PHOTOSYNTHESIS PART 1

Properties of Light

Light Reactions

Photosynthesis

- Purpose: use energy from light to convert inorganic compounds into organic fuels that have stored potential energy in their carbon bonds

- Carbon dioxide + water → glucose + oxygen
- $CO_2 + H_2O \rightarrow C_6H_{12}O_6 + O_2$

Comparing Metabolic Processes

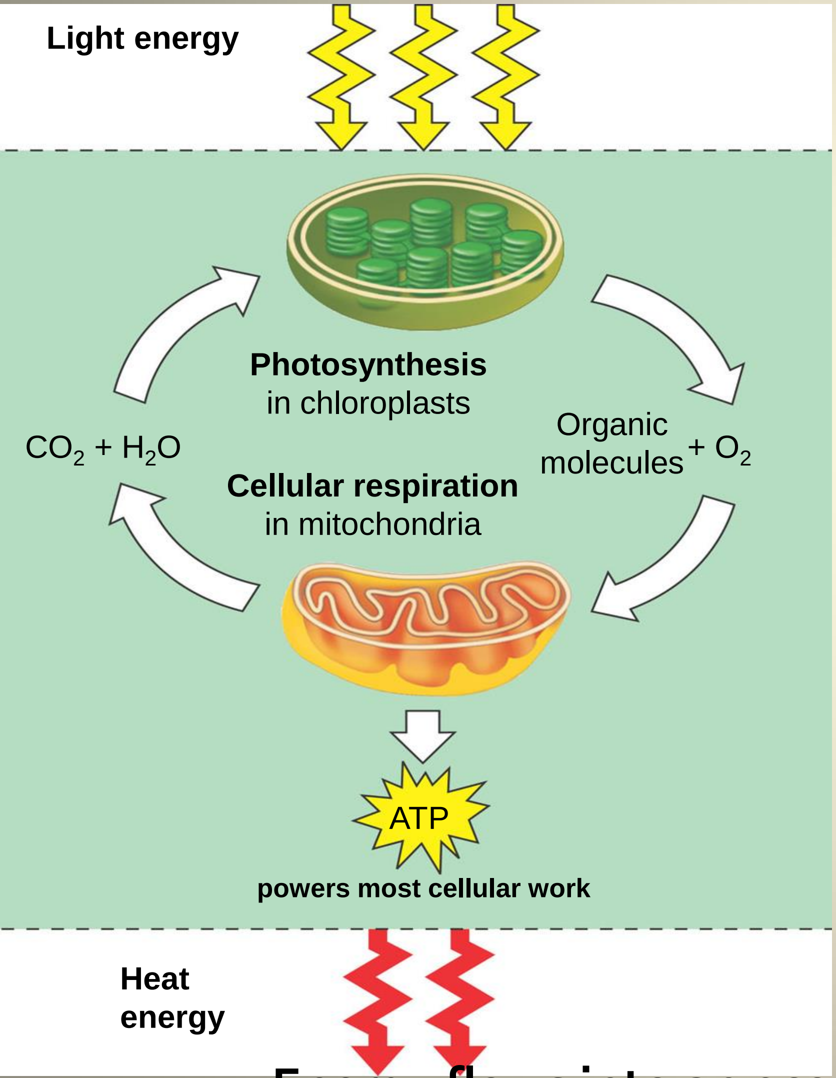


Figure 9.2

- Photosynthesis and cellular respiration are **complementary** processes
- They are not opposite reactions even though their overall equations are the reverse because the multiple steps the make up each process is different

Energy flows into an ecosystem as sunlight and leaves as heat

Autotrophs

- Organisms that obtain energy without needing to ingest other organisms
- Require the input of inorganic substances from the environment
- Photoautotrophs: also use light energy
  - Examples: green plants, algae, certain species of bacteria

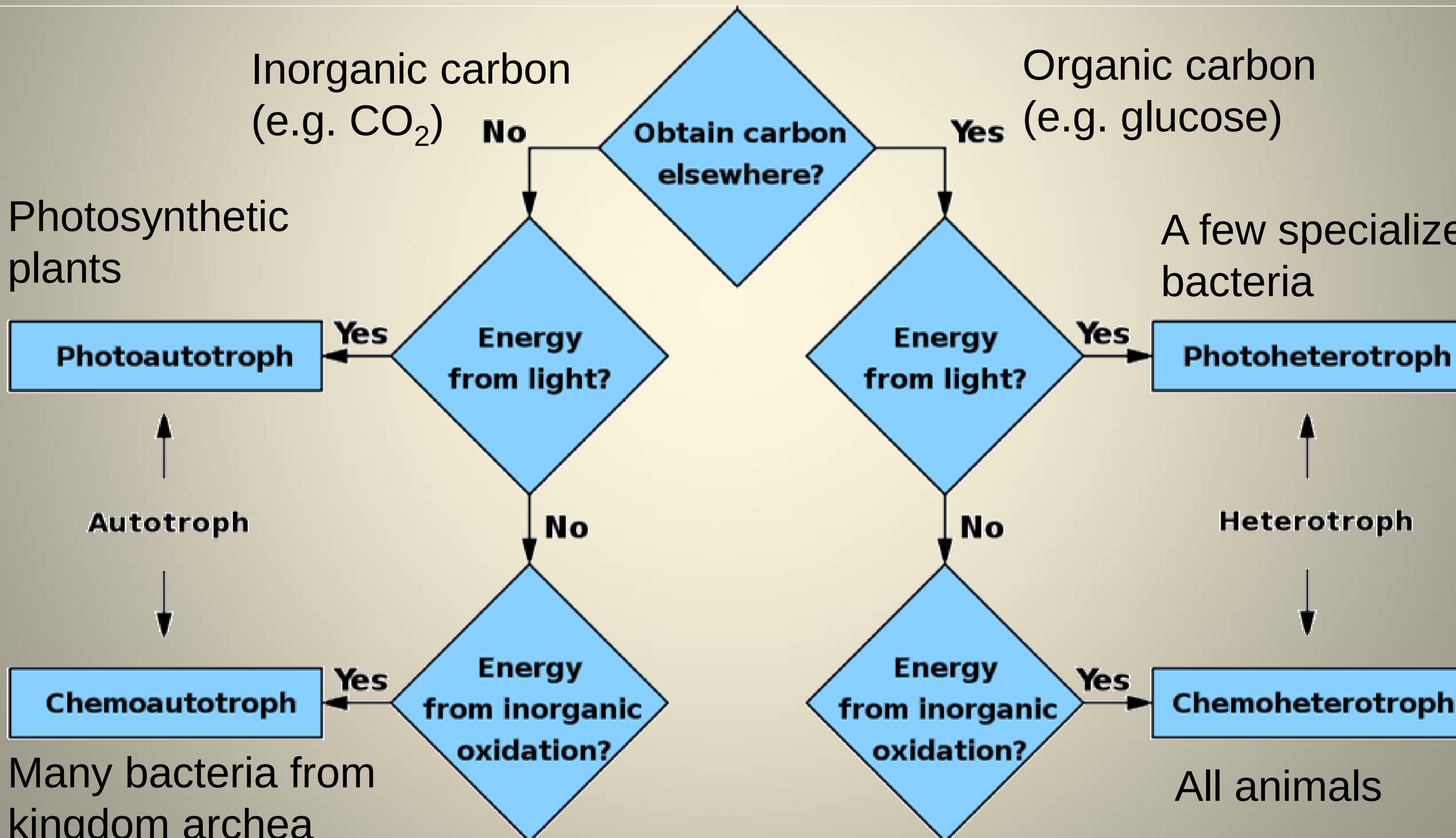
Types of Variants

Inorganic carbon
(e.g. CO_2)

Organic carbon
(e.g. glucose)

Photosynthetic
plants

A few specialized
bacteria

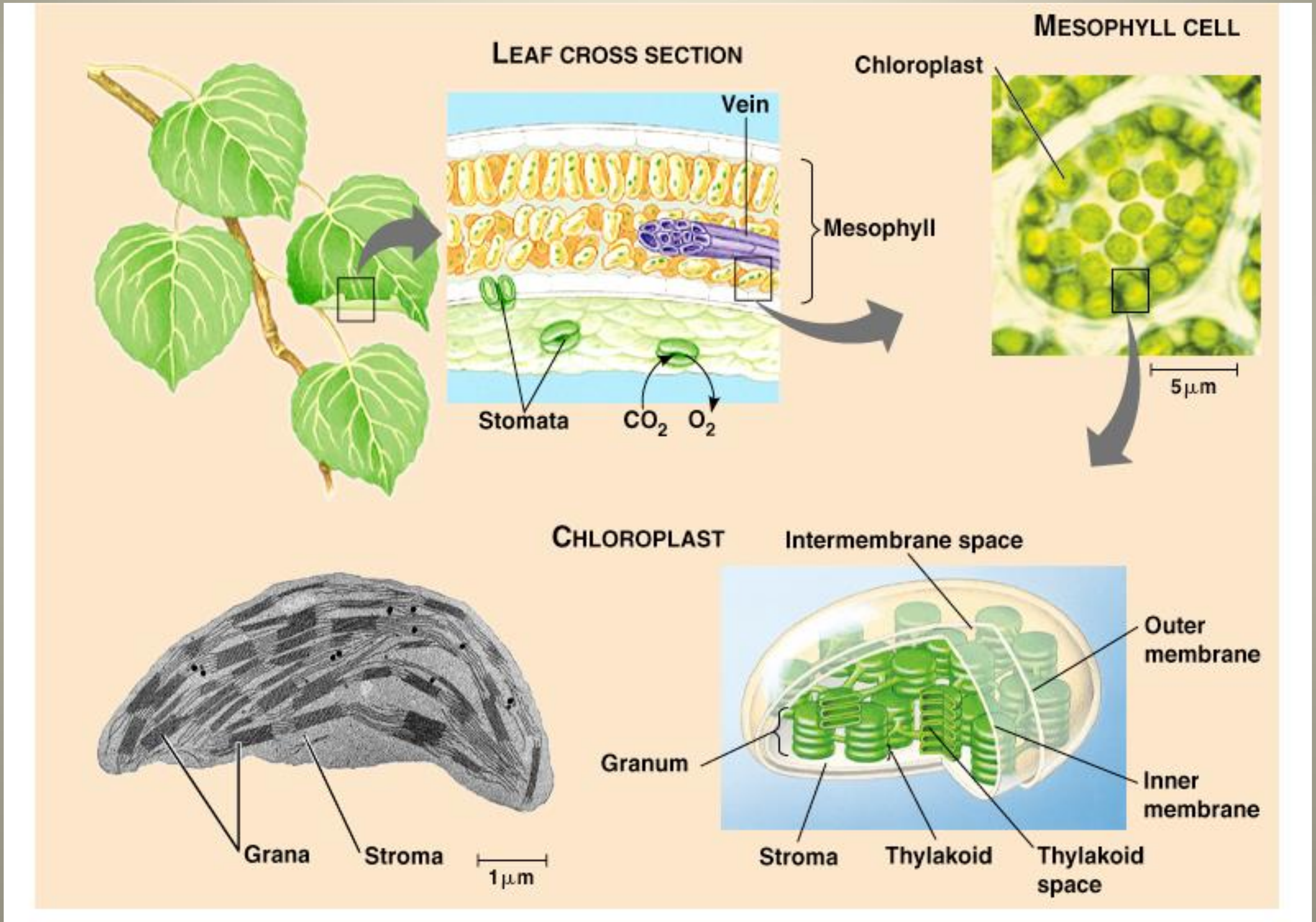


Many bacteria from
kingdom archea
(methanogens)

All animals

http://upload.wikimedia.org/wikipedia/commons/5/59/Troph_flowchart.png

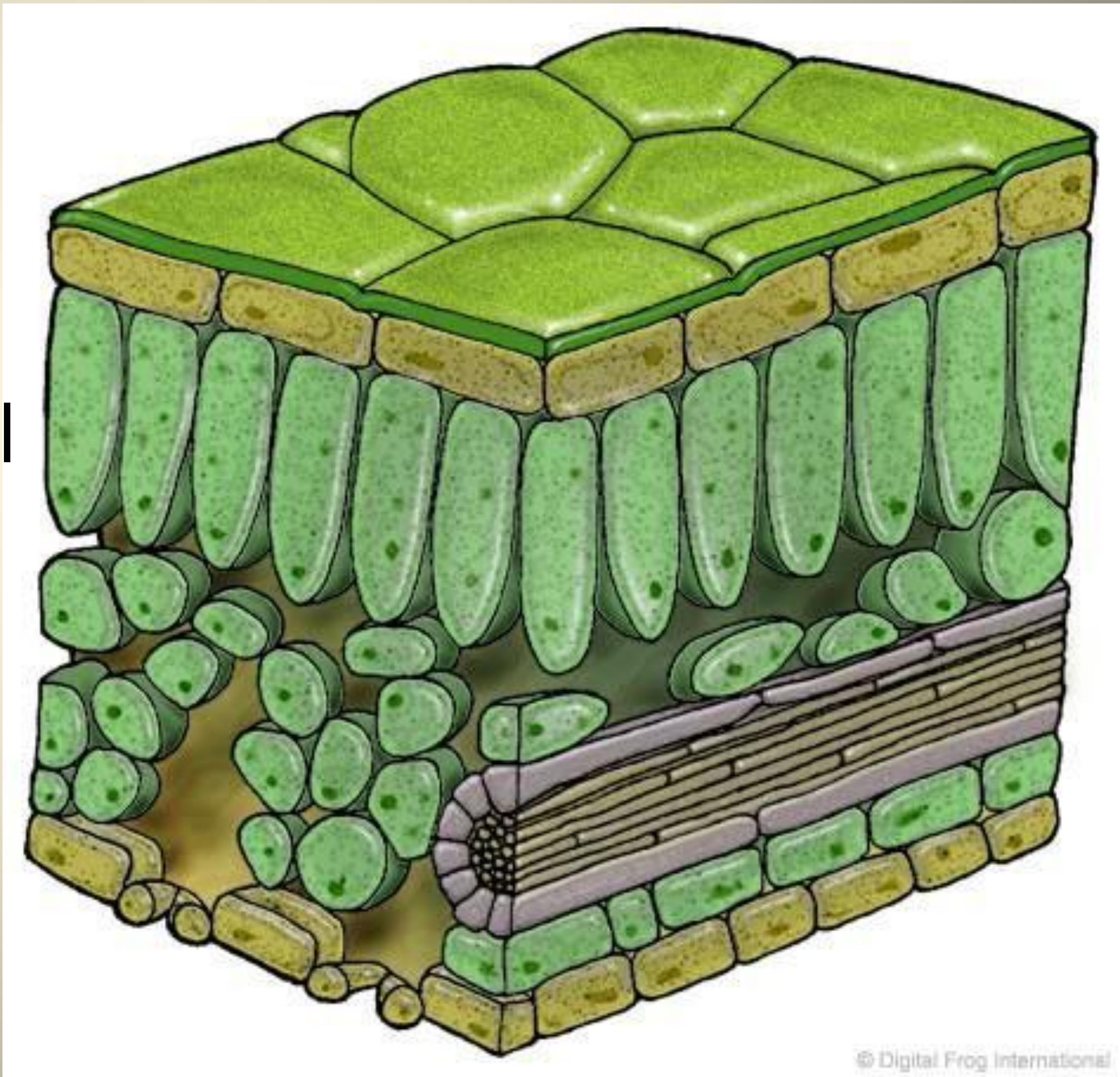
Review: Leaf Structure



Review: Leaf Structure

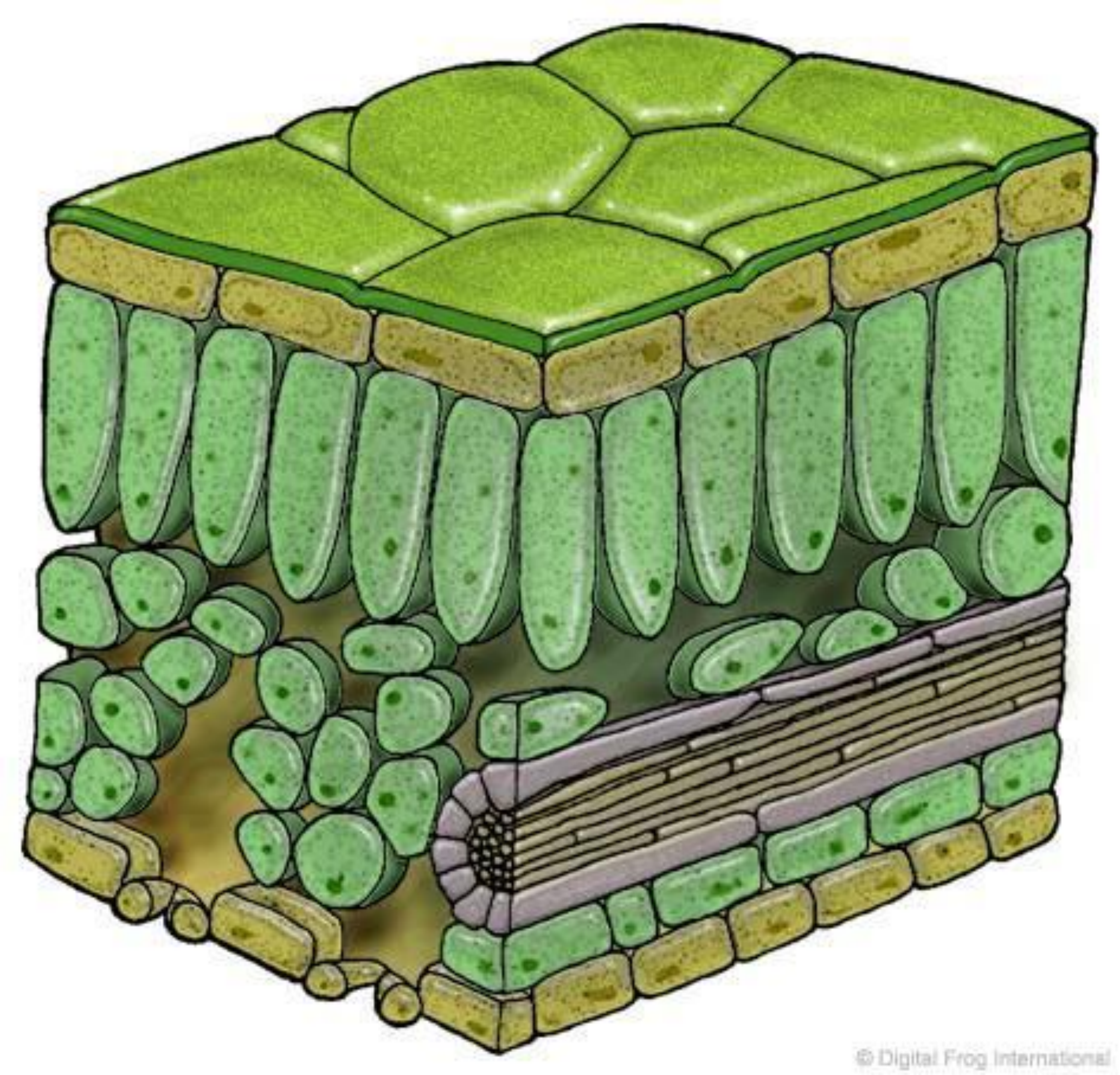
Identify:

- Cuticle
- Epidermis
- Palisade mesophyll
- Spongy mesophyll
- Guard cells
- Stoma / stomata
- Vascular bundle



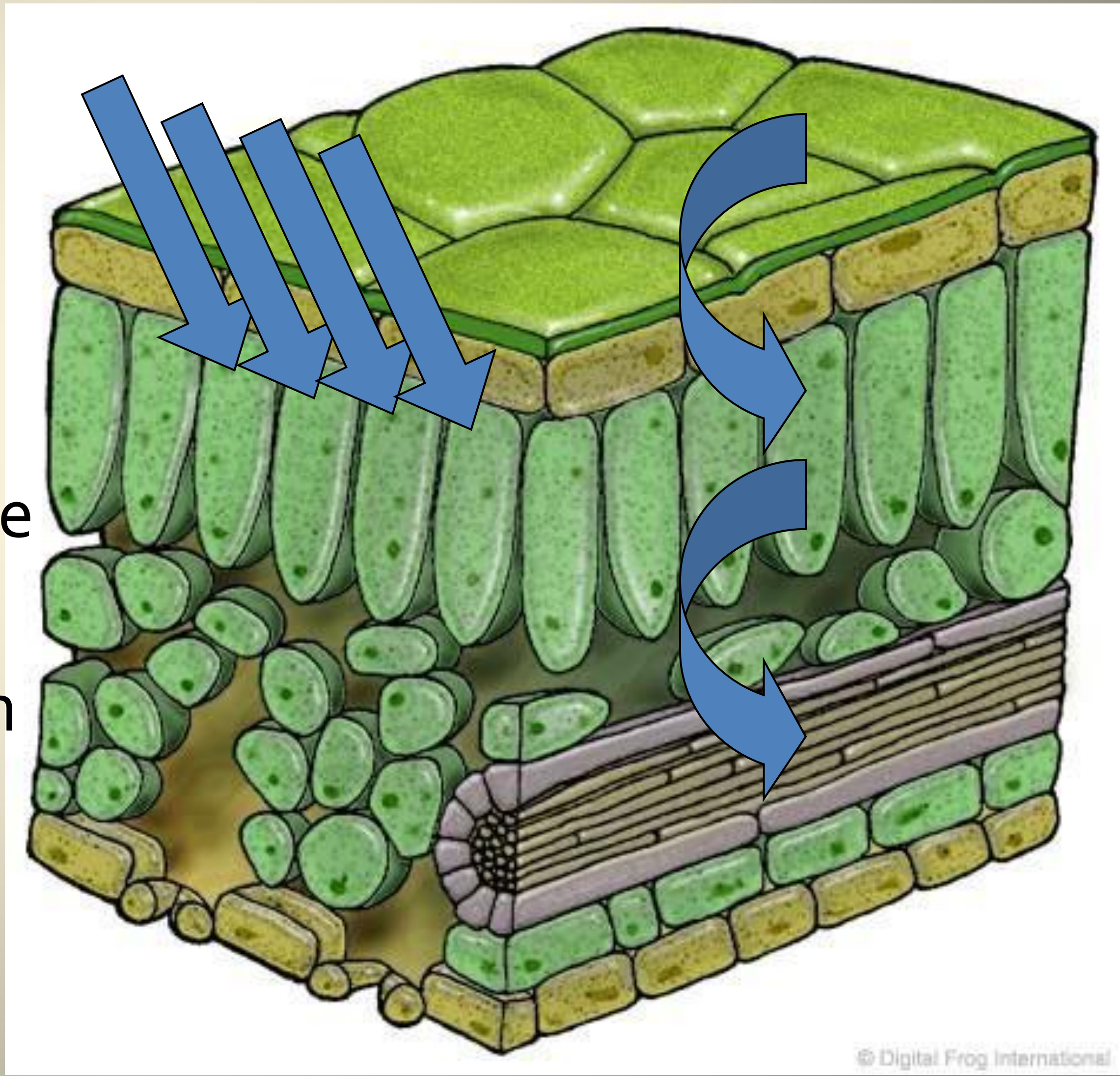
Review: Leaf Structure

- Which leaf structure perform each of these functions?
  - Prevent water loss and gas exchange
  - Regulates gas exchange
  - Transports water and nutrients
  - Mainly photosynthesis (contains the most chloroplast)

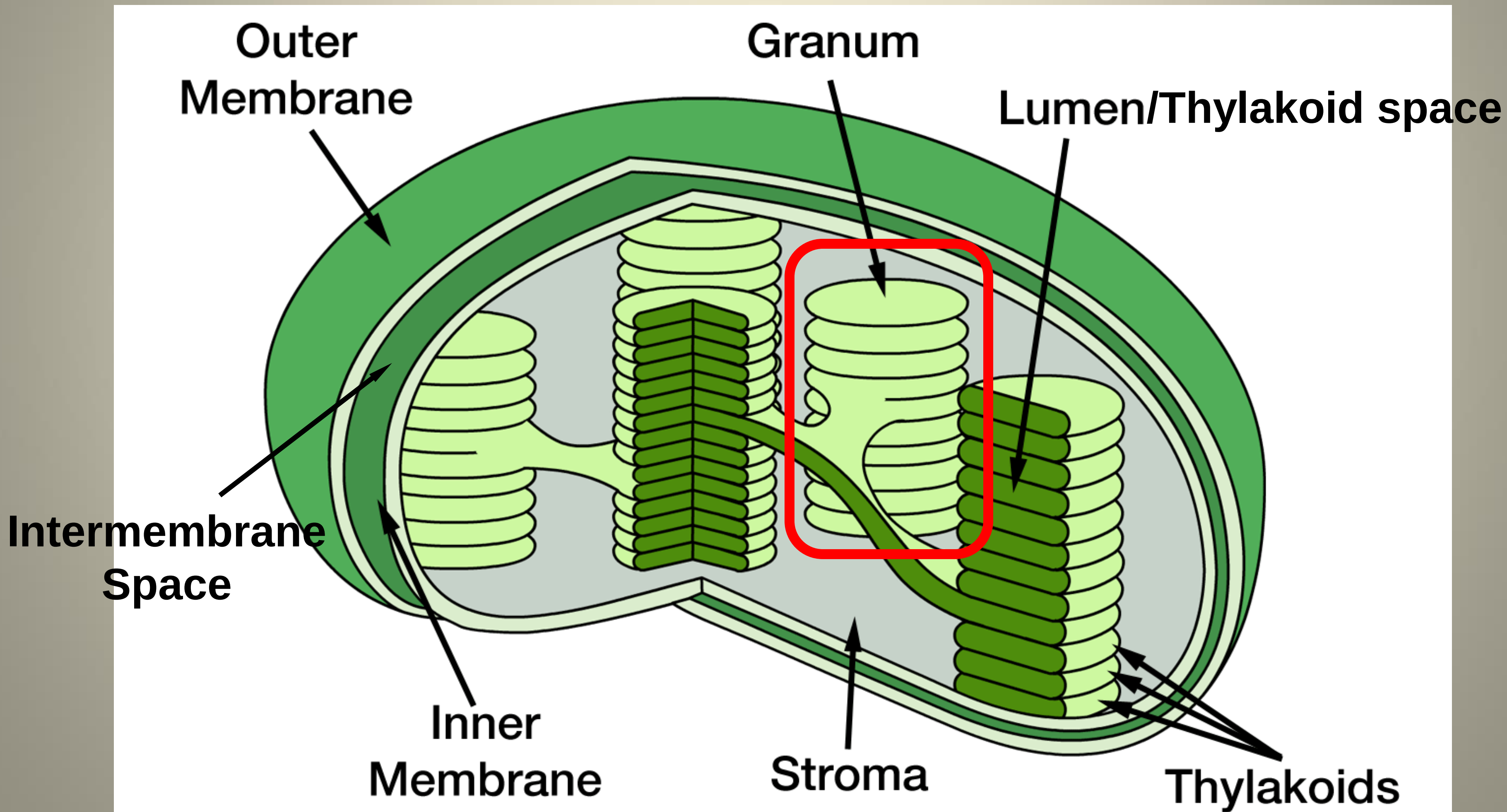


Review: Leaf Structure

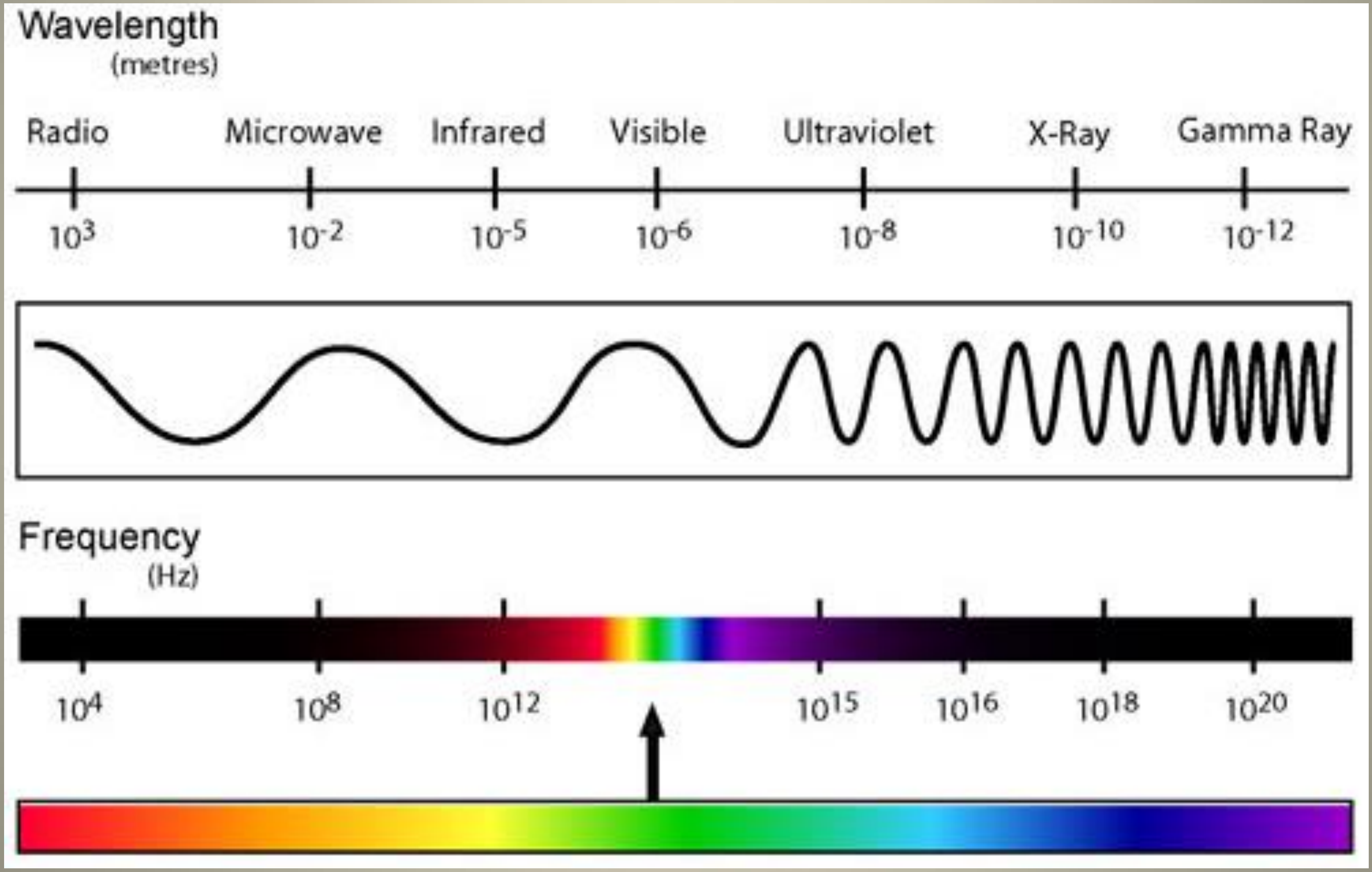
- Why are palisade cells long and narrow?
  - Fit more cells in the same space for more photosynthesis
  - Interaction between photosynthetic side and nutrient / gas absorption side



Review: Chloroplast Structure



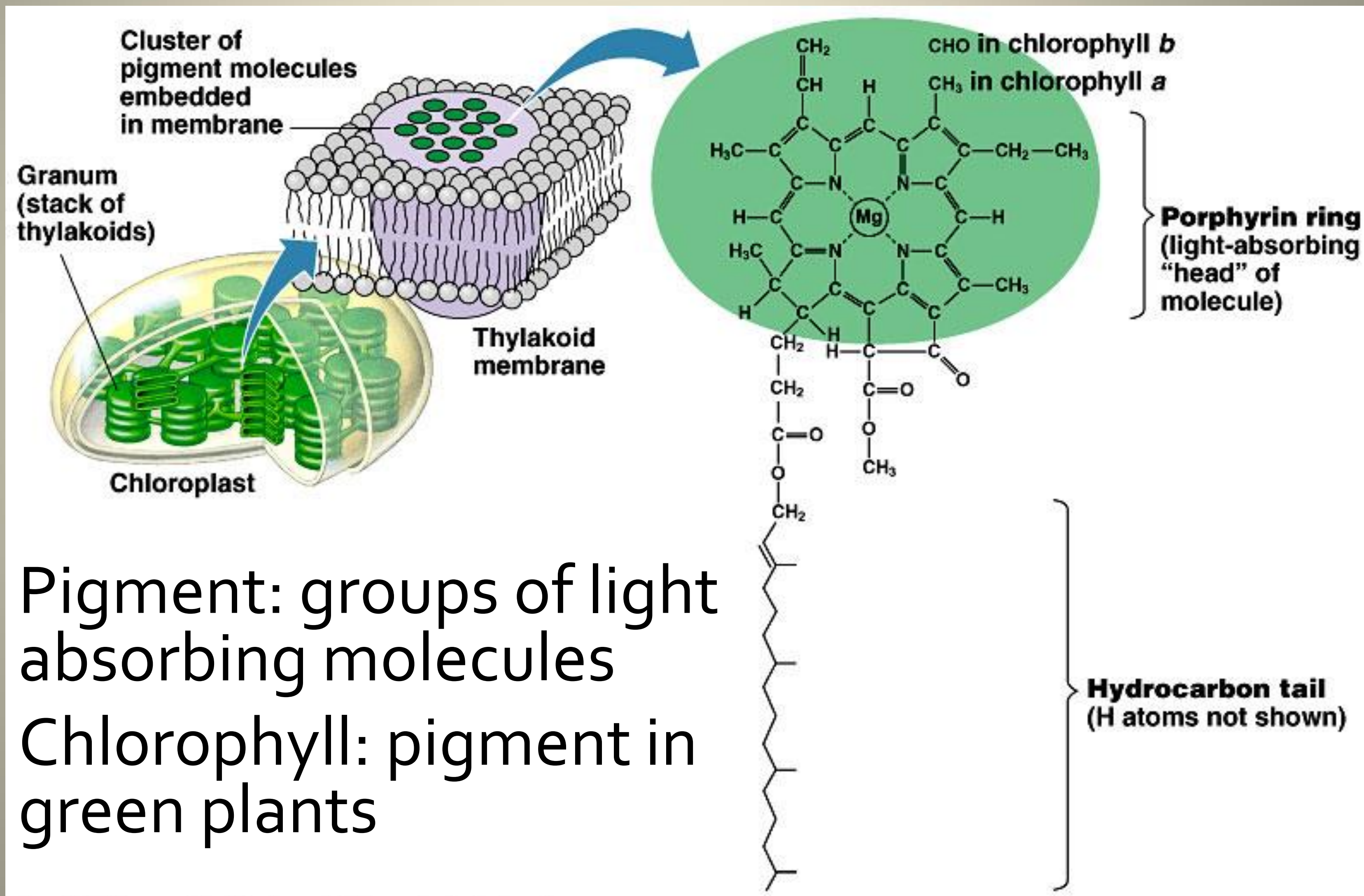
Nature of Light



Nature of Light

- Light is a form of energy with different wavelengths
- The shorter the wavelength, the greater the energy of each photon of light
- Certain wavelengths of light are detectable by human eyes and seen as colours
- Visible light drives photosynthesis

Light Absorbing Pigments

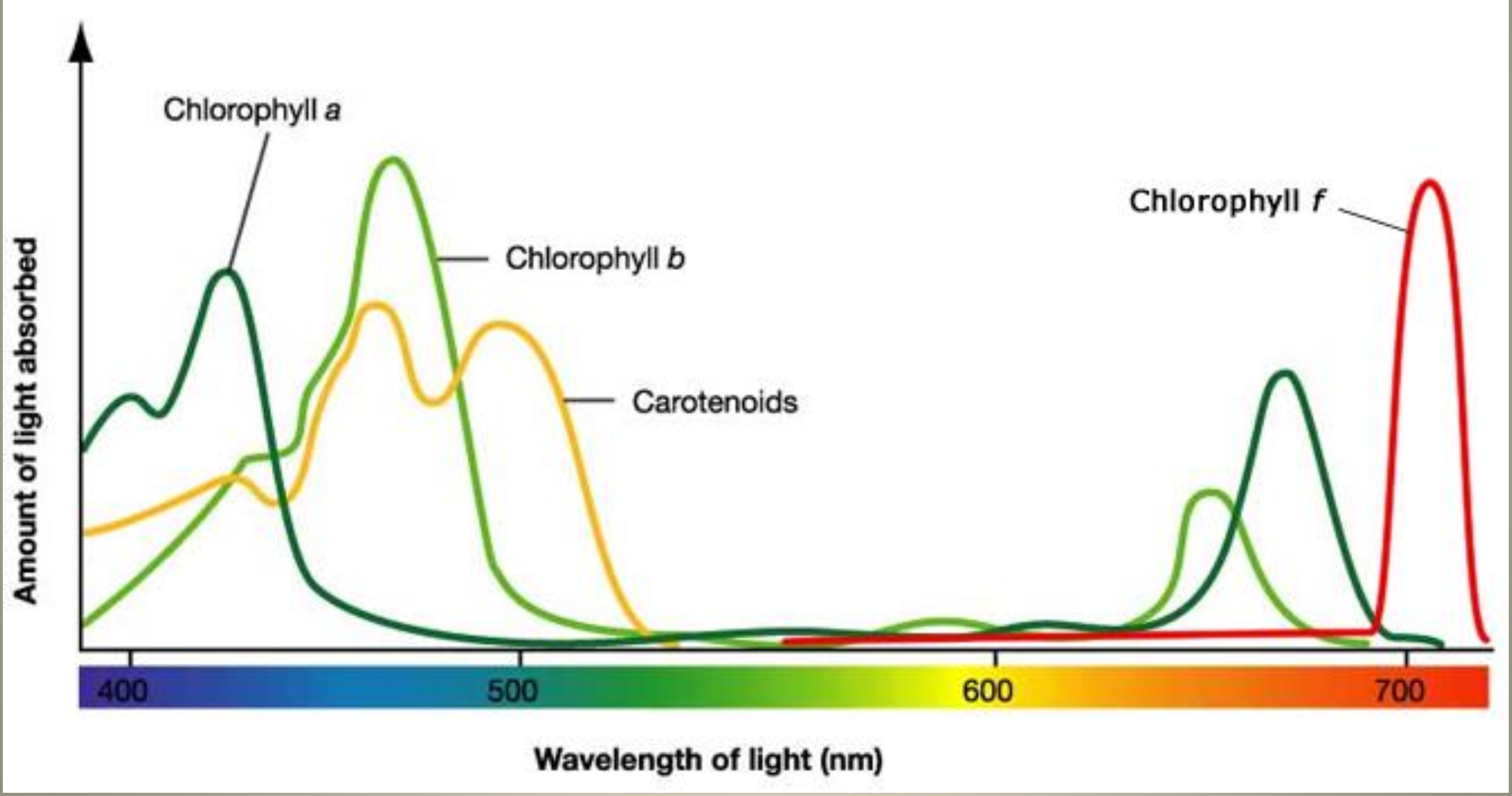


- Pigment: groups of light absorbing molecules
- Chlorophyll: pigment in green plants

Light Absorbing Pigments

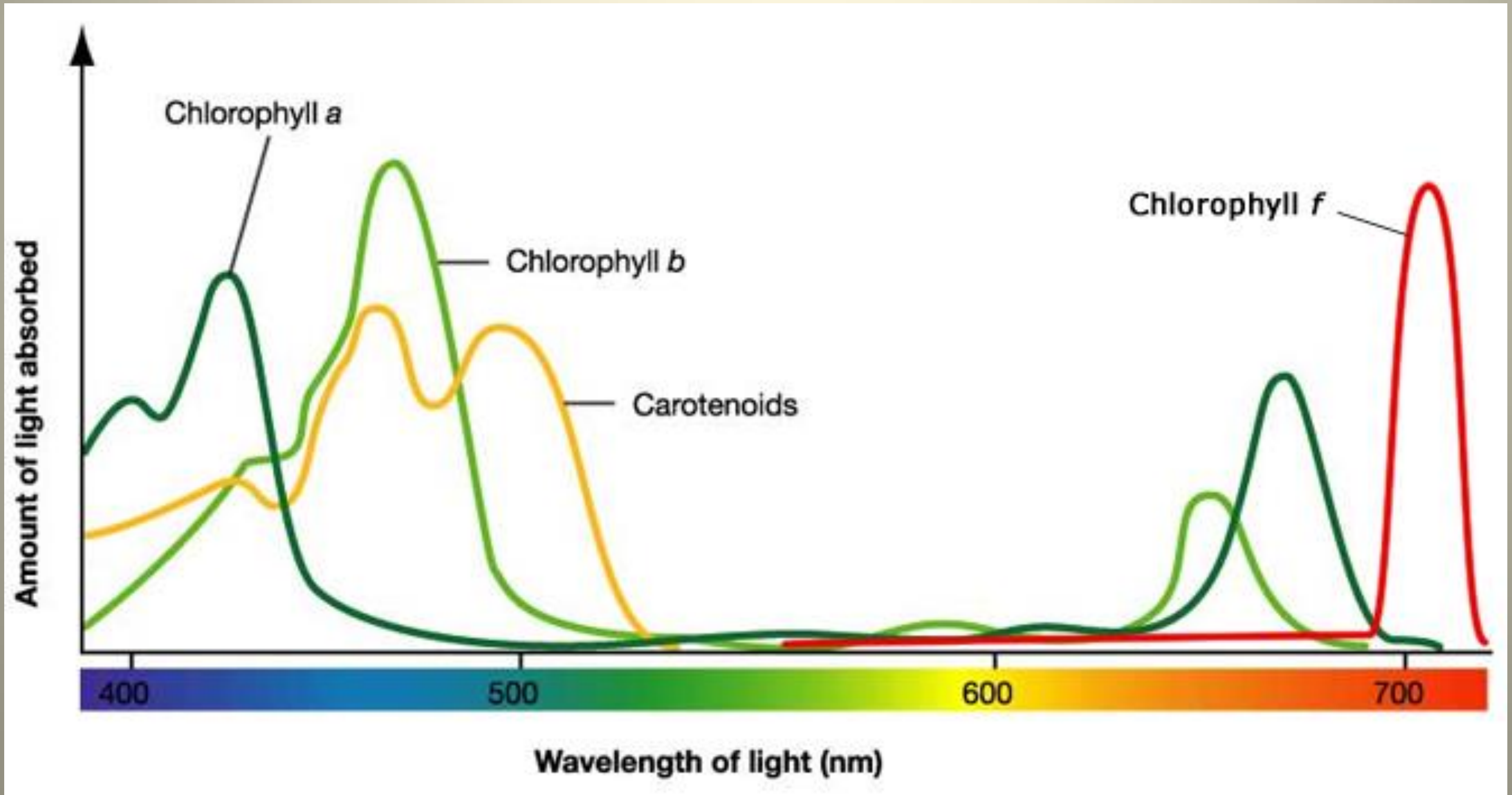
- The colour of the pigments is due to wavelengths of light reflecting back into our eyes
- Chlorophyll:
  - green pigment
  - absorbs mainly blue and red wavelengths of light
  - reflect back green
- Carotenoids:
  - pigments that absorb mainly blue and green
  - Reflect back orange and red
  - Help dissipate excessive light energy that would otherwise damage chlorophyll

Absorption Spectrum



Absorption Spectrum

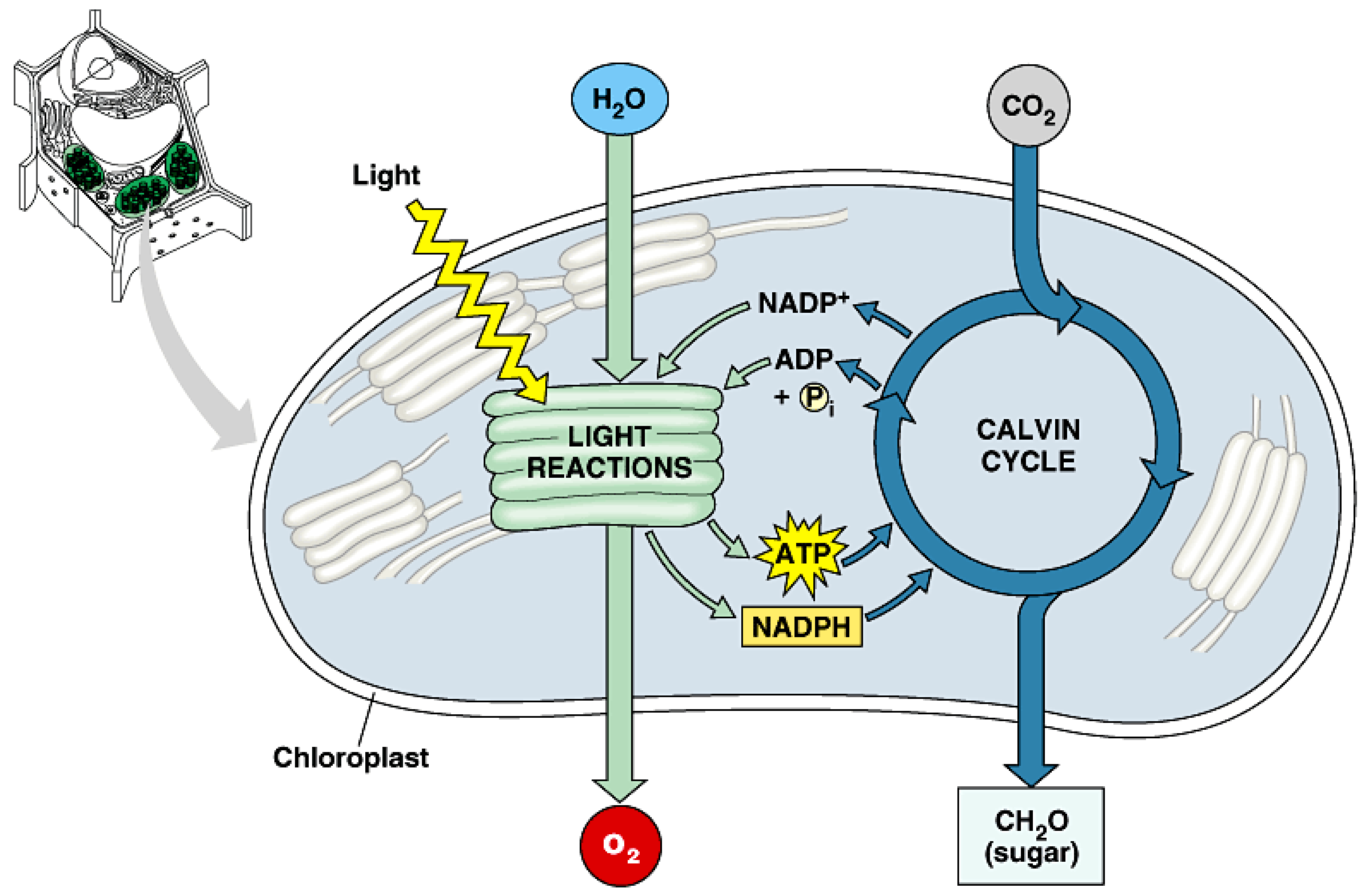
- In the fall chlorophyll pigments breakdown first leaving carotenoids which allow the reflection of orange and red wavelengths



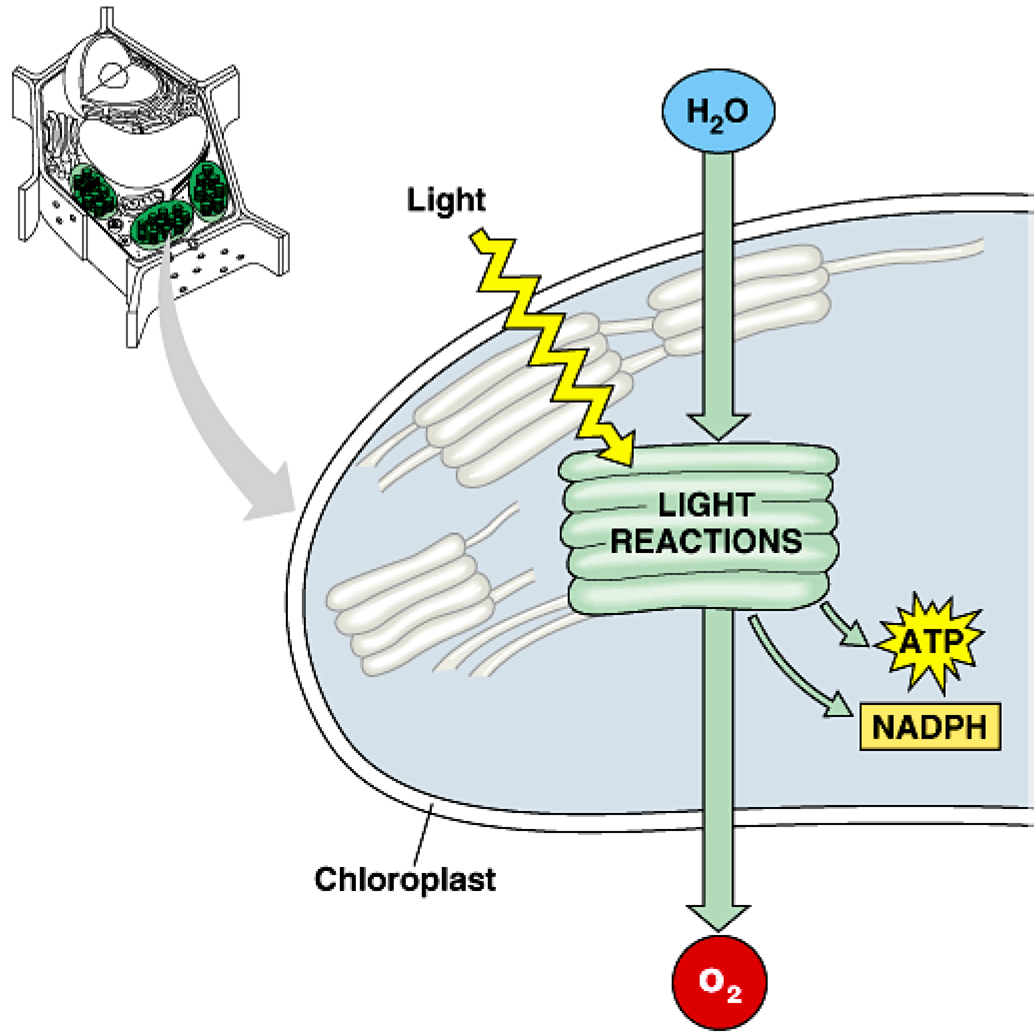
2 Stages of Photosynthesis

- "Photo" stage:
  - light dependent reactions
  - Energy fixing reactions
  - Convert light energy to make ATP & NADPH which will be used to drive the next stage
- "Synthesis" stage:
  - "dark" / light-independent reactions, Calvin cycle
  - Carbon fixing reactions
  - Uses ATP to convert inorganic molecules to organic fuel containing stored potential energy in the bonds

2 Stages of Photosynthesis



Light Reaction Purpose



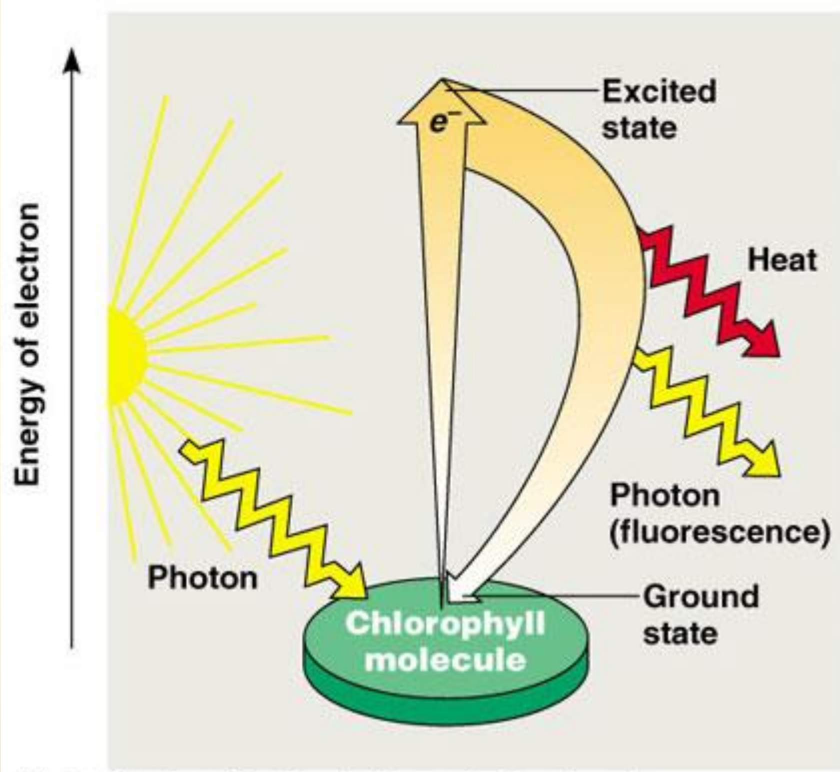
- What is the main purpose of the light reactions?
- Input:
  – Water
  – Photons of light
- Output:
  – Oxygen
  – ATP
  – NADPH

3 Parts to Light Reactions

- Photoexcitation & Photolysis
  - Absorption of light photons whose energy excites an electron that is trapped by an electron acceptor
  - Energy in light photons are also used to split water releasing electrons
- Electron transport
  - Harnessing the energy in electrons to form an electrochemical gradient (pump hydrogen ions against its concentration gradient)
- Photophosphorylation (chemiosmosis)
  - ATP synthesis due to electrochemical gradient and the proton motive force

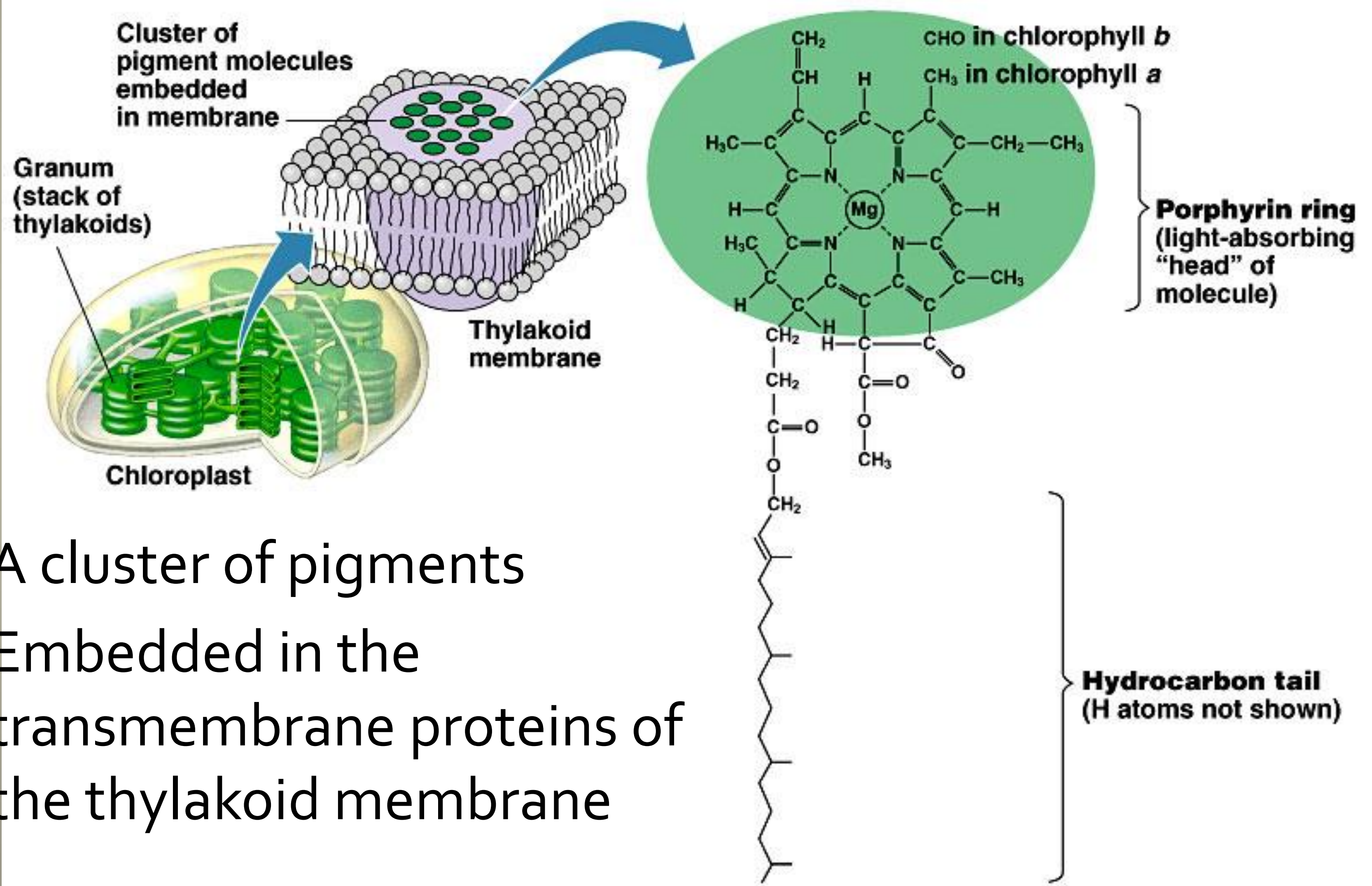
Photoexcitation

- When atoms absorb energy from the sun, electrons gain energy becoming excited
- Excited electrons will fall back to ground state if it isn't transferred to an electron acceptor



(a) Excitation of isolated chlorophyll molecule

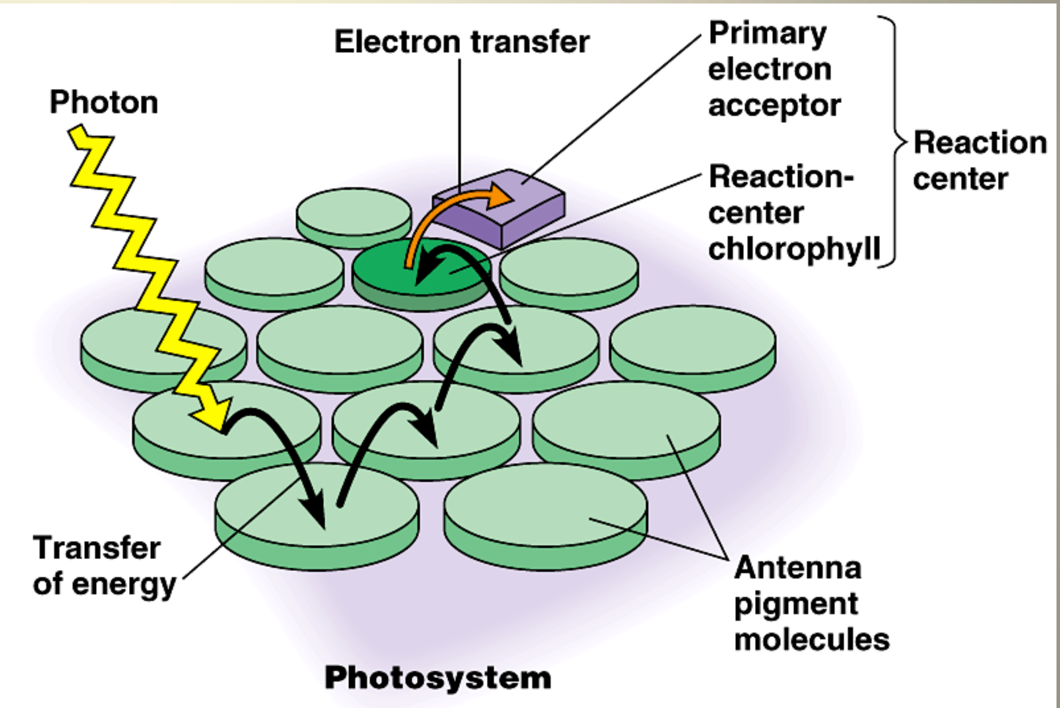
Photosystems



- A cluster of pigments
- Embedded in the transmembrane proteins of the thylakoid membrane

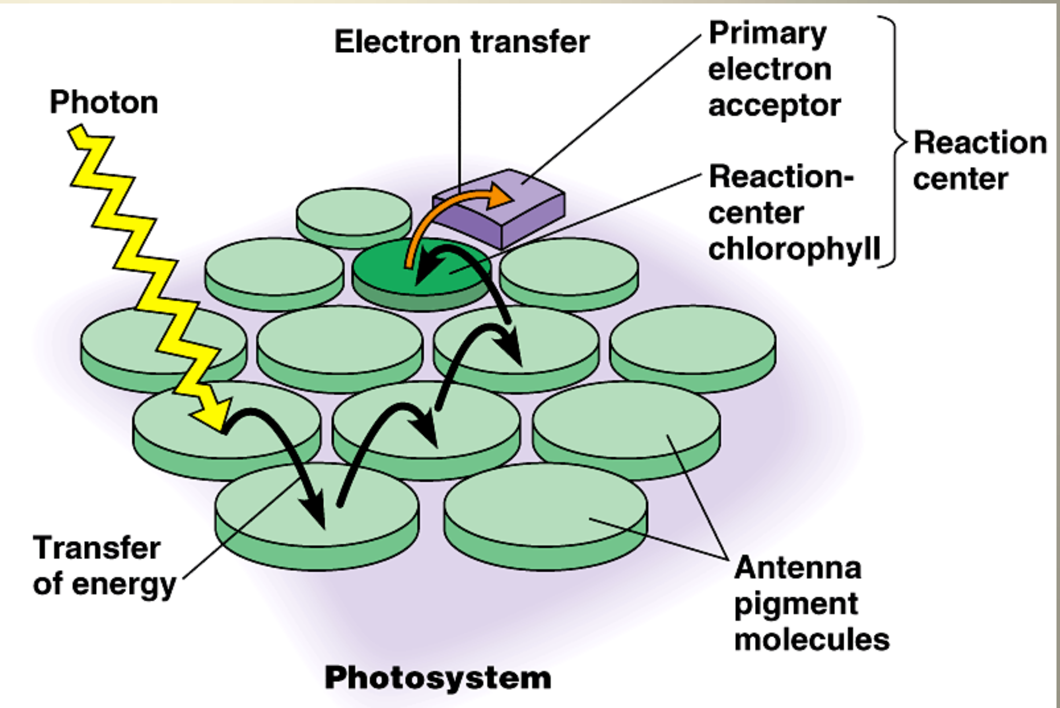
Photosystem Structure

- Consists of a few hundred pigment molecules
- Reaction centre contains a chlorophyll a that is located next to a primary electron acceptor



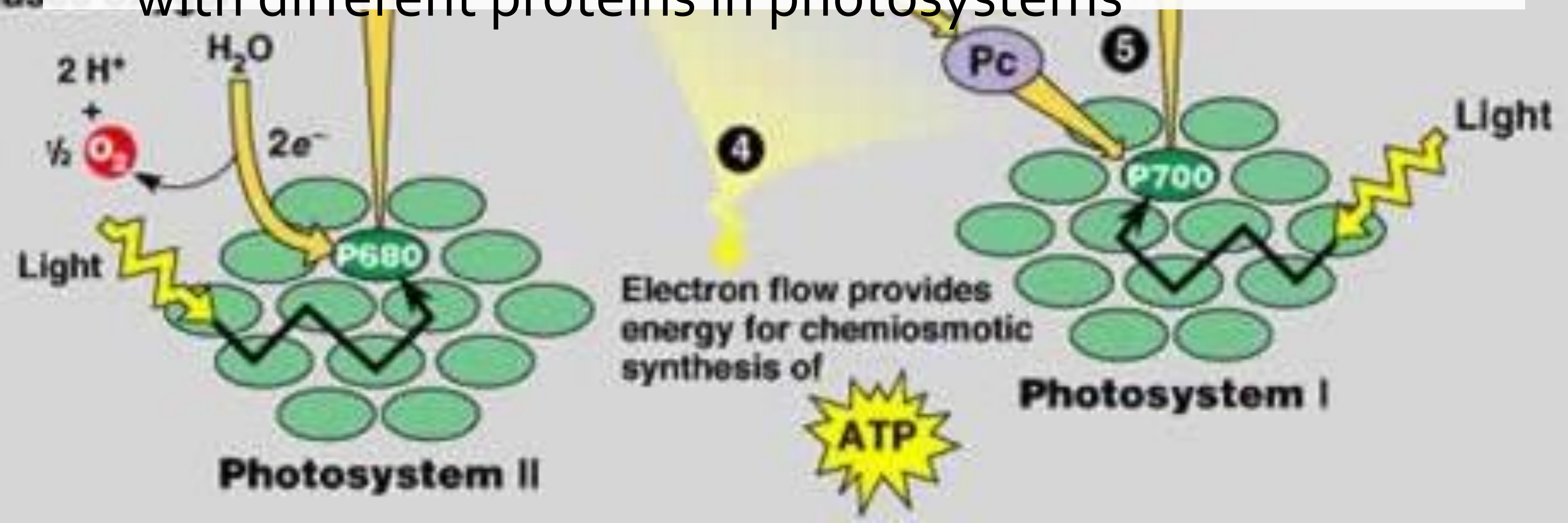
Photosystem Mechanism

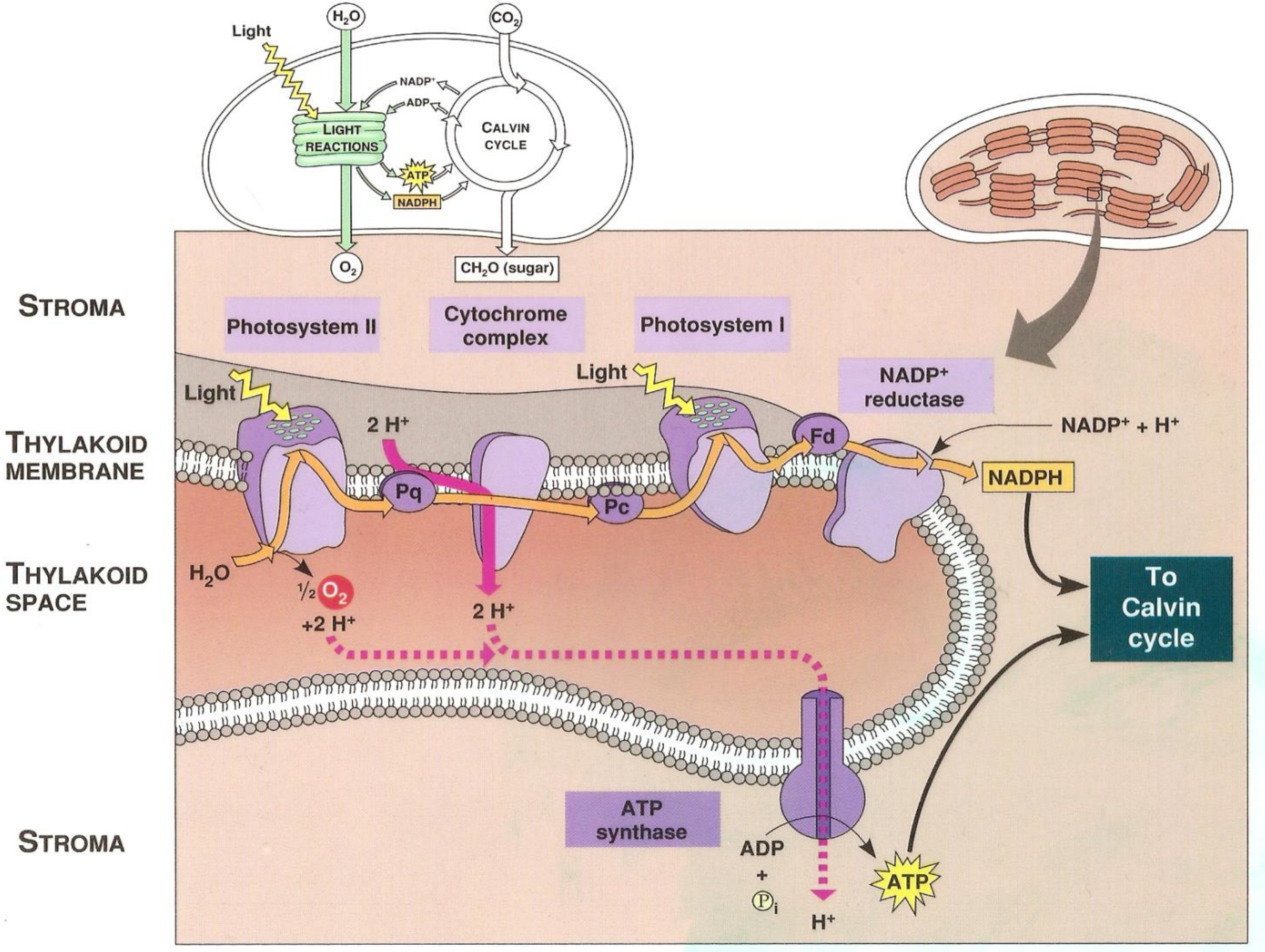
- Light excites an electron on the reaction-centre chlorophyll a
- Primary electron acceptor traps the high energy electron before it can return to ground state



Photosystem Mechanism

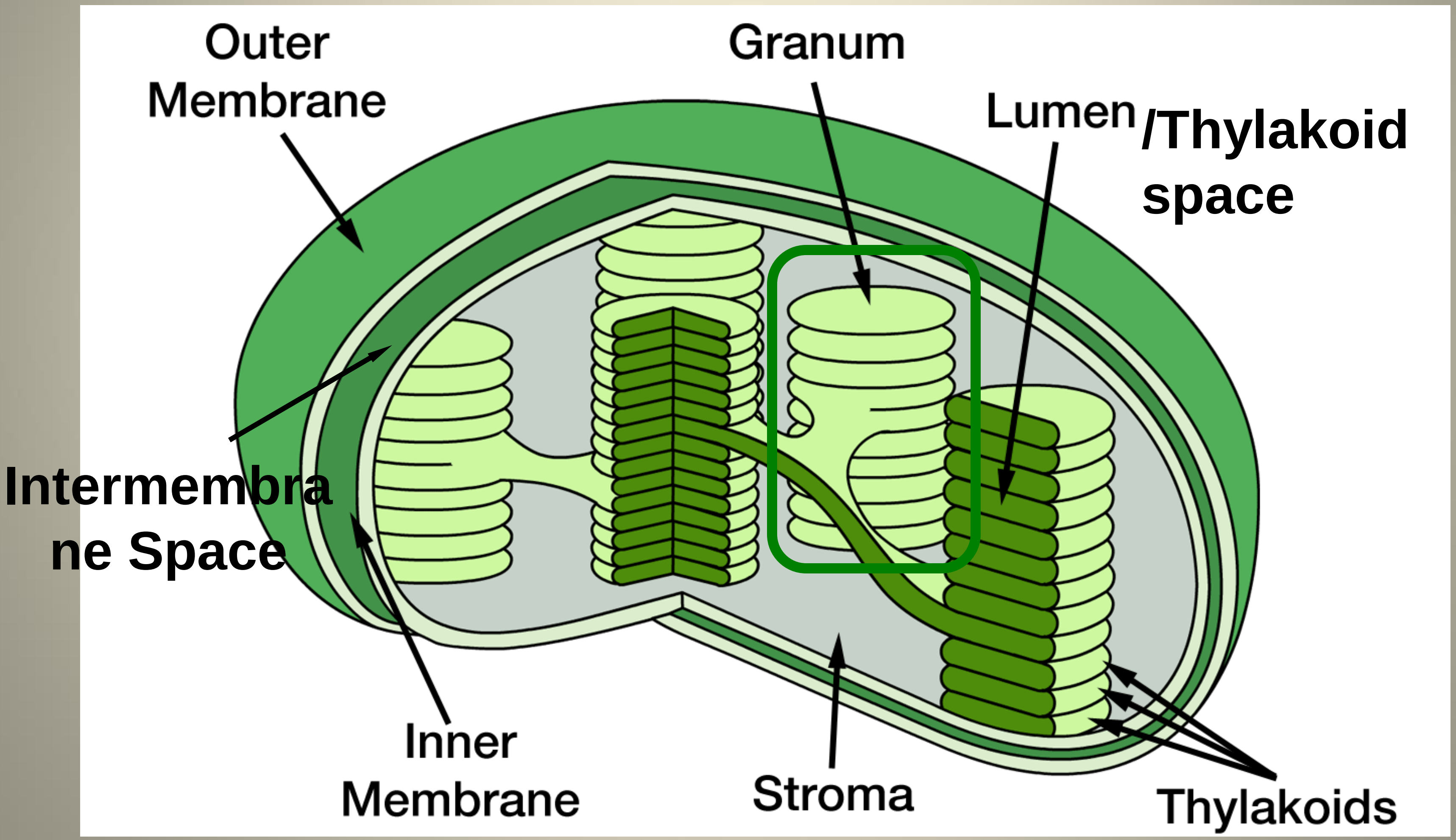
- **Photosystem I**: Reaction-centre chlorophyll is **P700**
- **Photosystem II**: Reaction-centre chlorophyll is **P680**
- Numbers indicate optimal wavelength for absorption
- different absorption preferences due to interaction with different proteins in photosystems



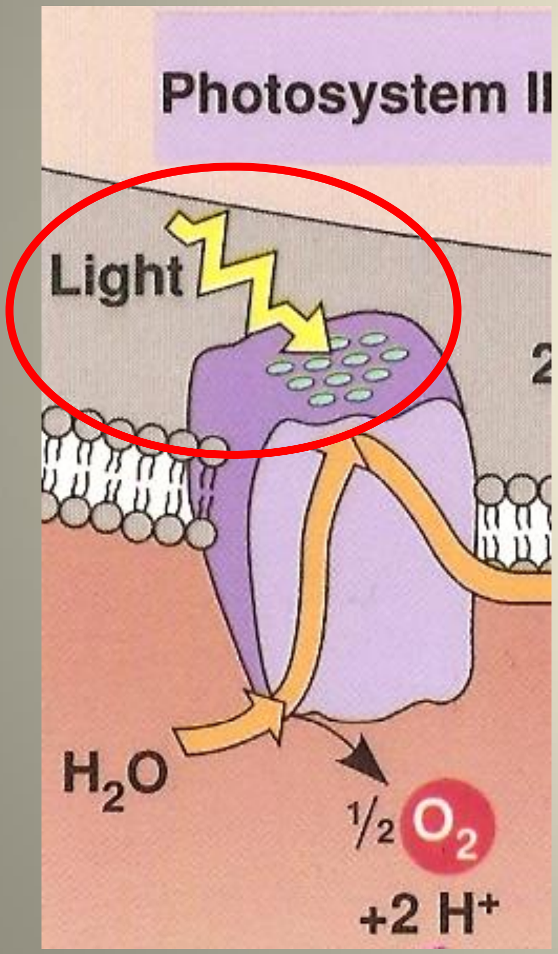


Light
H_2O
CO_2
$NADP^+$
ADP
LIGHT REACTIONS
CALVIN CYCLE
ATP
NADPH
O_2
CH_2O (sugar)
STROMA
Photosystem II
Cytochrome complex
Photosystem I
Light
NADP⁺ reductase
Light
THYLAKOID MEMBRANE
2 H^+
Fd
$NADP^+ + H^+$
NADPH
Pq
Pc
THYLAKOID SPACE
H_2O
$\frac{1}{2}$ O_2
+2 H^+
2 H^+
To Calvin cycle
ATP synthase
STROMA
ADP
+
P_i
ATP
H^+

Review: Chloroplast Structure

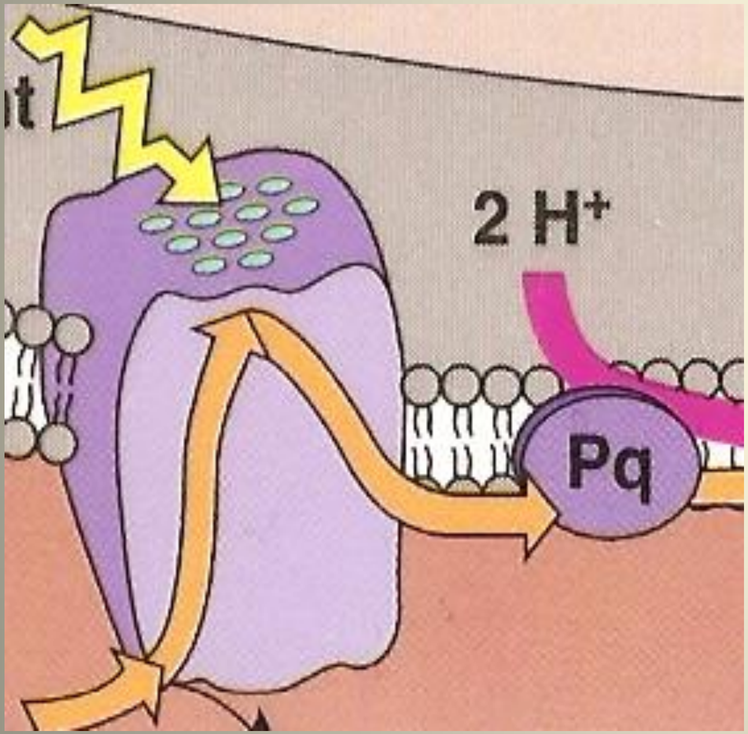


Thylakoid Proteins: PSII (P680)



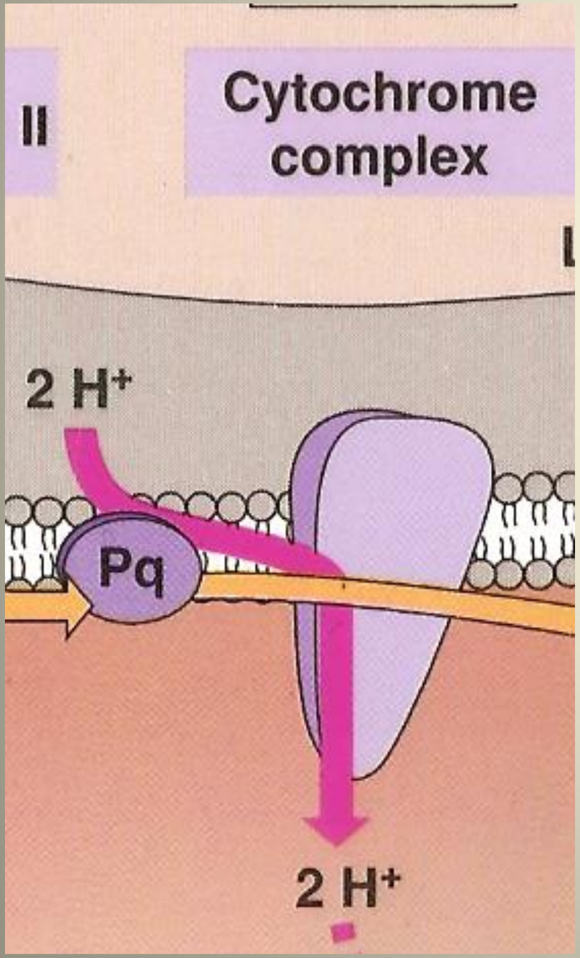
- PSII absorbs light
- Excited electron in the reaction-centre chlorophyll (P680) is captured by the primary electron acceptor
- P680 that has lost an electron ($P680^+$) is oxidized

Thylakoid Proteins: Pq



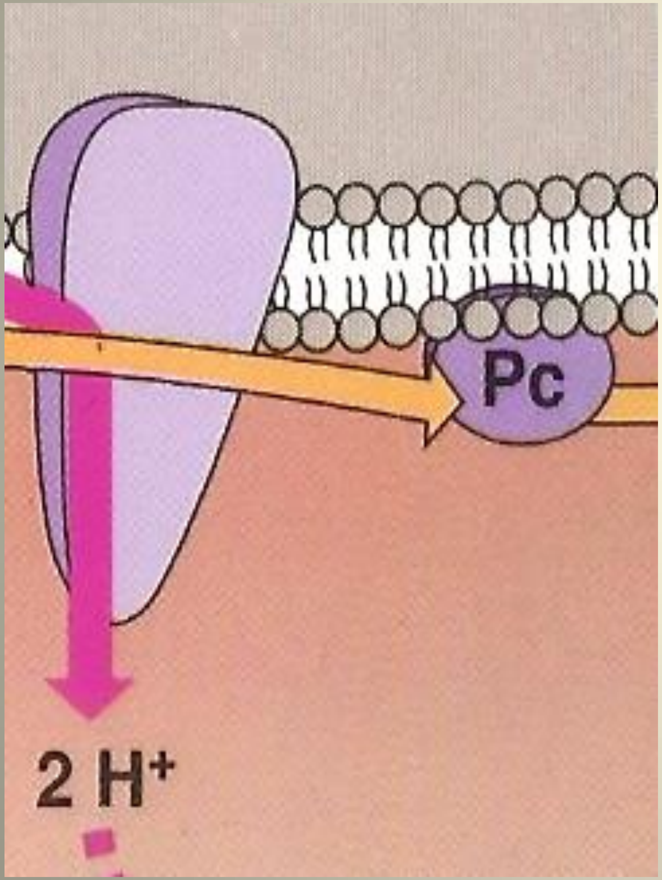
- Electron capture by primary electron acceptor of PSII will now be passed through an electron transport chain
- The electron is first transferred to plastiquinone (Pq)
- Pq is a mobile component within the thylakoid membrane

Thylakoid Proteins: Cytochrome Complex



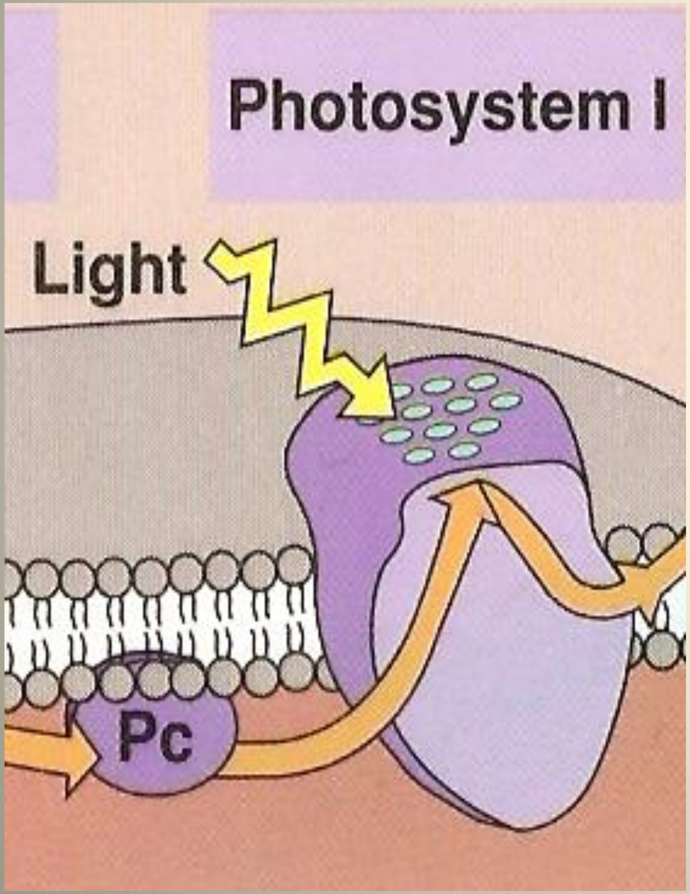
- Electrons are transferred from Pq to cytochrome complex
- protons are pumped against its concentration gradient from stroma across thylakoid membrane to the lumen

Thylakoid Proteins: Pc



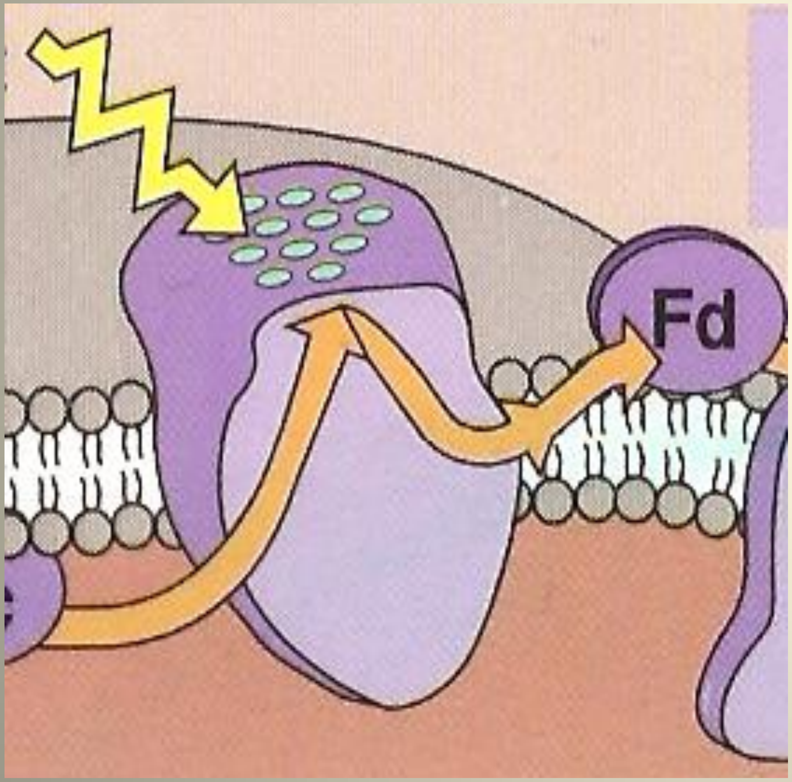
- Electrons are transferred to plastocyanin (Pc)
- Pc is a movable component on lumen side of the thylakoid membrane

Thylakoid Proteins: PSI (P700)



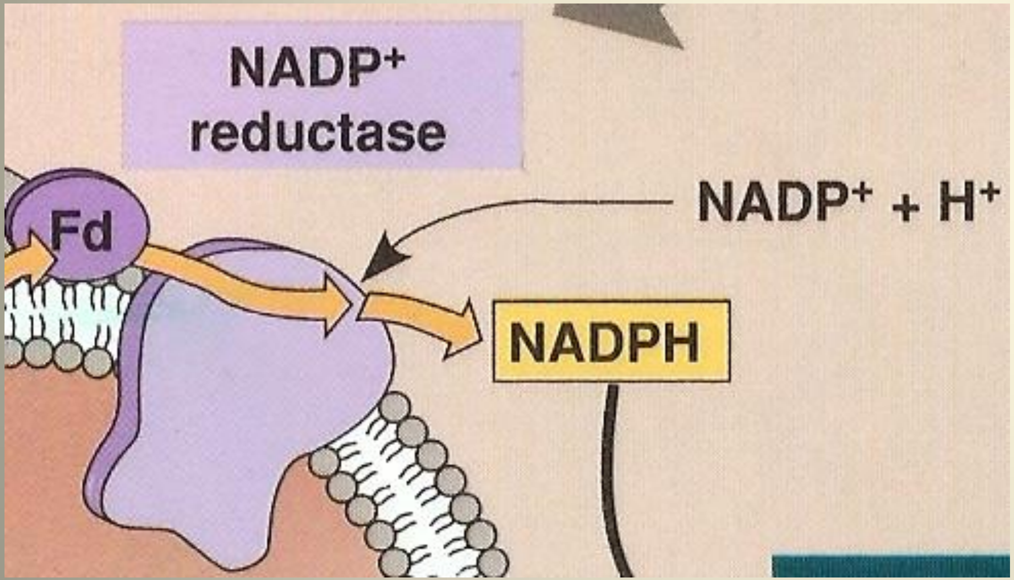
- Electrons on P700 is excited by light and captured by the primary electron acceptor leaving P700 oxidized
- Electrons transferred from Pc to P700 replaces the electrons that were lost

Thylakoid Proteins: Fd



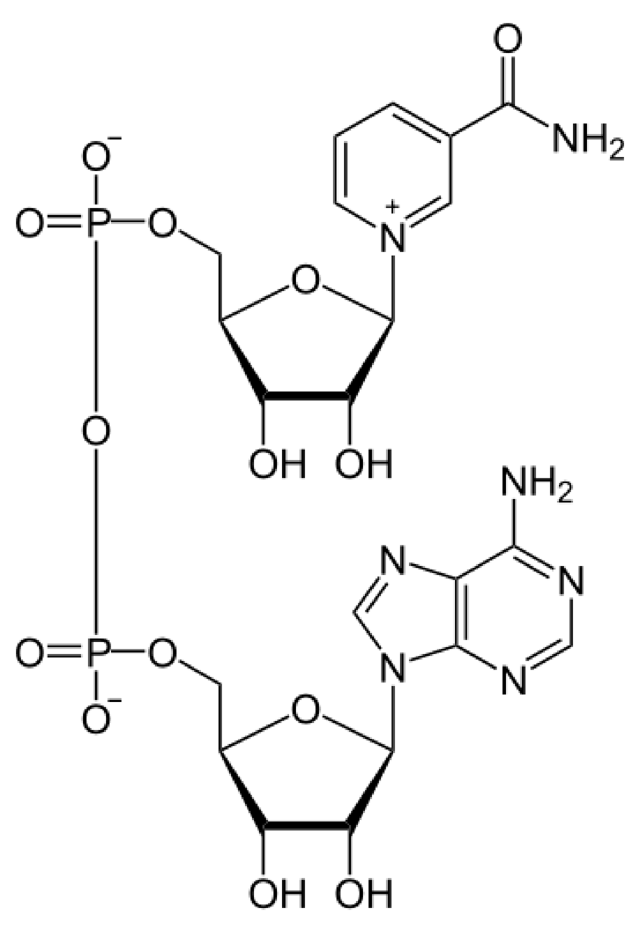
- Electrons undergo a second transport chain
- Electrons are transferred to ferrodoxin (Fd)
- Fd is an iron containing mobile component on the stromal side of the thylakoid membrane

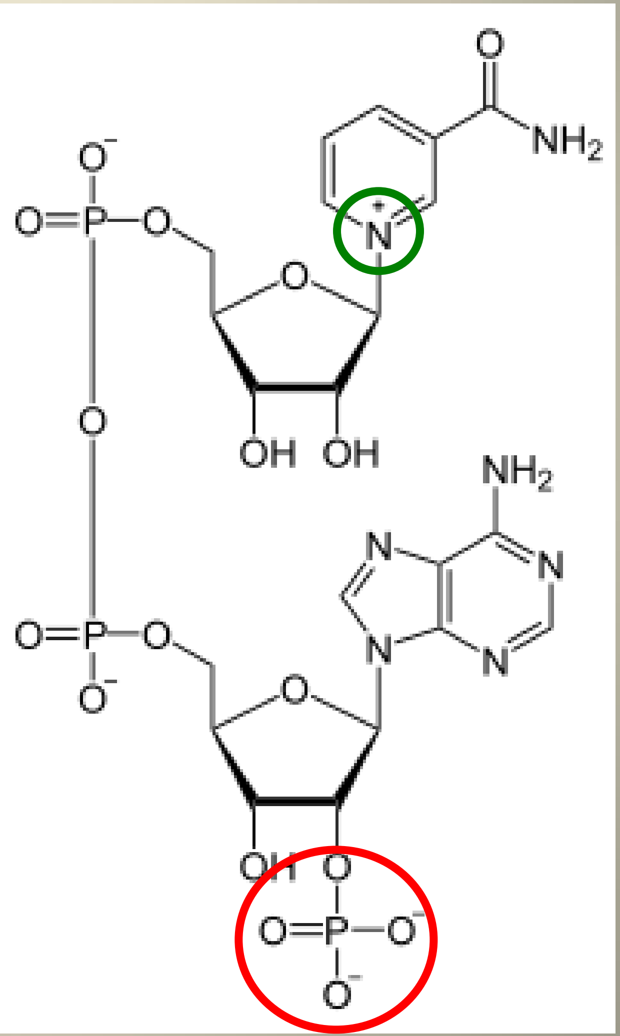
Thylakoid Protein: NADP+ Reductase



- electrons transferred by enzyme NADP+ reductase to the final electron acceptor NADP+
- NADP+ is reduced to NADPH

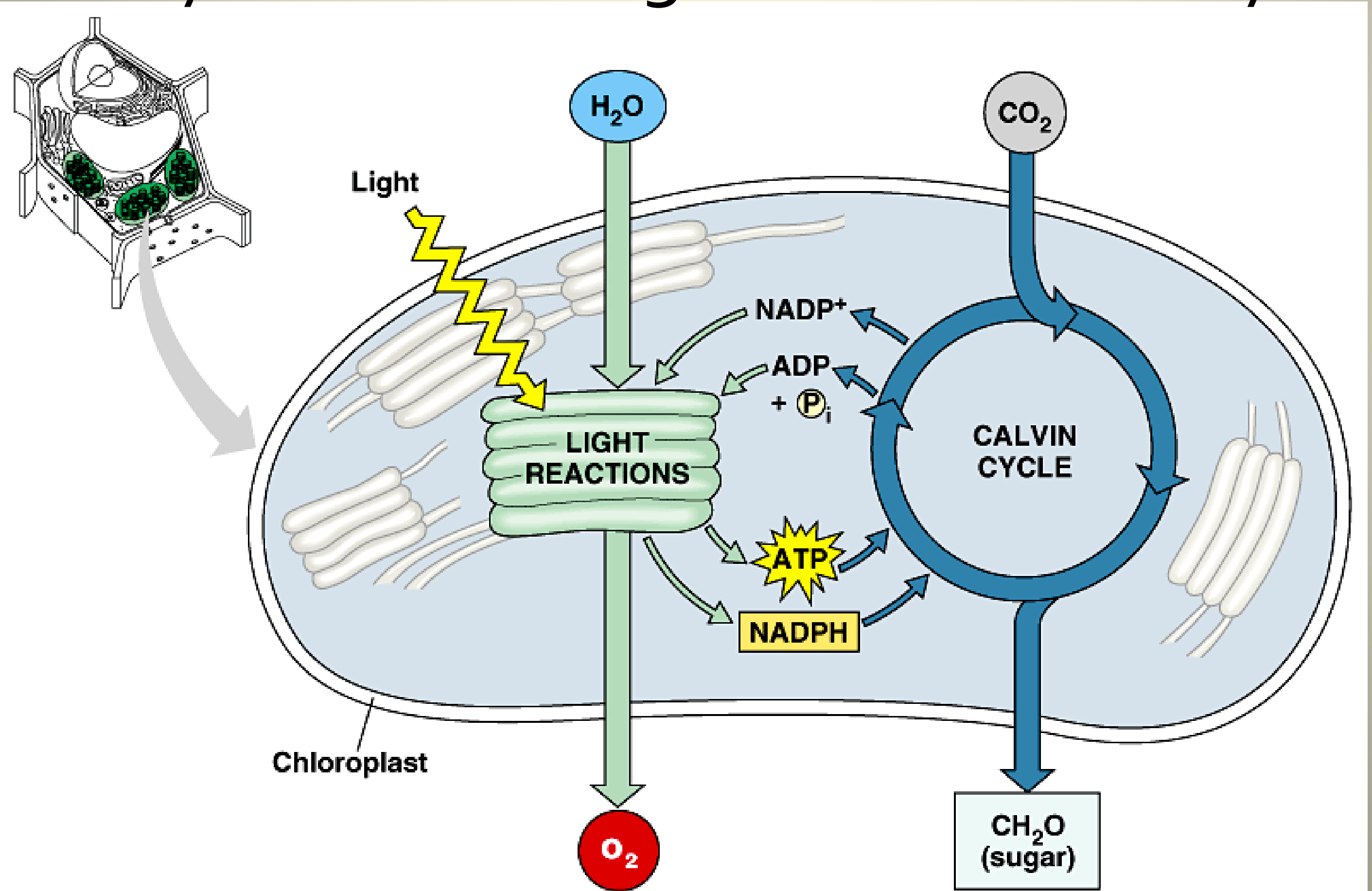
Compare NAD+ to NADP+



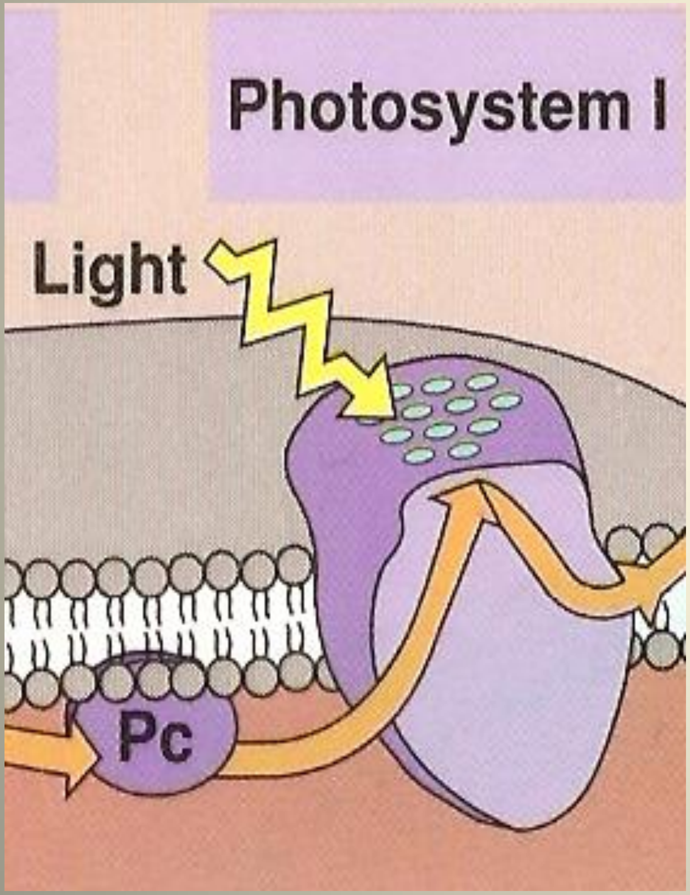


Purpose of NADPH

- NADPH will provide the reducing power for the synthesis of sugar in the Calvin cycle

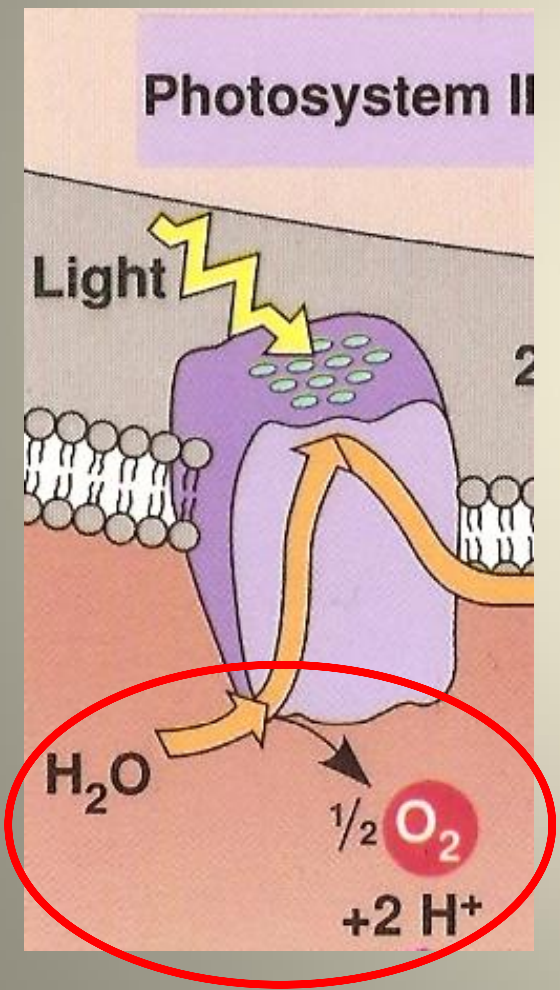


Replacing Lost Electrons in PS I



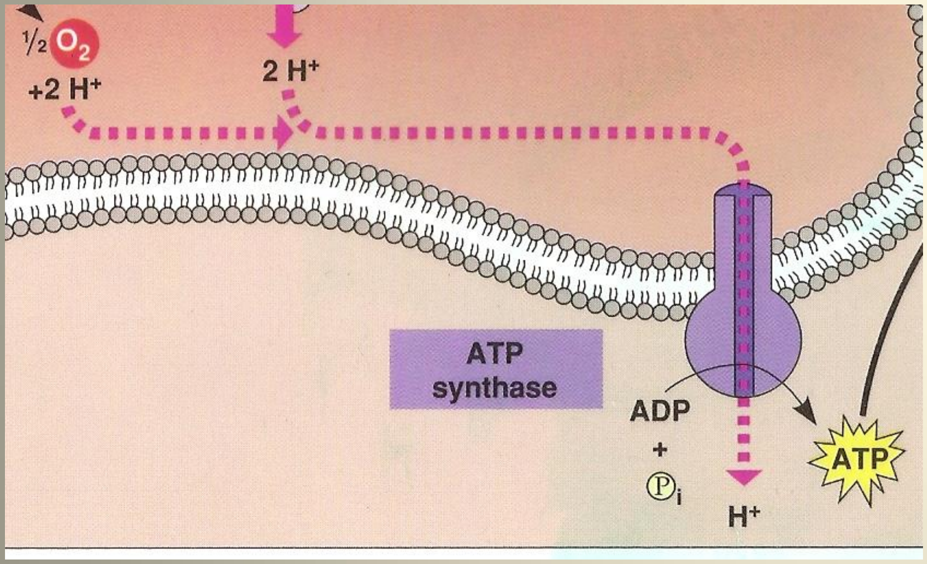
- Electrons on photosystem I (P700) that were lost are replaced by electrons that came originally from photosystem II

Replacing Lost Electrons in PSII: Photolysis



- In photosystem II, the oxidized P680 ($P680^+$) is a very strong oxidizing agent
- Electrons are extracted from water (in the lumen) to replace the missing electrons on P680
- As a result, water is split into oxygen and hydrogen ions

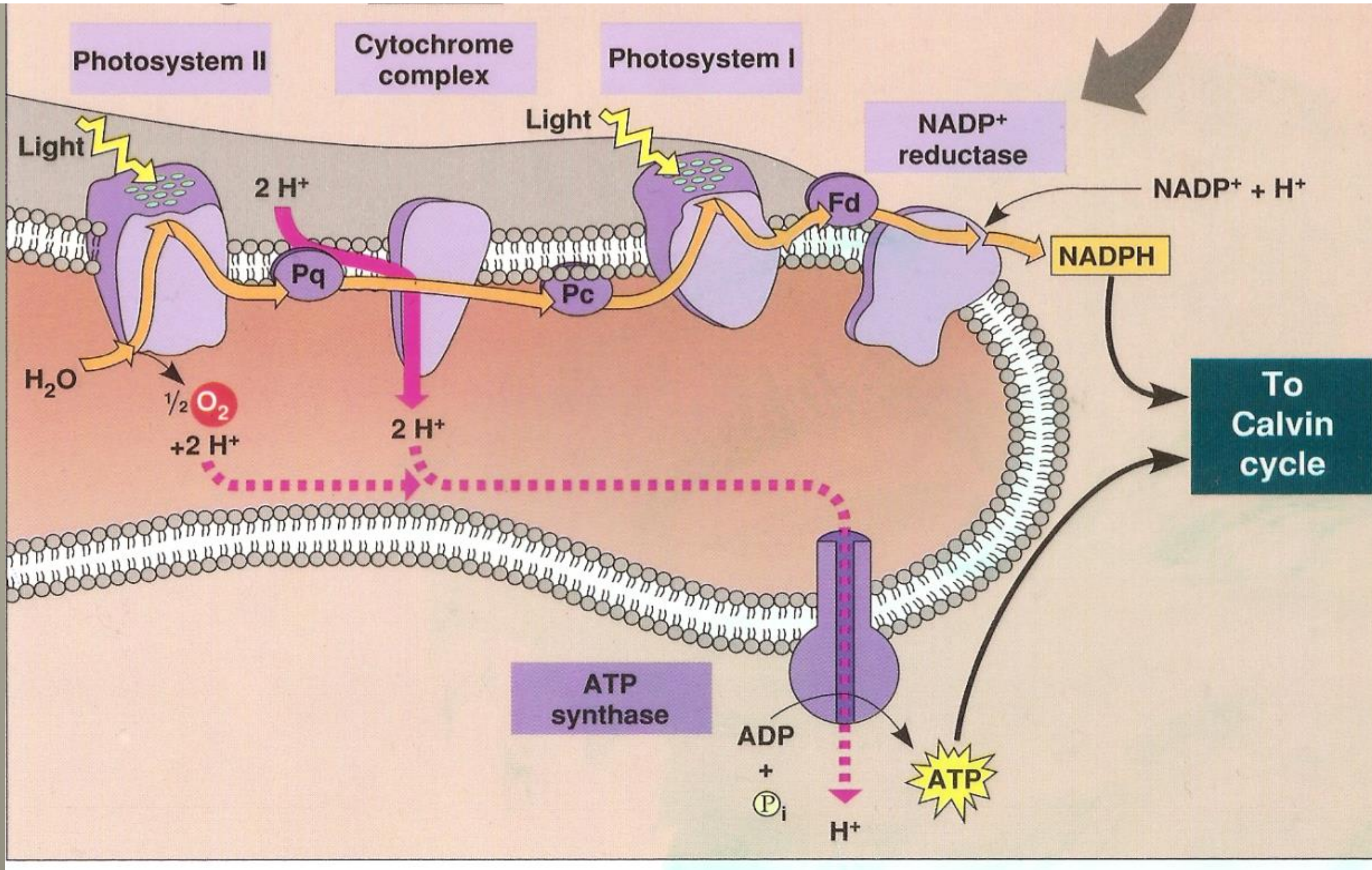
Thylakoid Proteins: ATP Synthase



- protons pumped into the lumen pass through ATP synthase using the same mechanism as seen in cellular respiration
- ATP is produced in the stroma

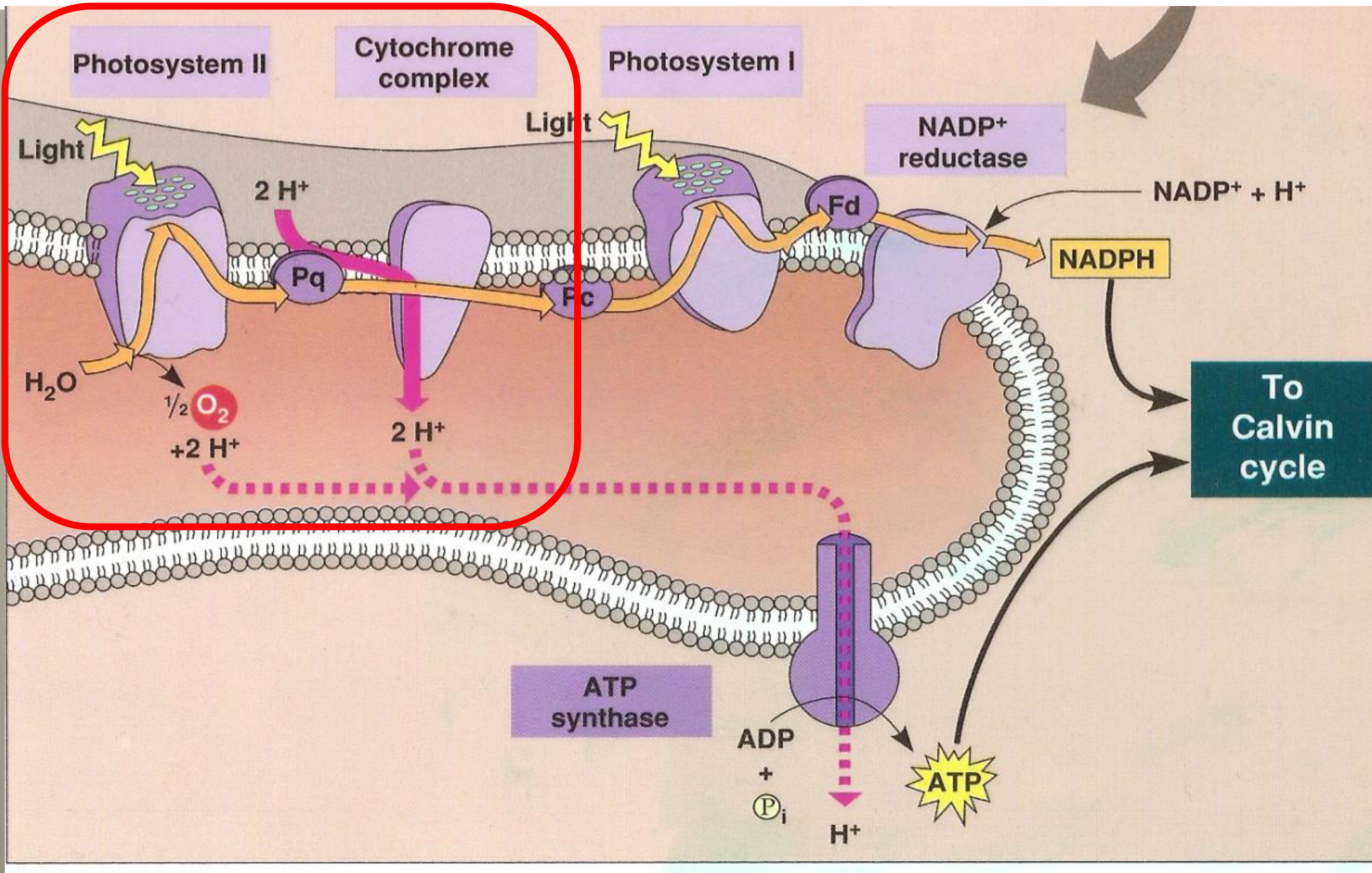
Photophosphorylation

- light-dependent formation of ATP by chemiosmosis



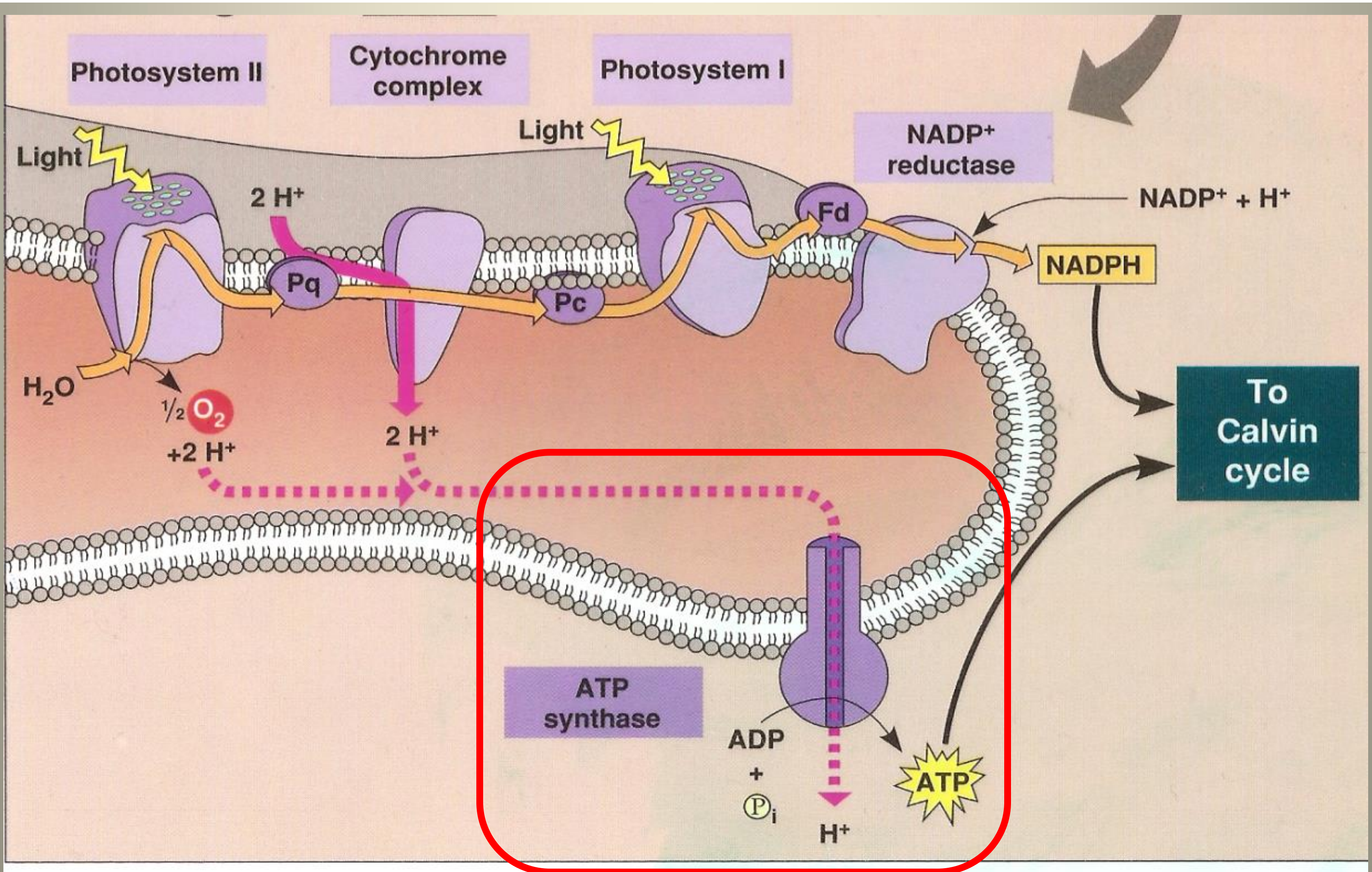
Photophosphorylation

- ETC provides energy for photosystems to pump H+ from stroma to lumen



Photophosphorylation

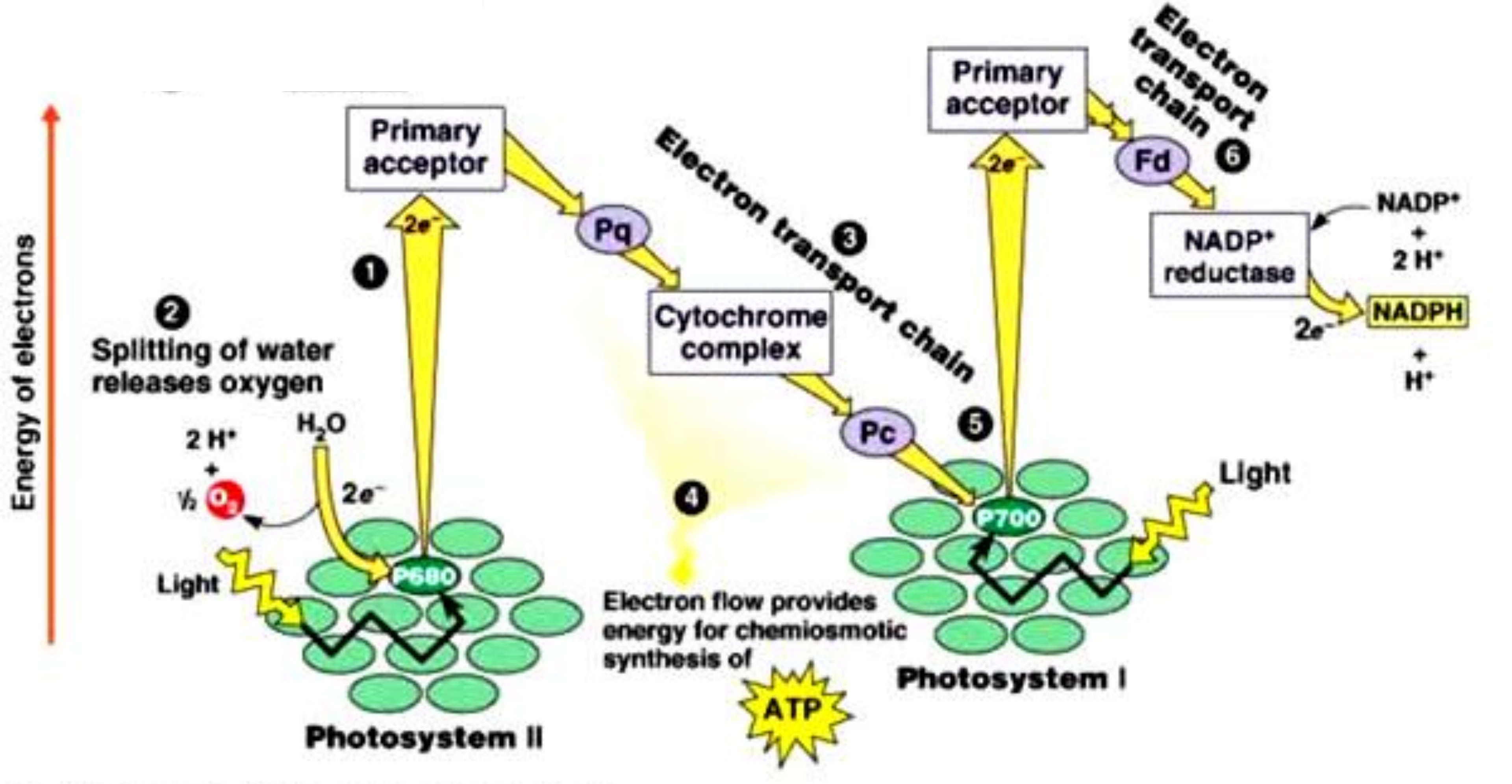
- Electrochemical proton gradient provides proton motive force needed to synthesize ATP



Types of Electron Transport Mechanisms

- Non-cyclic electron flow
- Cyclic electron flow

Non-cyclic Electron Flow: Z-Scheme



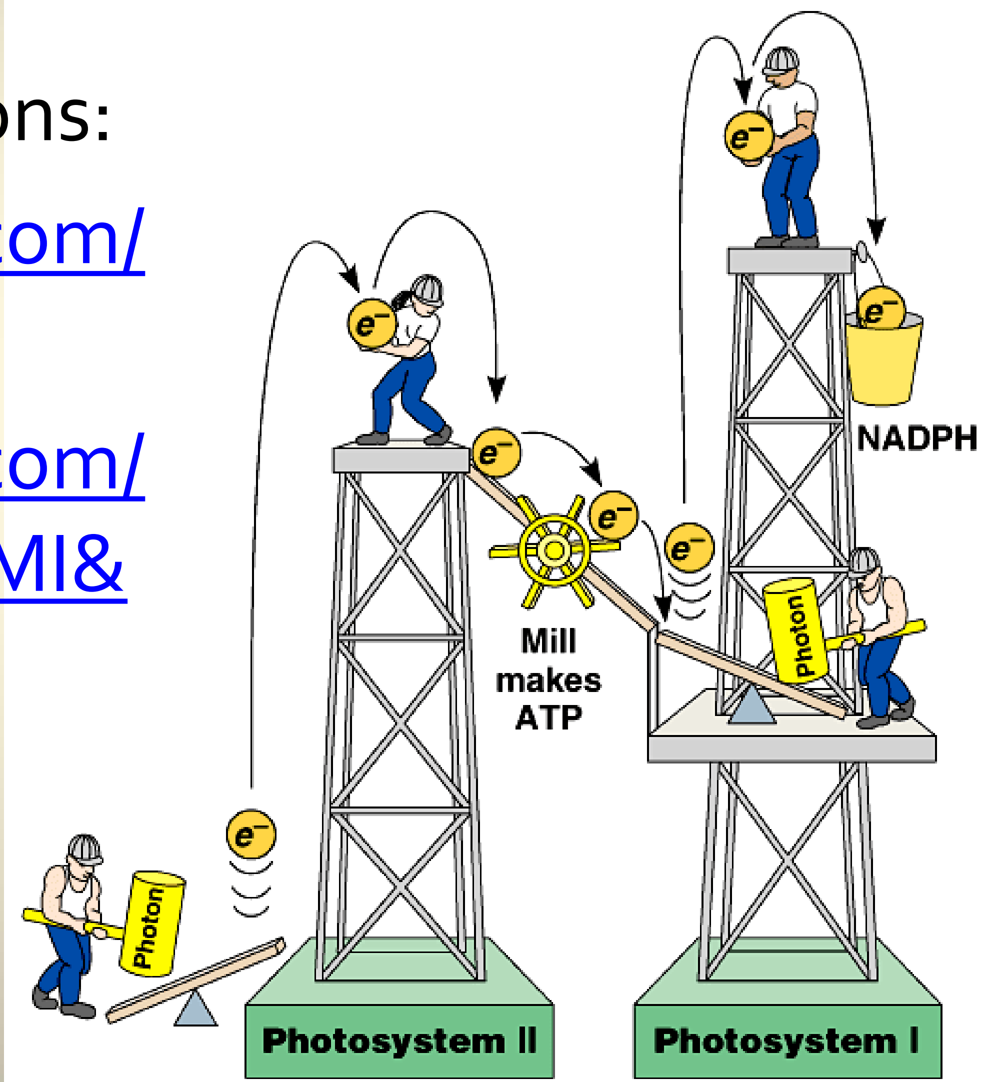
Non-cyclic Electron Transfer Summary

- H_2O is split to produce O_2 (released from cell) and H+ ions (released into lumen)
- Electron transport chain helps establish electrochemical proton gradient
- **Photophosphorylation**: light-dependent formation of ATP by chemiosmosis
- NADP+ is final electron acceptor and produces NADPH

Noncyclic Electron Flow Analogy

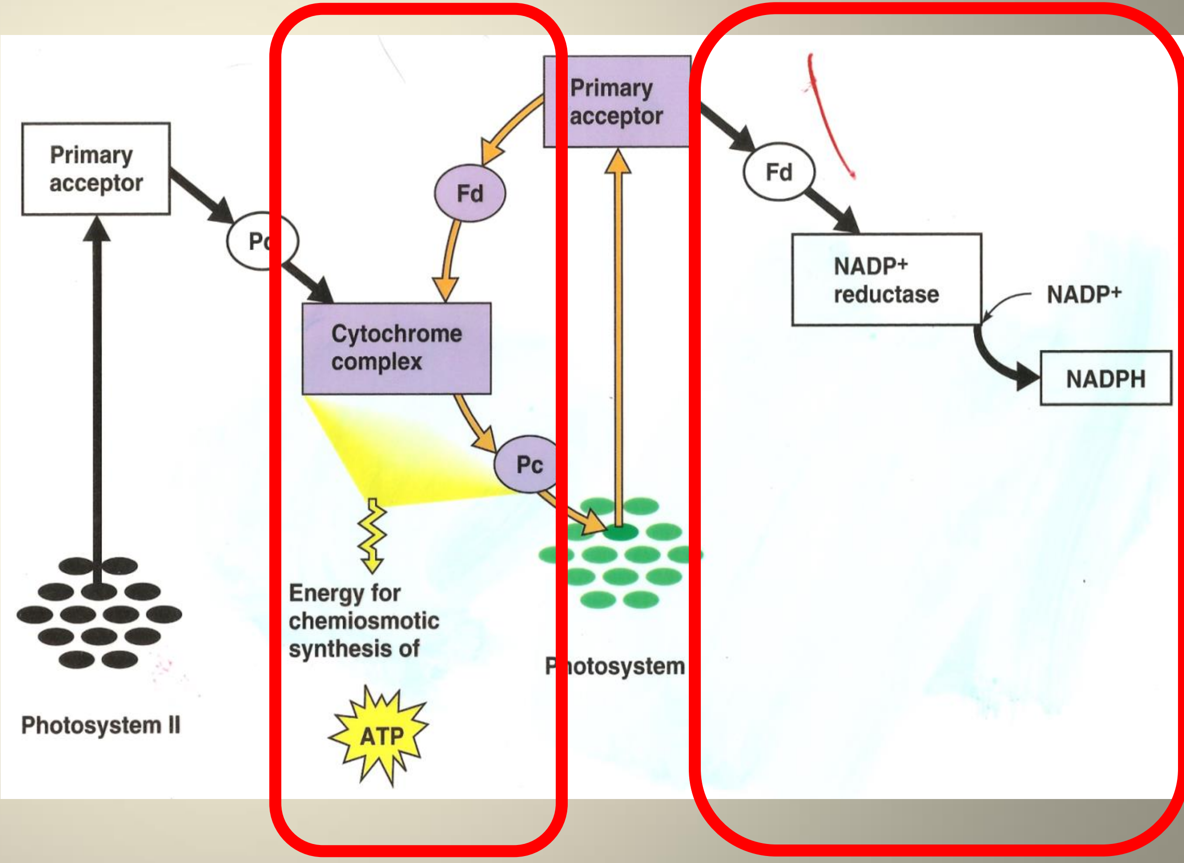
Light Reaction Animations:

- http://www.youtube.com/watch?v=v590JJV96lc
- http://www.youtube.com/watch?v=hj_WKgnL6MI&feature=related

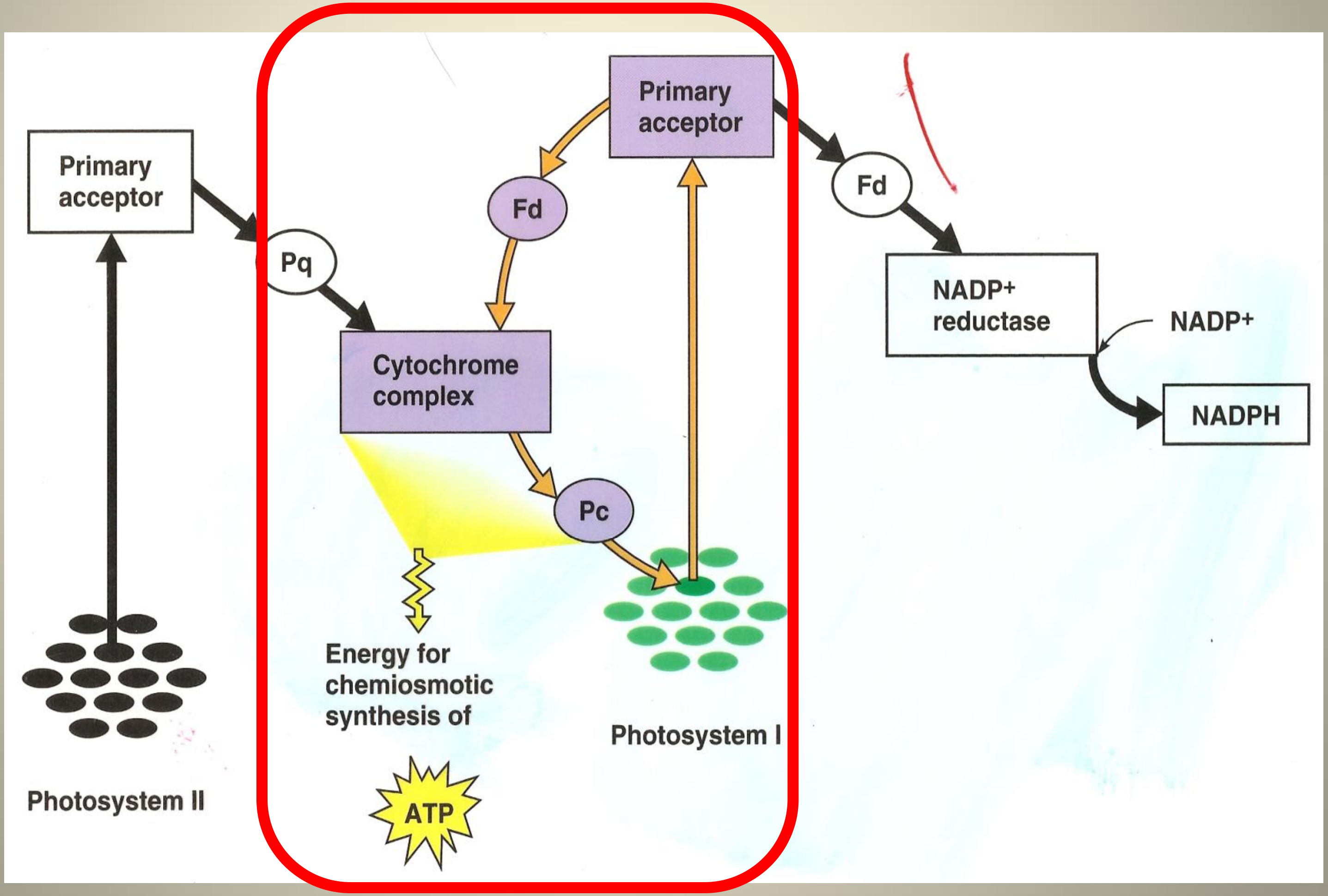


Role of Ferredoxin (Fd)

- Ferredoxin has 2 possible fates:
  - Transfer electrons to NADP+ reductase (noncyclic electron flow)
  - Transfer electrons to cytochrome complex (cyclic electron flow)



Cyclic Electron Flow

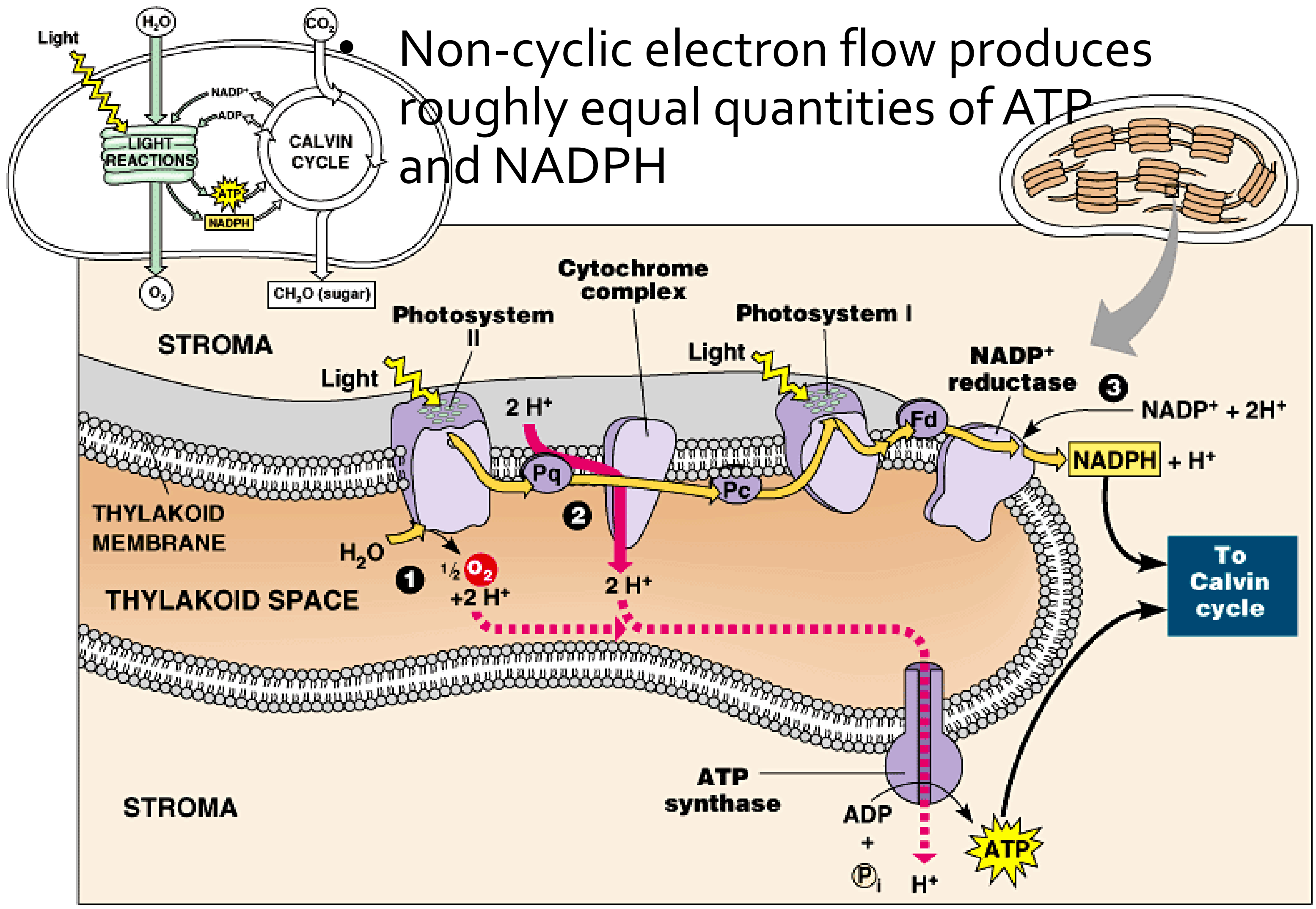


Cyclic Electron Transfer Summary

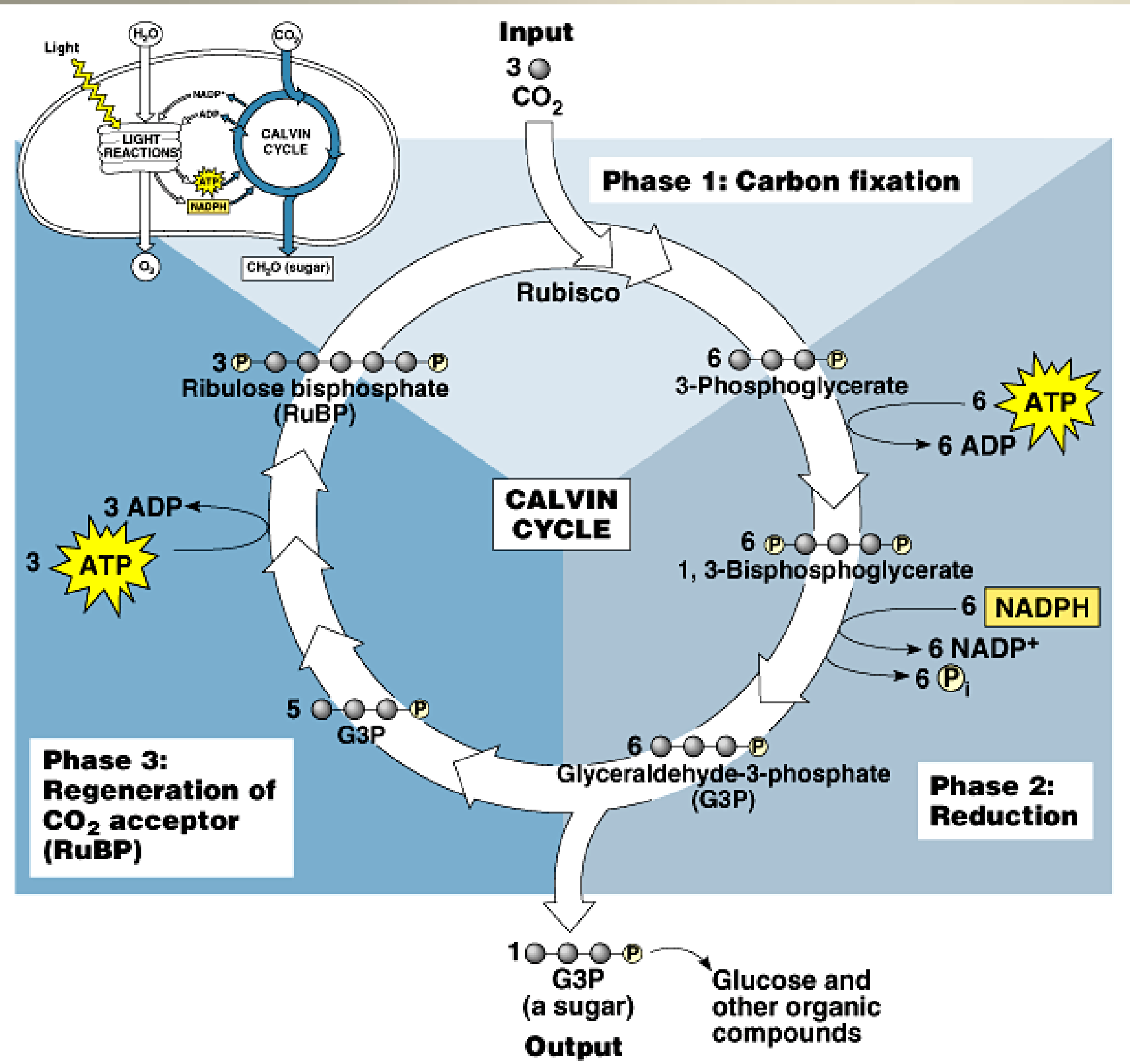
- only involves photosystem I (P700)
- ferrodoxin returns electrons back to cytochrome complex
- protons pumped into lumen to produce more ATP through chemiosmosis
- no NADPH produced

Purpose of Cyclic Electron Flow

- Non-cyclic electron flow produces roughly equal quantities of ATP and NADPH

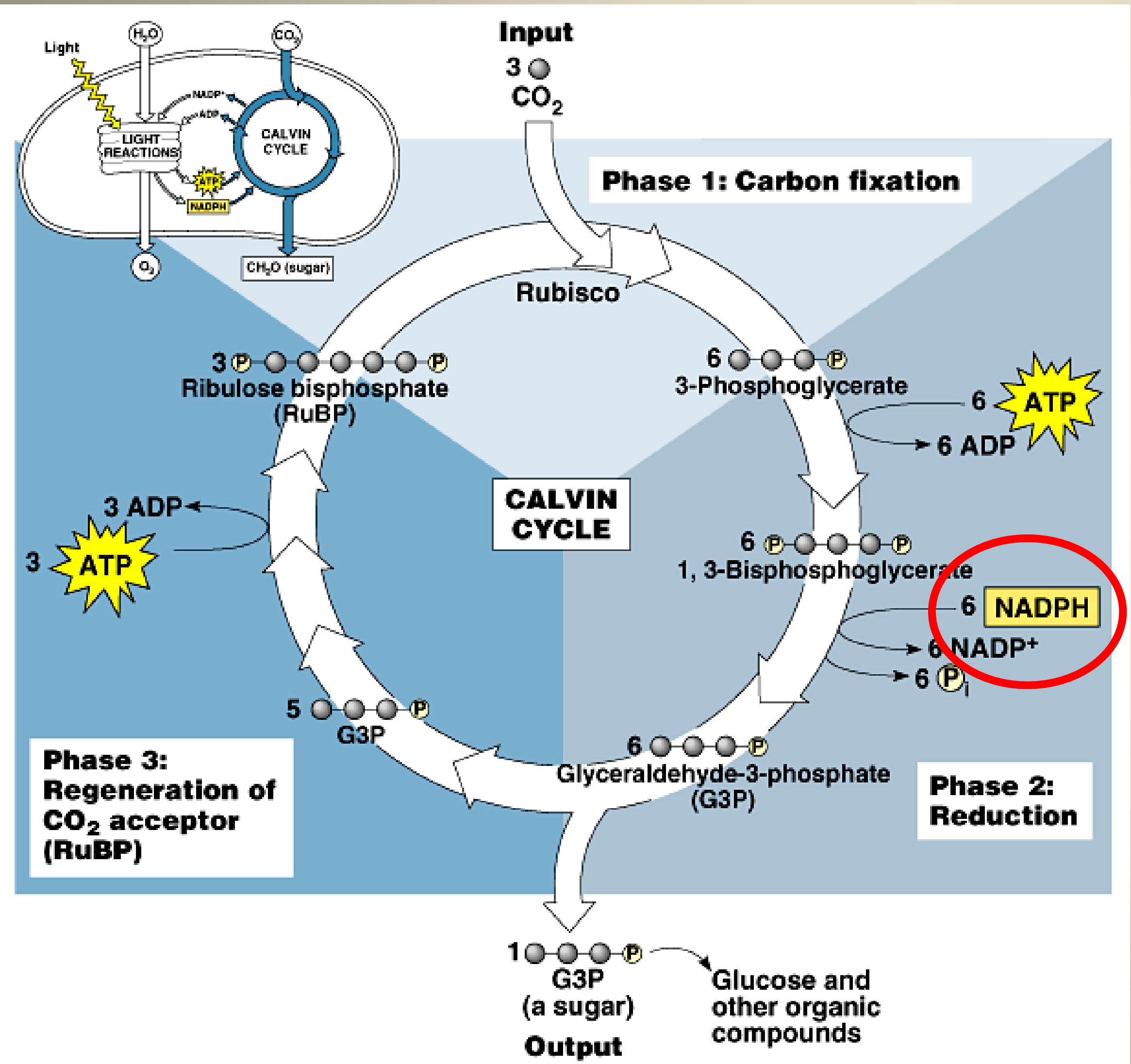


Purpose of Cyclic Electron Flow



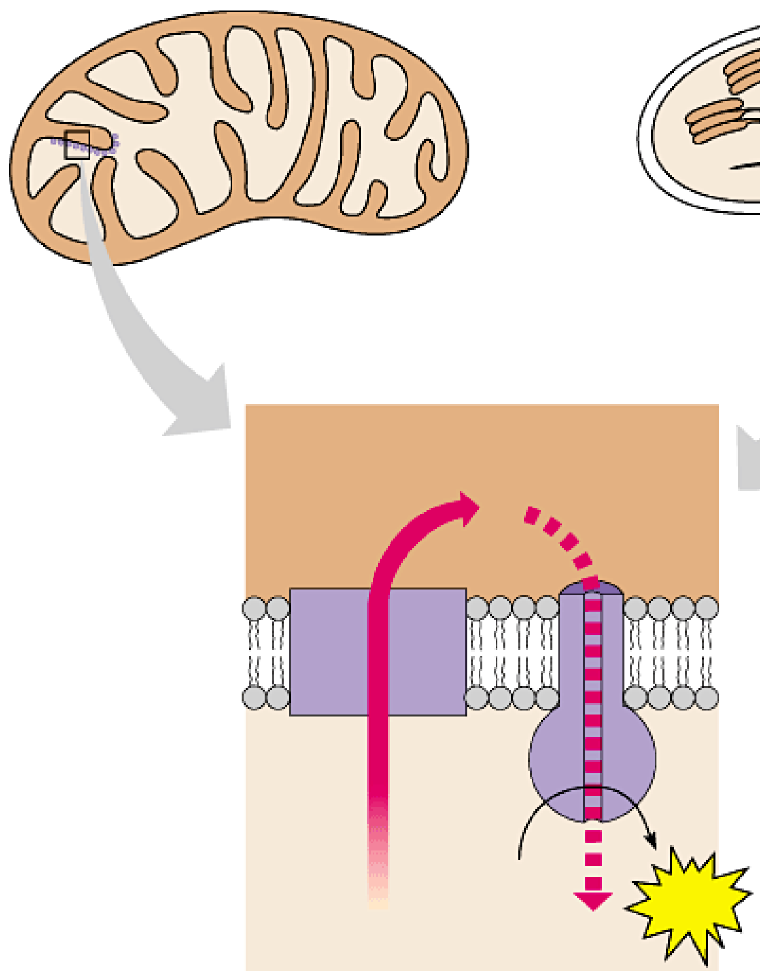
- In the Calvin cycle, more ATP is consumed than NADPH
- Need a method to increase ATP production without affecting NADPH

Purpose of Cyclic Electron Flow



- When ATP runs low, NADPH will accumulate because the Calvin cycle slows down
- Rise in NADPH levels stimulate a temporary shift to cyclic electron flow

Compare Cellular Respiration and Photosynthesis



Compare Cellular Respiration and Photosynthesis