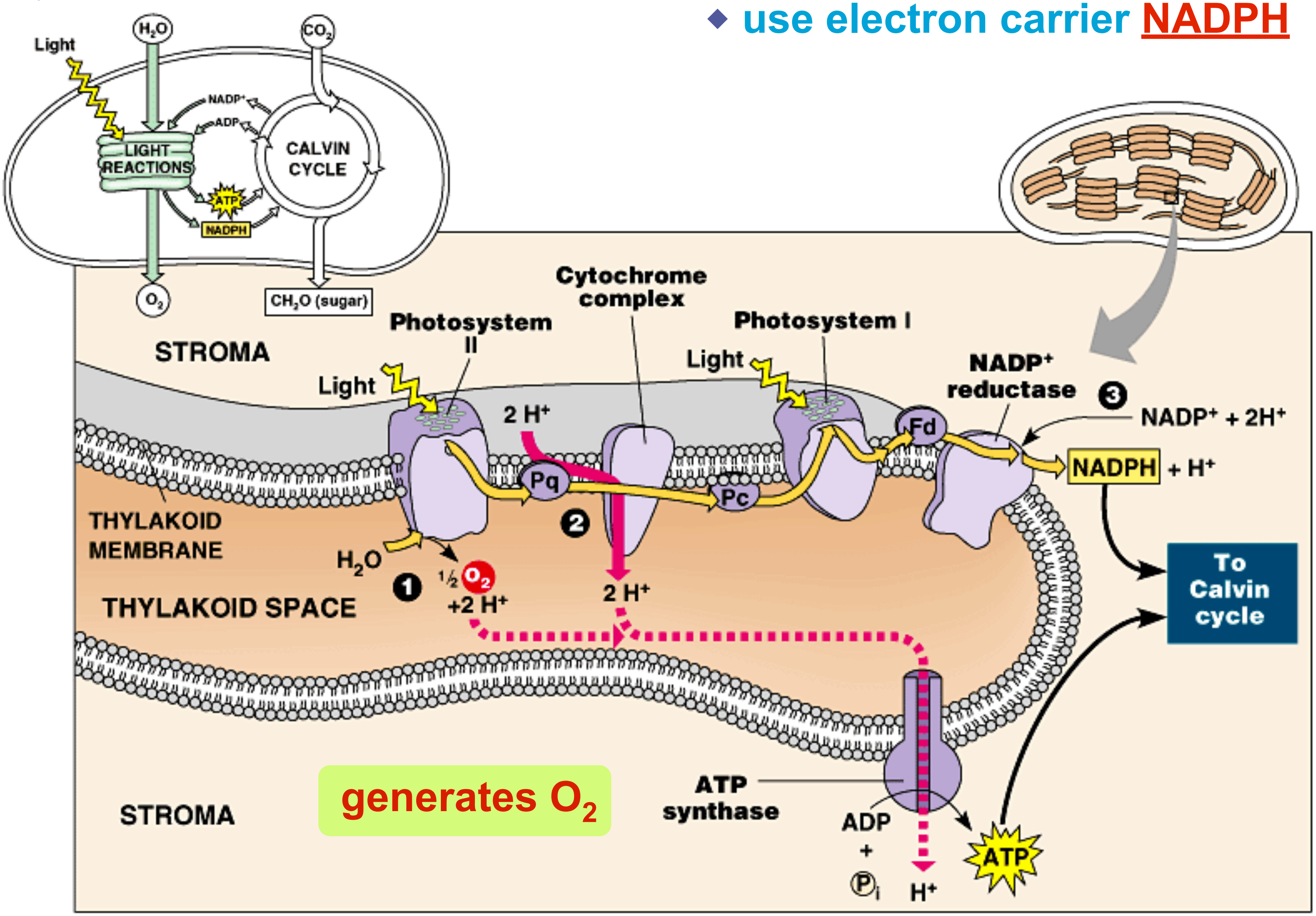


generates H_2O

ETC of Photosynthesis

Chloroplasts transform light energy into chemical energy of ATP

- use electron carrier NADPH



ATP production by chemiosmosis

photosynthesis

sunlight

respiration

breakdown of $C_6H_{12}O_6$

- move the electrons through ETC
- run the cytochrome pumps
- pump the protons
- builds the proton gradient
- drive the passive flow of protons through ATP synthase
- ATP Synthase bonds P_i to ADP using the energy release by the proton diffusion
- generates the ATP