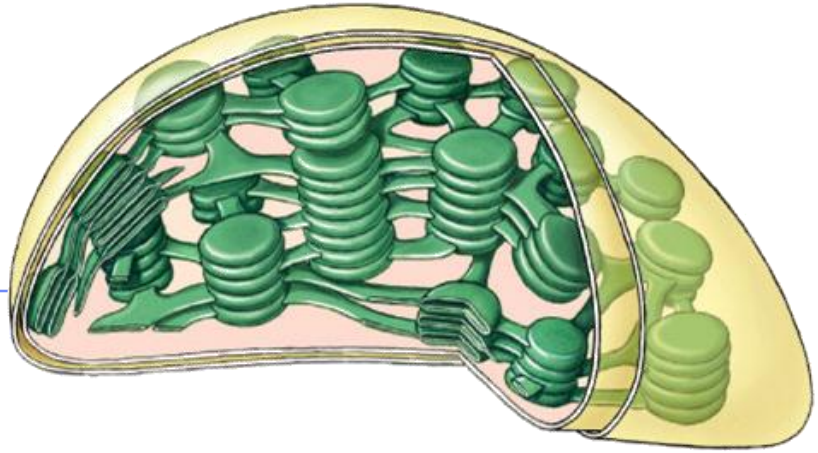
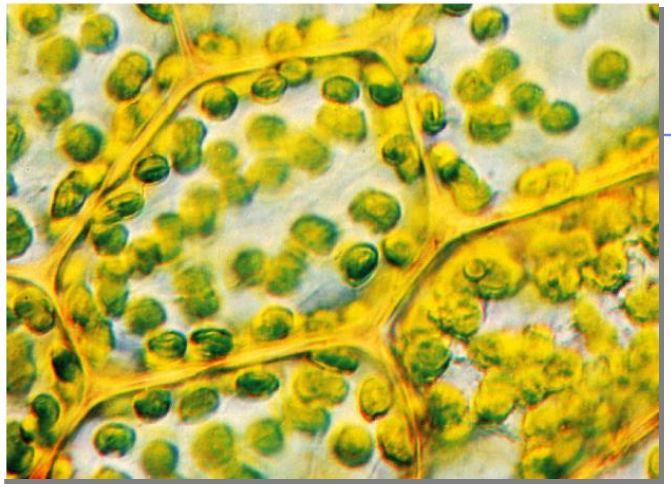

Benjamin
Cummings



Photosynthesis:
Life from Light and Air



Energy needs of life

- All life needs a constant input of energy
  - Heterotrophs (Animals)
    - get their energy from "eating others"
      - eat food = other organisms = organic molecules
    - make energy through respiration
  - Autotrophs (Plants)
    - produce their own energy (from "self")
    - convert energy of sunlight
    - build organic molecules (CHO) from CO_2
    - make energy & synthesize sugars through photosynthesis

consumers

producers

How are they connected?

Heterotrophs

making energy & 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

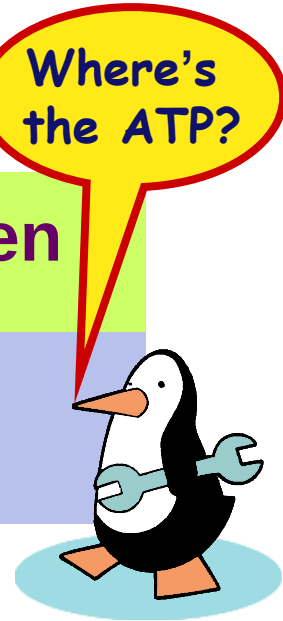
Autotrophs

making energy & organic molecules from light energy

carbon dioxide + water + energy → glucose + oxygen

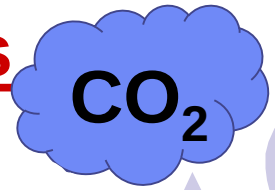
$6CO_2 + 6H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6O_2$

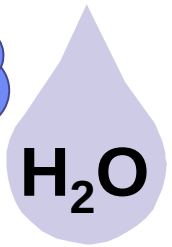
reduction = endergonic

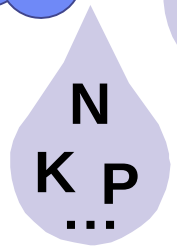


What does it mean to be a plant

- 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
  - 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 collectors
  - CO_2
    - stomates = gas exchange
  - H_2O
    - uptake from roots
  - nutrients
    - N, P, K, S, Mg, Fe…
    - uptake from roots

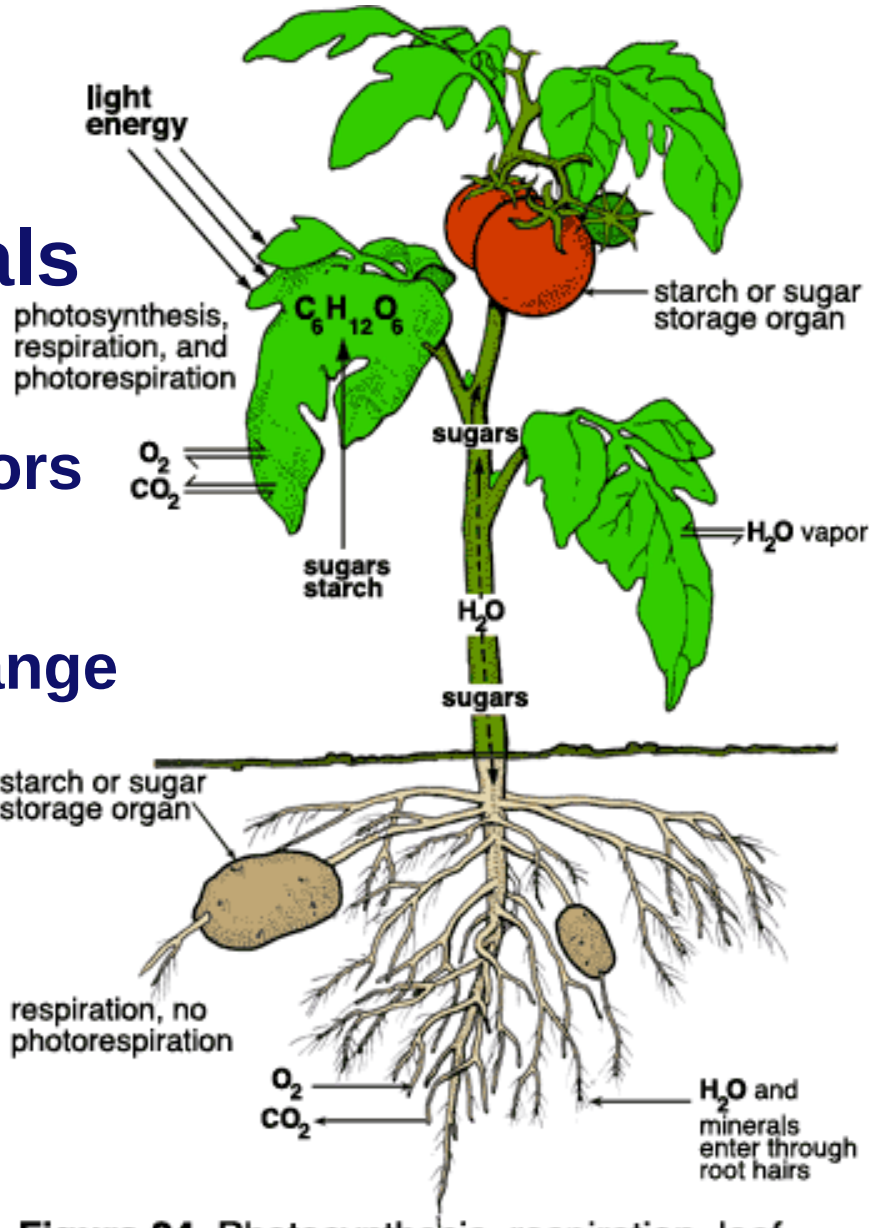


Figure 24. Photosynthesis, respiration, leaf water exchange, and translocation of sugar (photosynthate) in a plant.

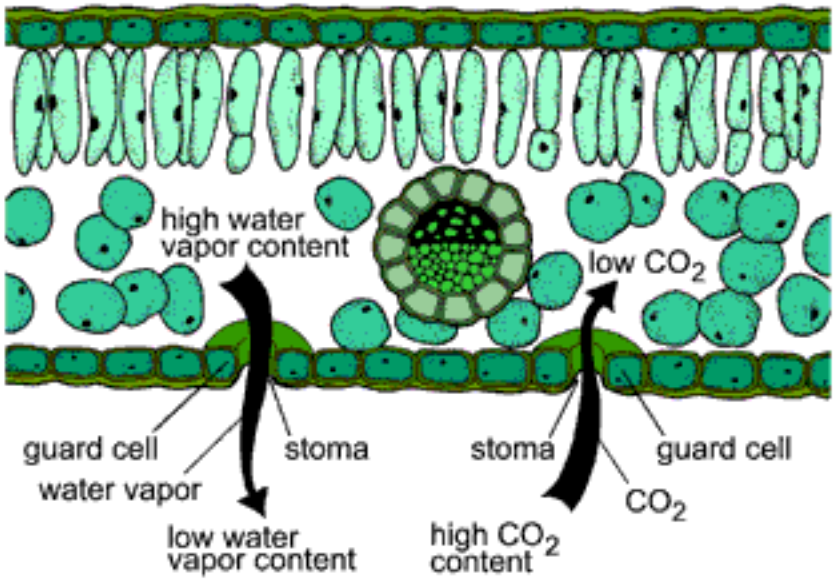
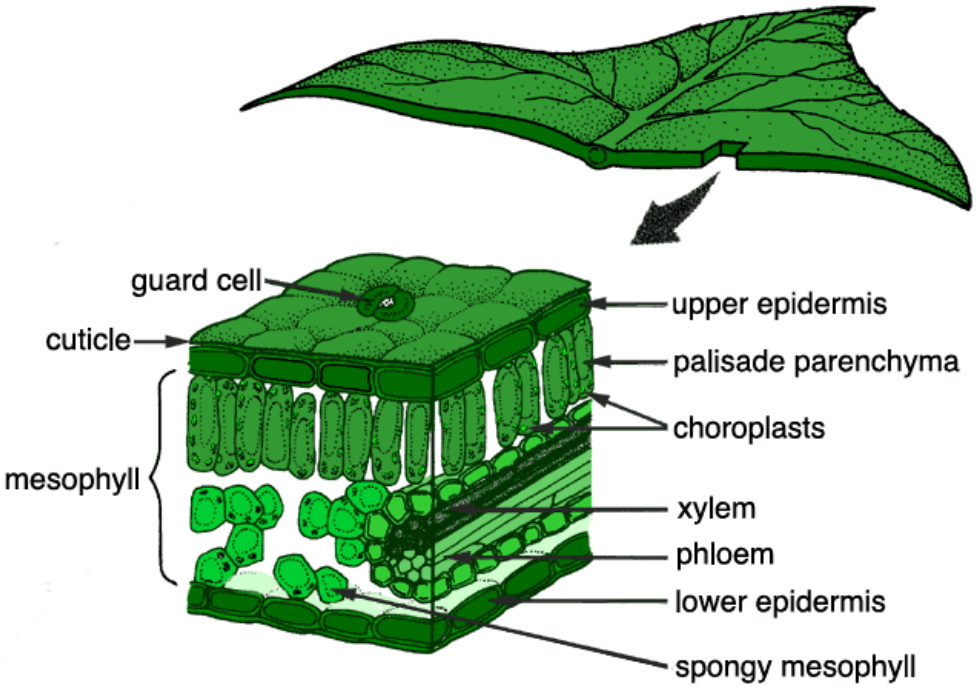
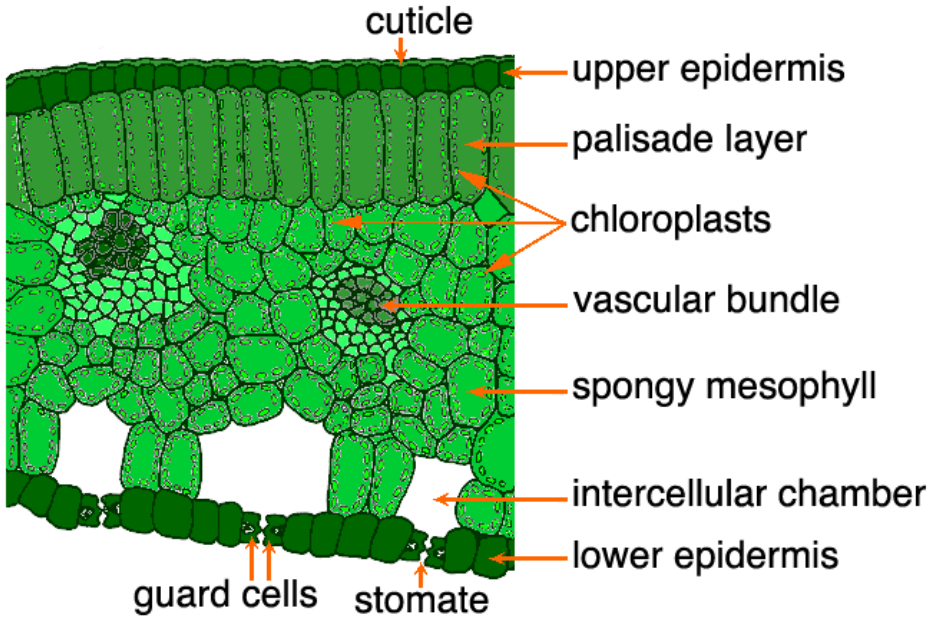


Figure 25. Stomata open to allow carbon dioxide (CO_2) to enter a leaf and water vapor to leave.

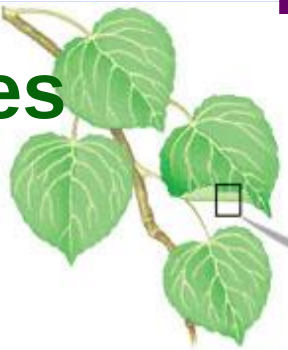


✓transpiration
✓gas exchange

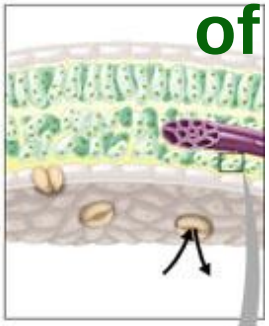


Chloroplasts

leaves

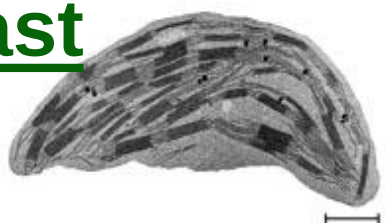


cross section of leaf



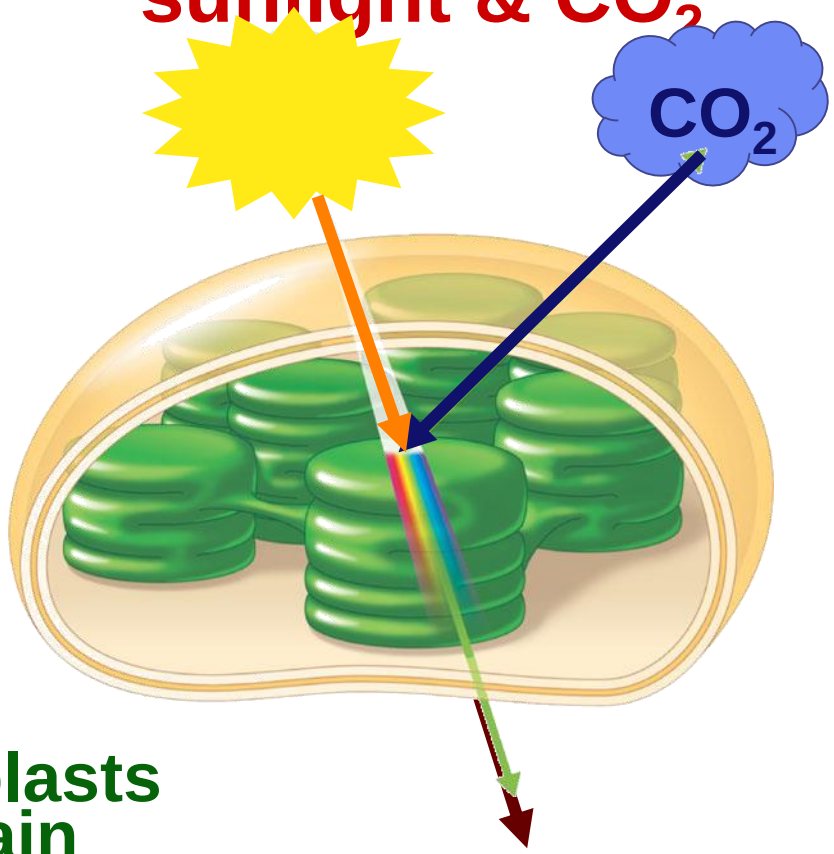
chloroplasts in plant cell

chloroplast



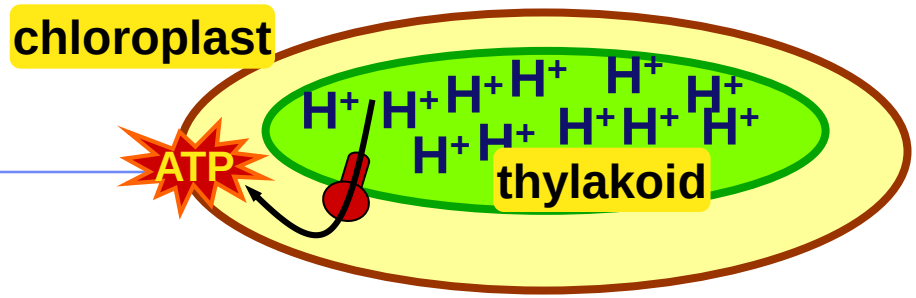
chloroplasts contain chlorophyll

absorb sunlight & CO_2

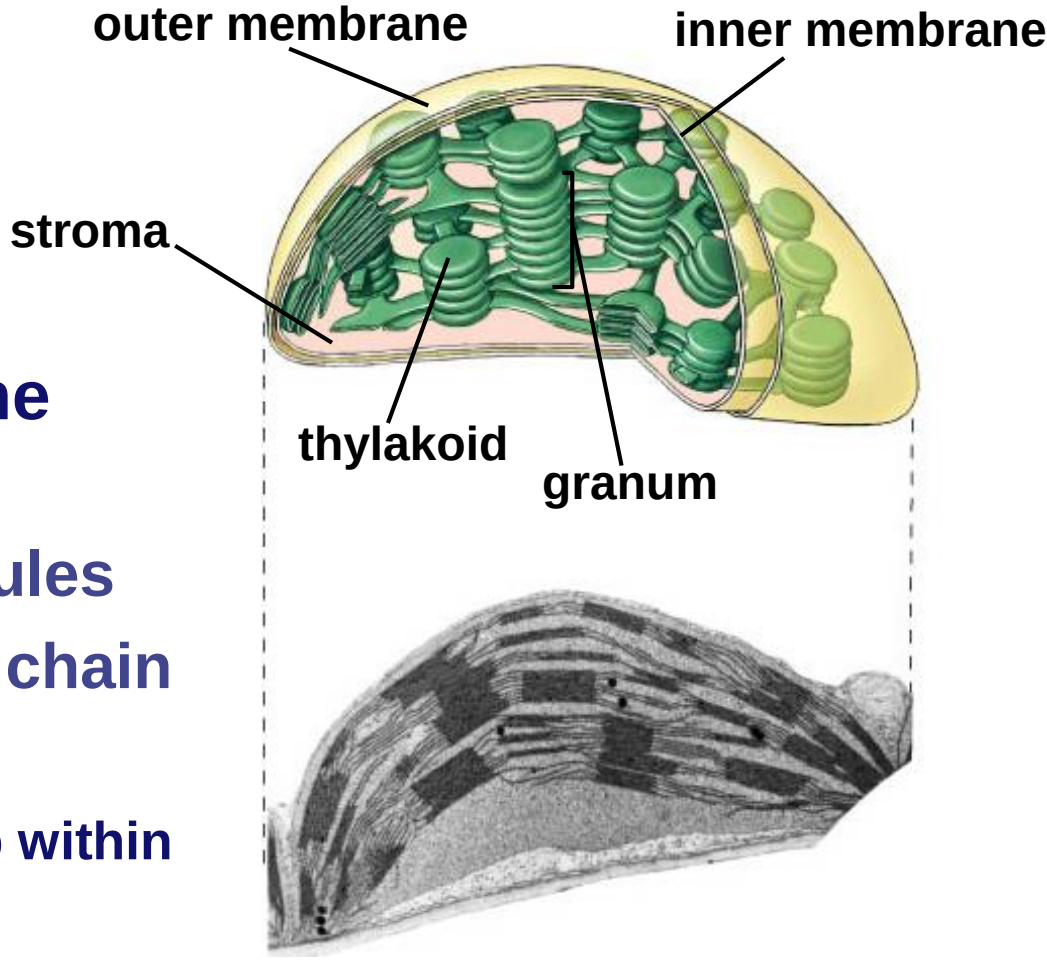


make energy & sugar

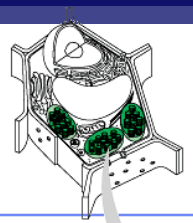
Plant structure

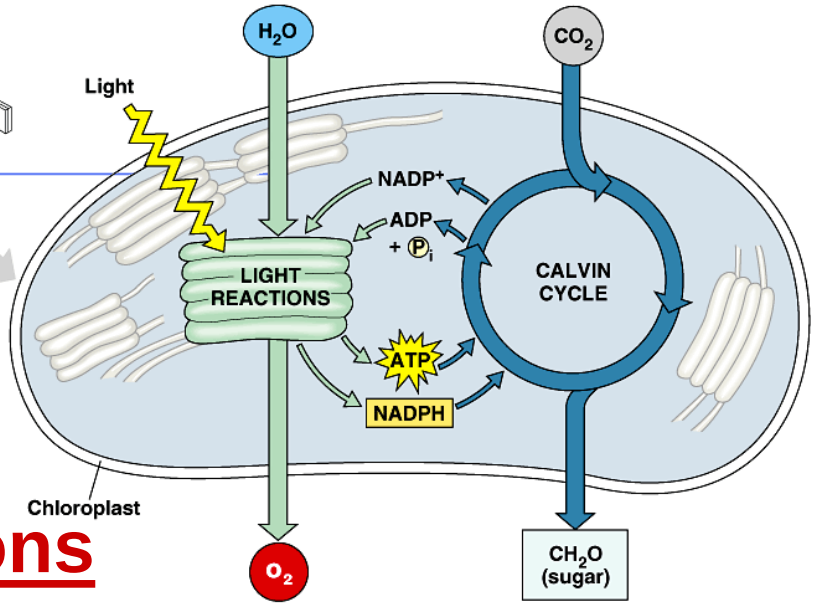


- **Chloroplasts**
  - double membrane
  - **stroma**
    - fluid-filled interior
  - **thylakoid sacs**
  - **grana stacks**
- **Thylakoid membrane contains**
  - chlorophyll molecules
  - electron transport chain
  - ATP synthase
    - H^+ gradient built up within thylakoid sac



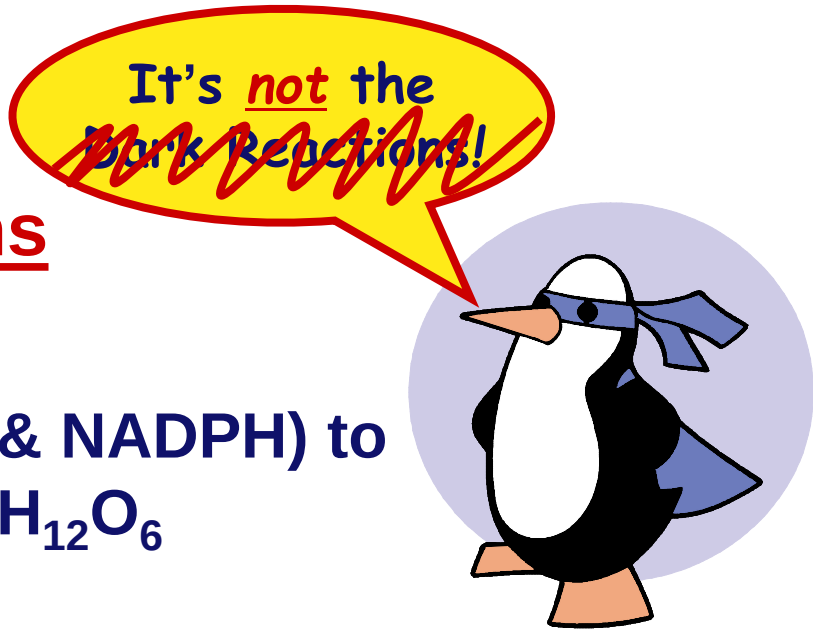
Photosynthesis



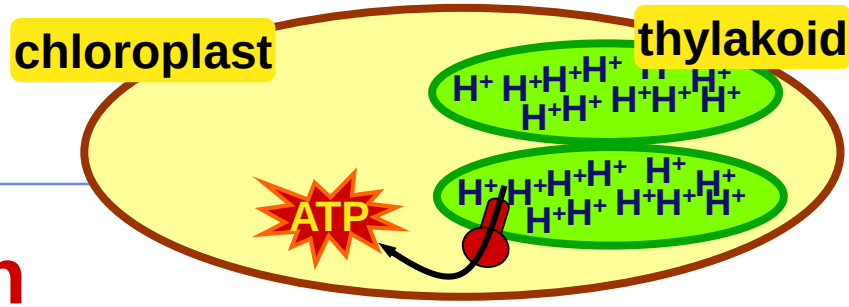


- **Light reactions**
  - **light-dependent reactions**
  - **energy conversion reactions**
    - convert solar energy to chemical energy
    - ATP & NADPH

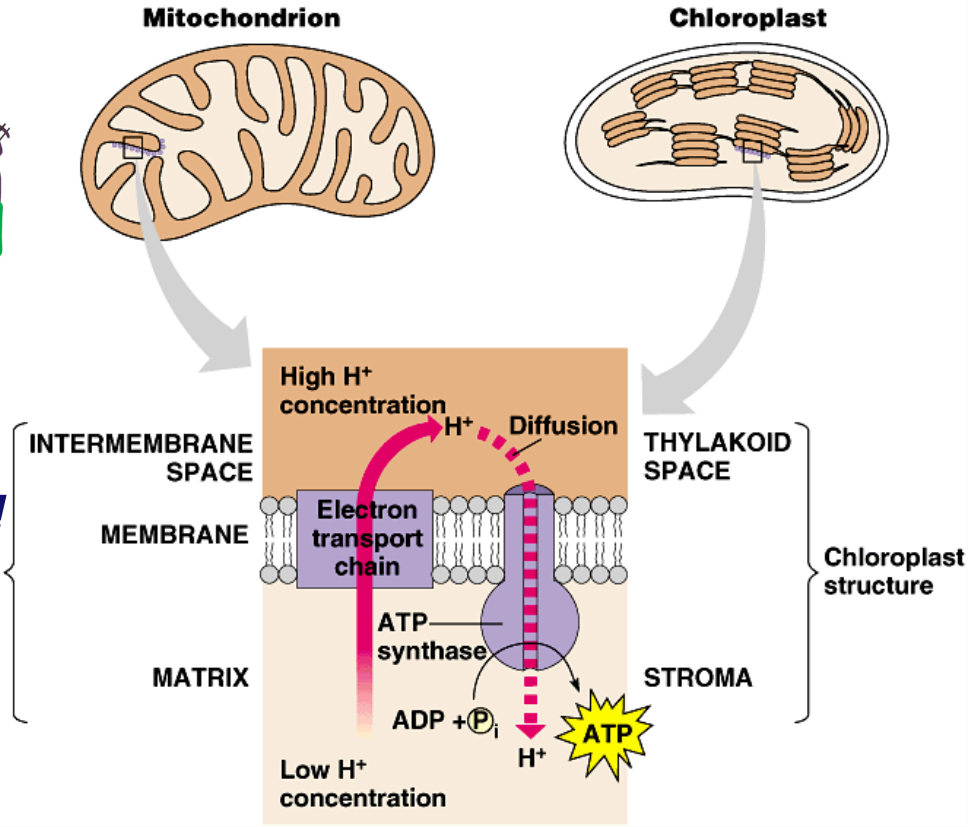
- **Calvin cycle**
  - **light-independent reactions**
  - **sugar building reactions**
    - uses chemical energy (ATP & NADPH) to reduce CO_2 & synthesize $C_6H_{12}O_6$



Light reactions



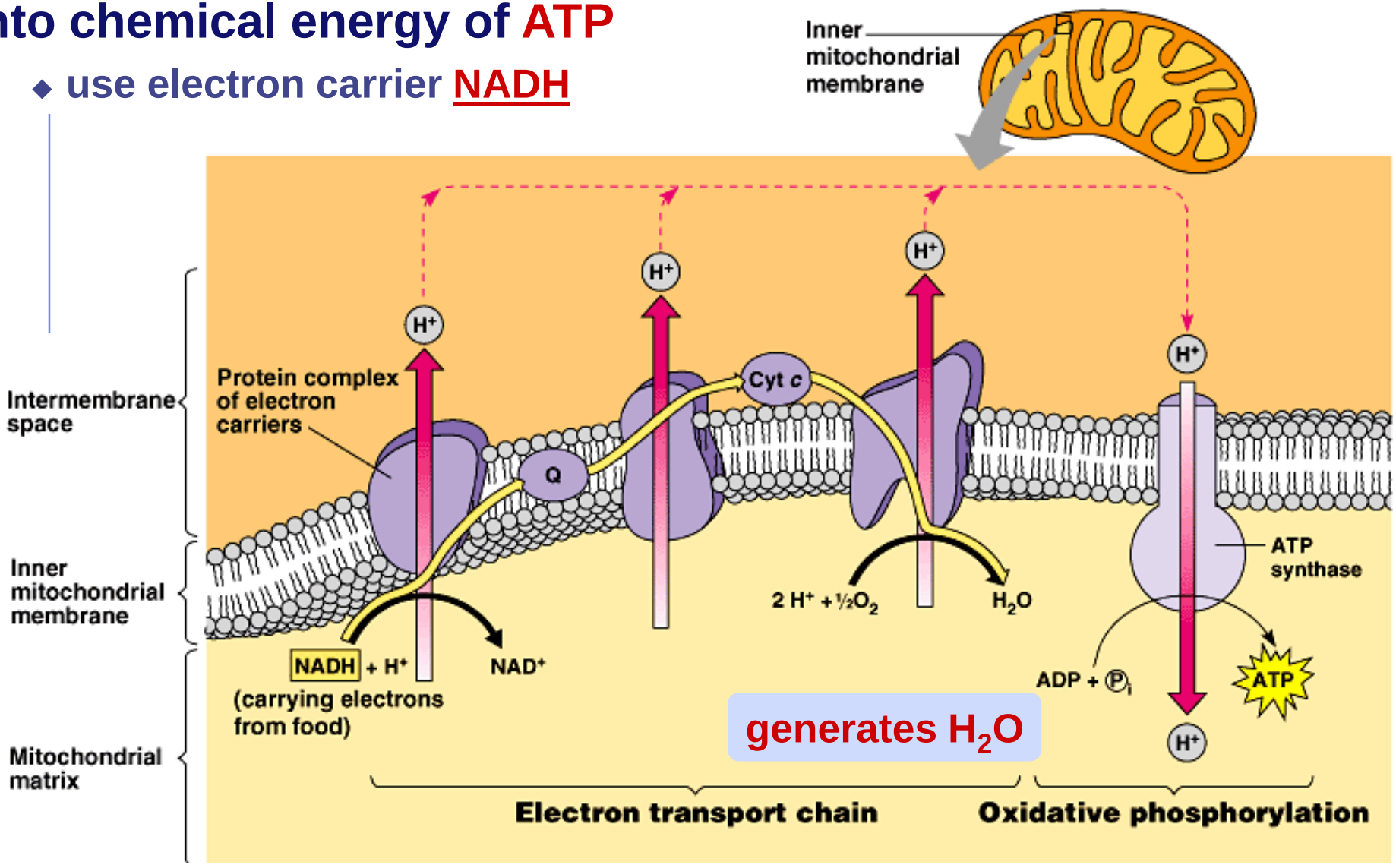
- **Electron Transport Chain**
  - like in cellular respiration
  - proteins in organelle membrane
  - **electron acceptors**
    - **NADPH**
  - proton (H^+) gradient across inner membrane
    - find the double membrane*!*
  - ATP synthase enzyme



ETC of Respiration

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

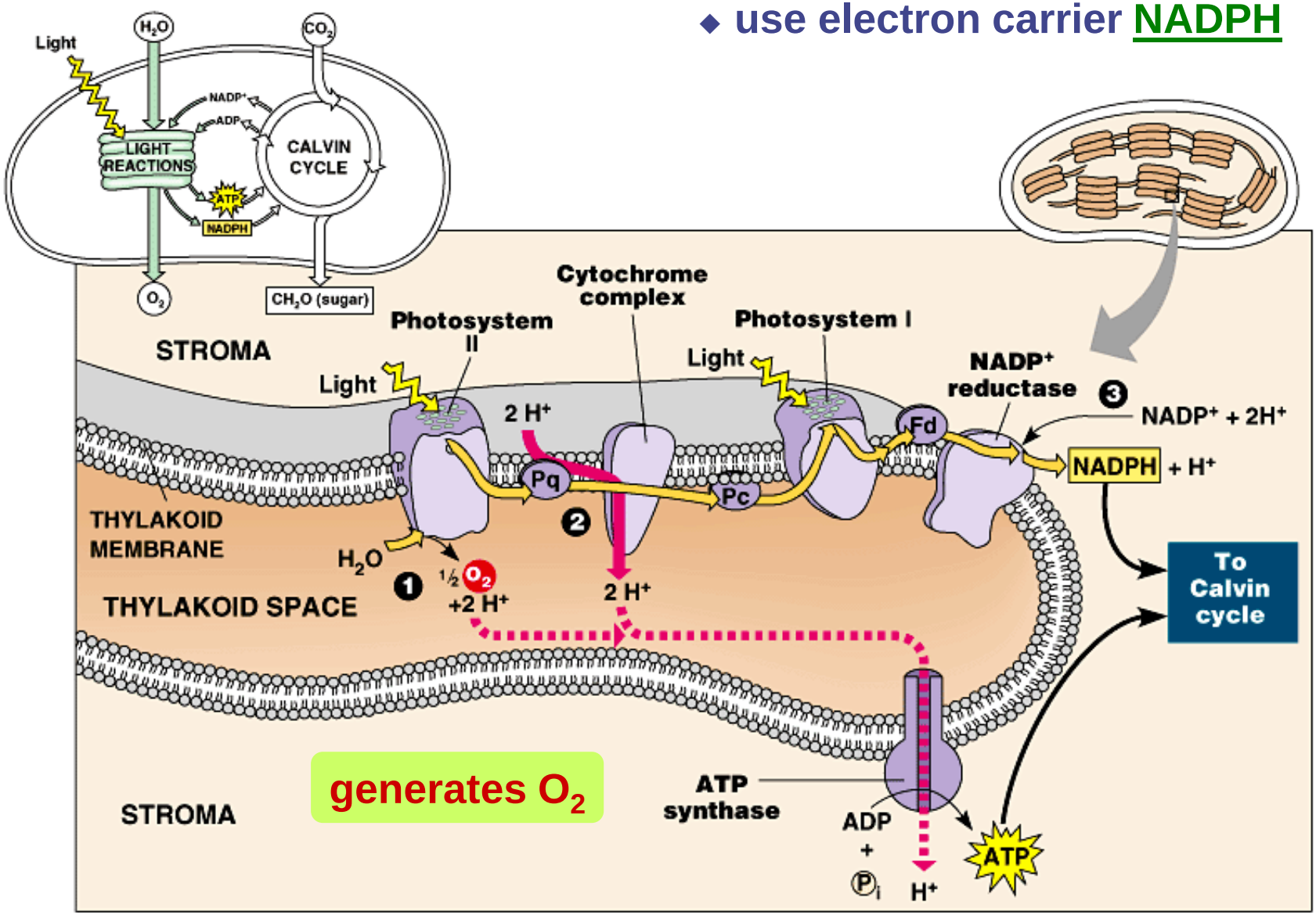
- use electron carrier NADH



ETC of Photosynthesis

Chloroplasts transform light energy into chemical energy of ATP

- use electron carrier **NADPH**



The ATP that "Jack" built

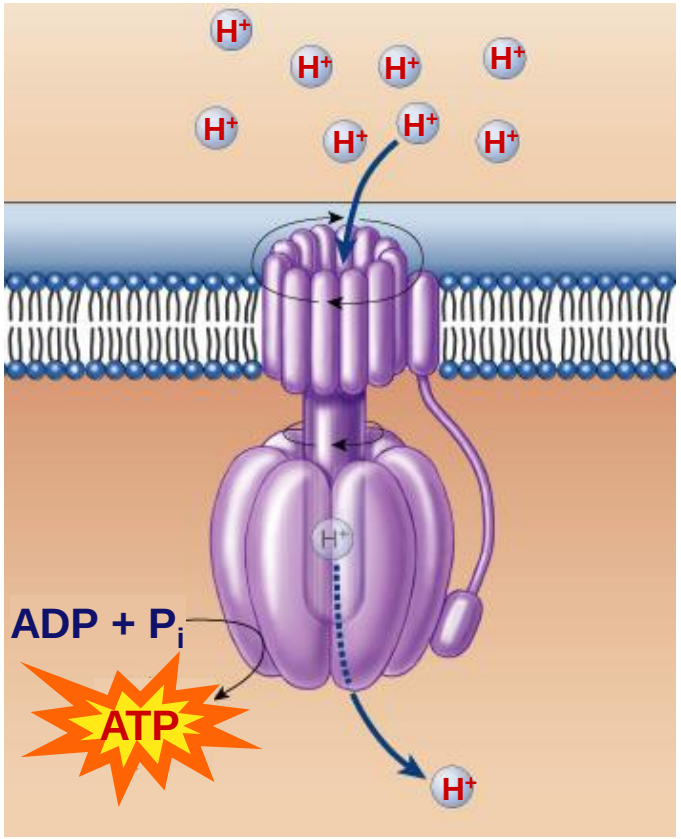
photosynthesis

sunlight

respiration

breakdown of $C_6H_{12}O_6$

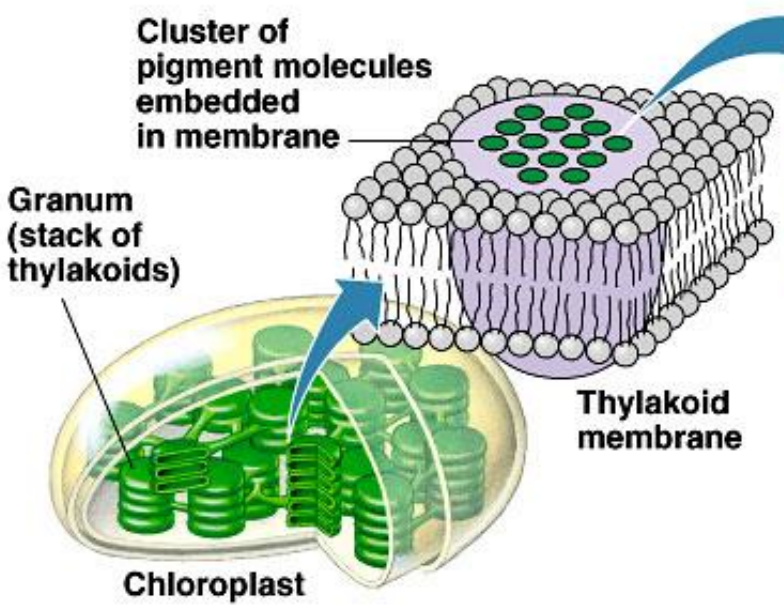
- moves the electrons
- runs the pump
- pumps the protons
- builds the gradient
- drives the flow of protons through ATP synthase
- bonds P_i to ADP
- generates the ATP

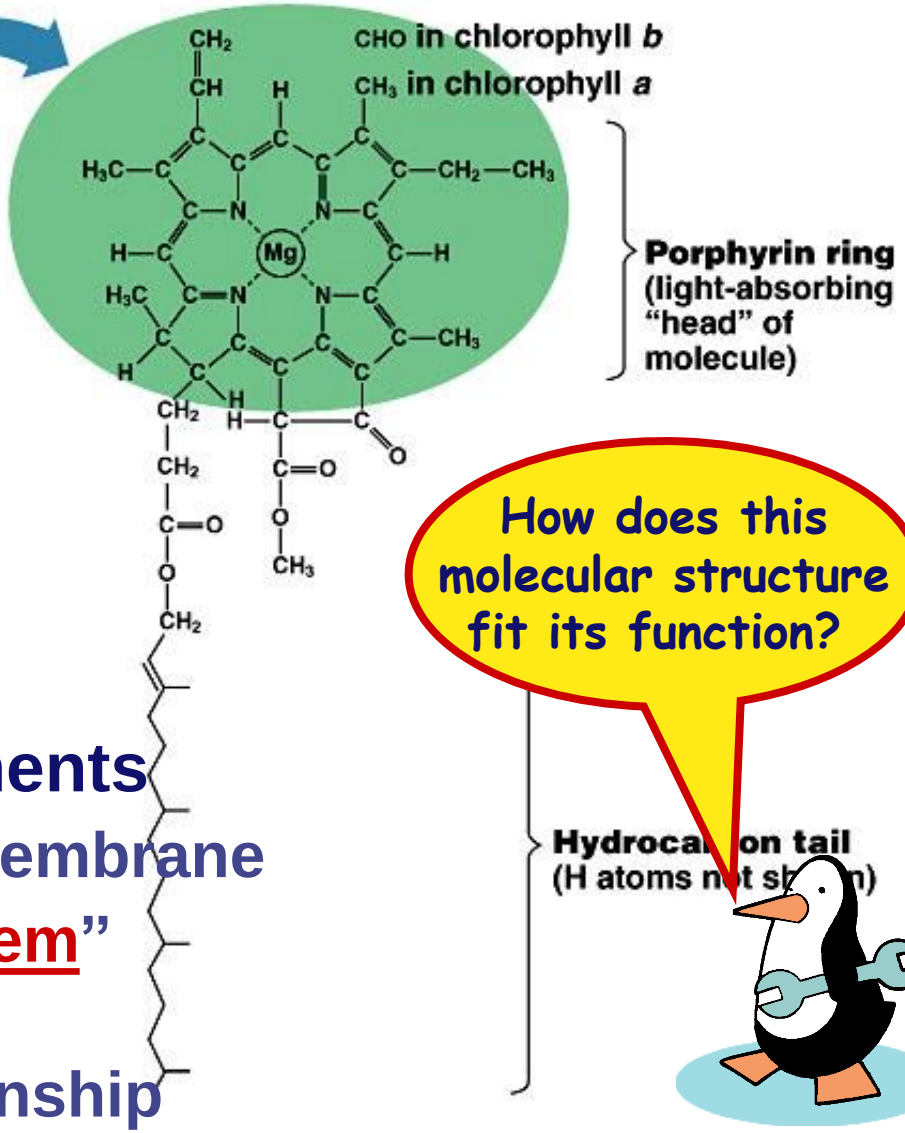


AP

… that evolution built

Pigments of photosynthesis



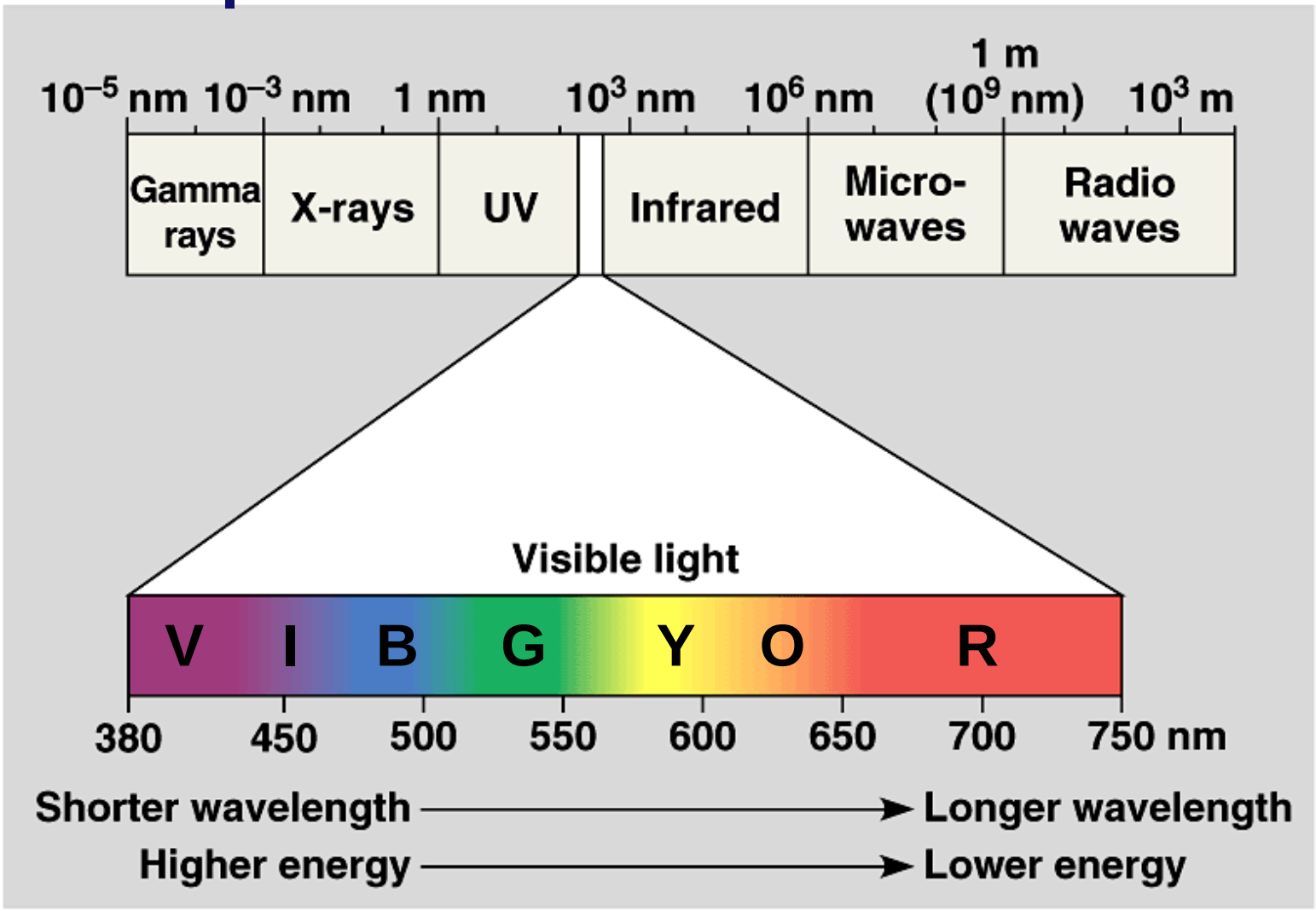


How does this molecular structure fit its function?

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

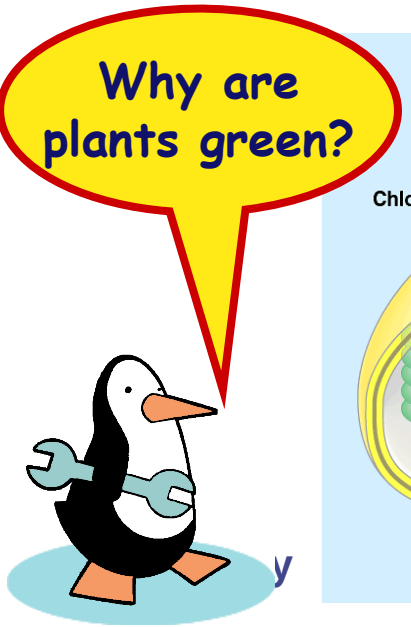
A Look at Light

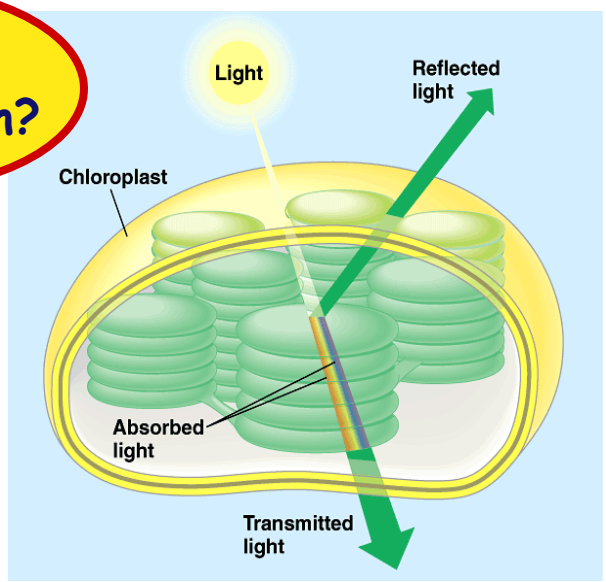
- The spectrum of color

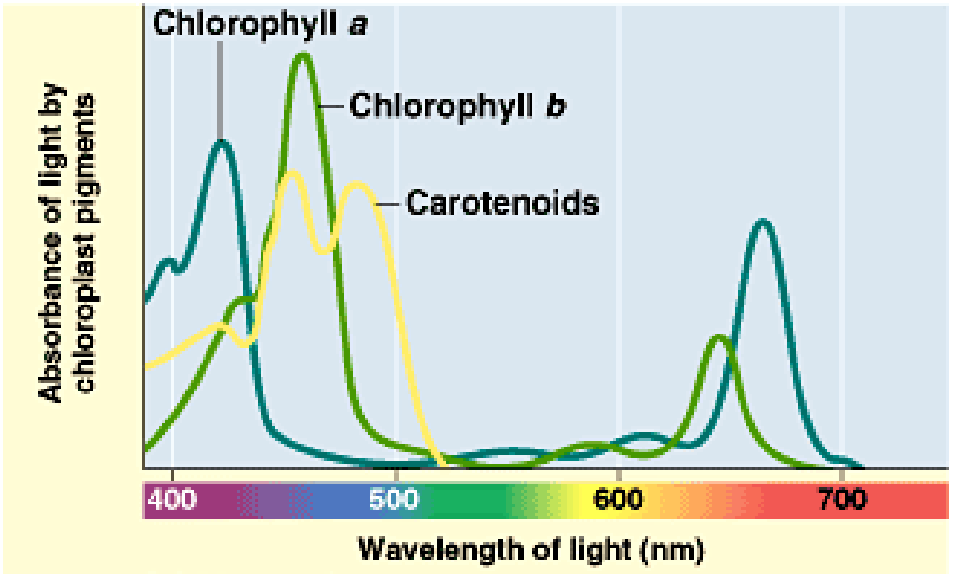


Light: absorption spectra

- Photosynthesis gets energy by absorbing wavelengths of light
  - chlorophyll *a*
    - absorbs best in red & blue wavelengths & least in green
  - accessory pigments with different structures absorb light of different wavelengths
    - chlorophyll b, carotenoids, xanthophylls

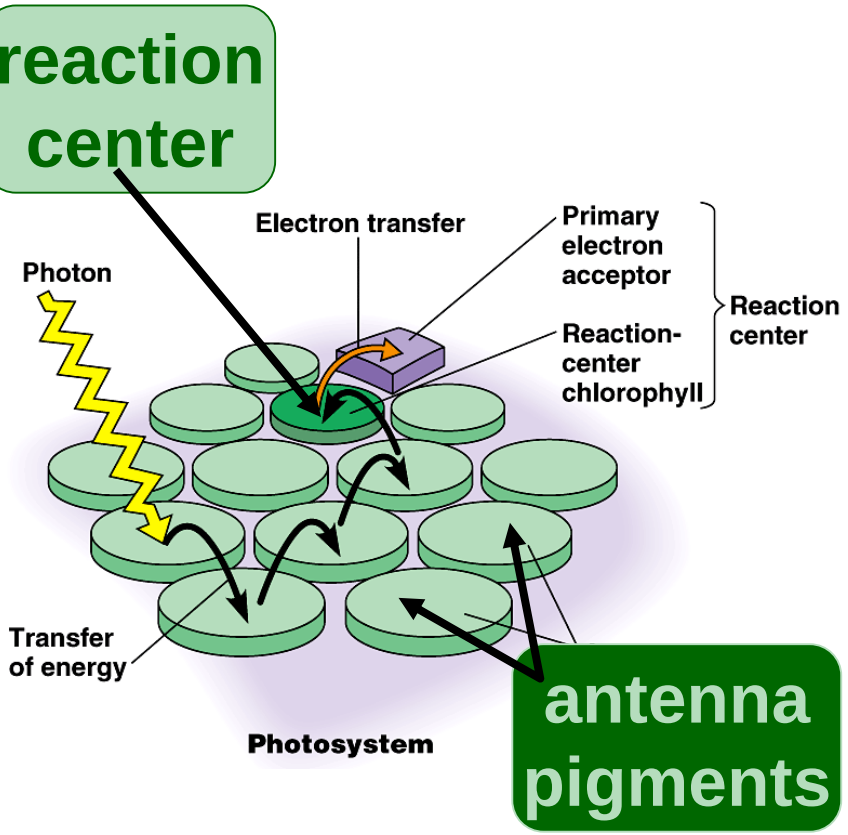




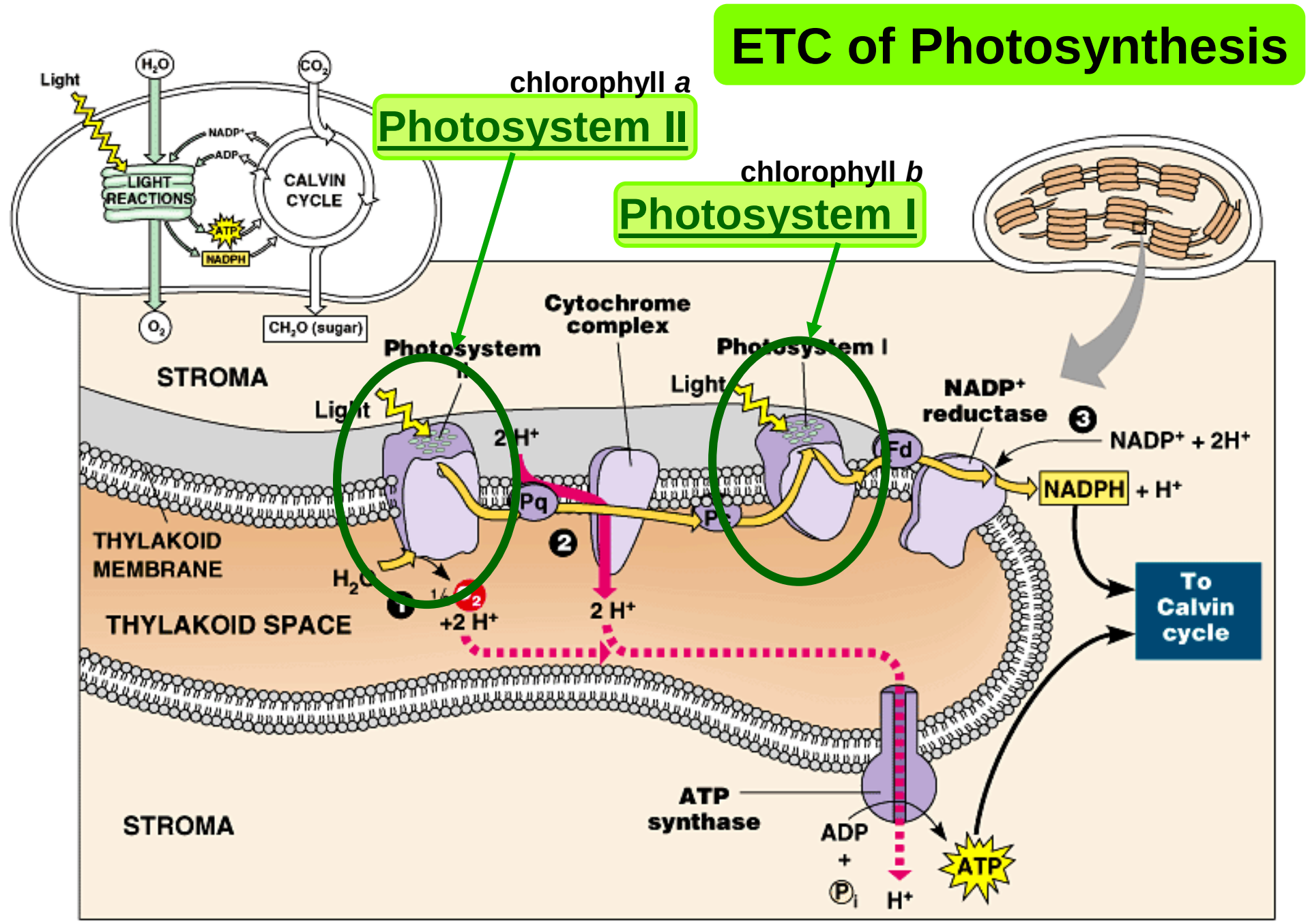


Photosystems of photosynthesis

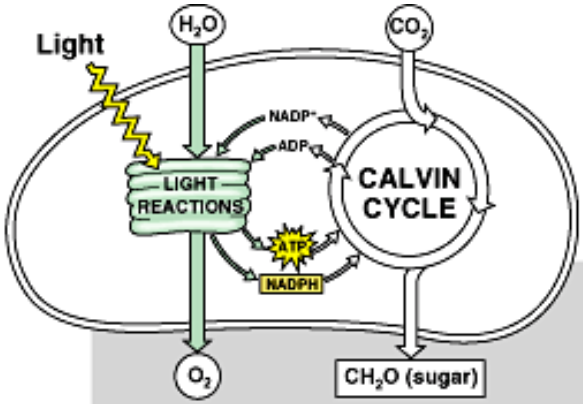
- 2 photosystems in thylakoid membrane
  - collections of chlorophyll molecules
  - act as light-gathering molecules
  - **Photosystem II**
    - chlorophyll *a*
    - P_{680} = absorbs 680nm wavelength red light
  - **Photosystem I**
    - chlorophyll *b*
    - P_{700} = absorbs 700nm wavelength red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

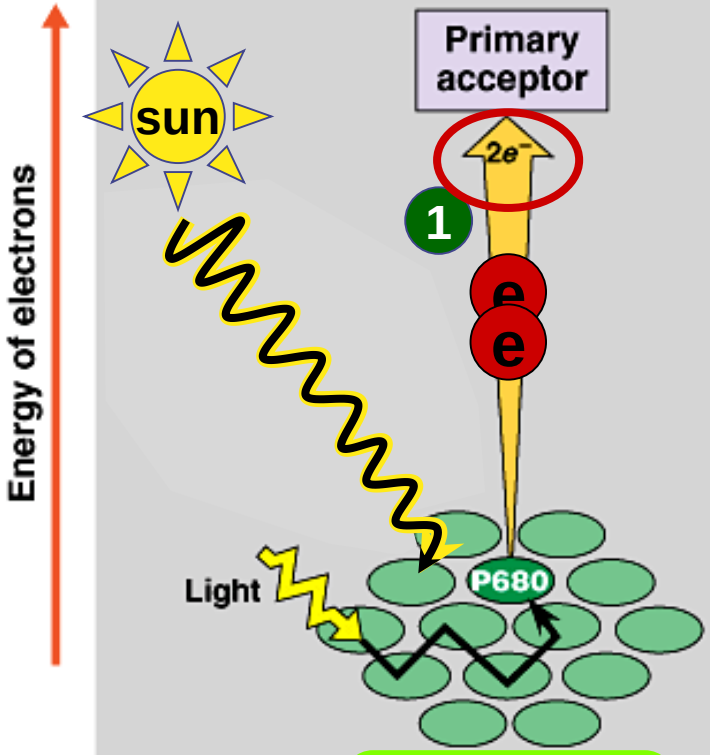


ETC of Photosynthesis



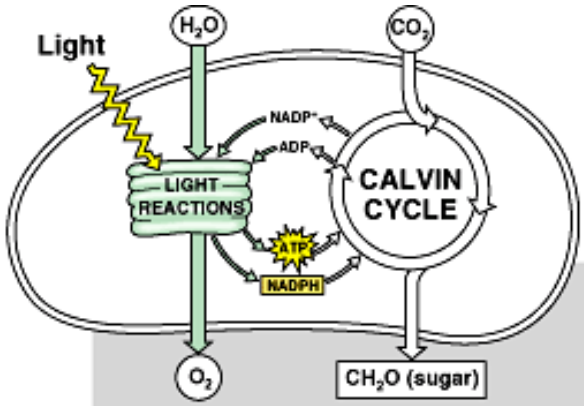
ETC of Photosynthesis



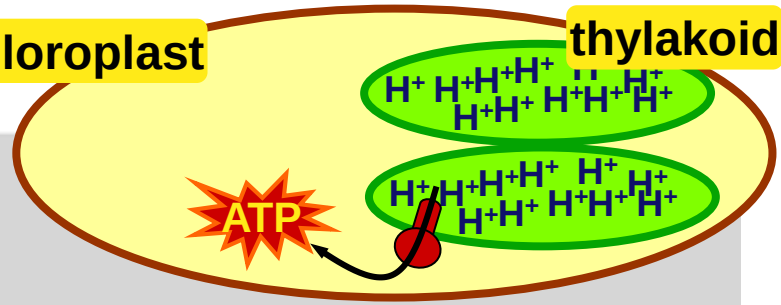


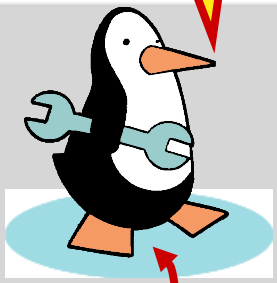
Photosystem II
P680
chlorophyll a

ETC of Photosynthesis



Inhale, baby!





Primary acceptor

Energy of electrons

2

Splitting of water releases oxygen

1

$2e^-$

$2\ H^+ + \frac{1}{2}\ O_2$

H_2O

$2e^-$

Light

P680

e e e e

H_2O

O_2

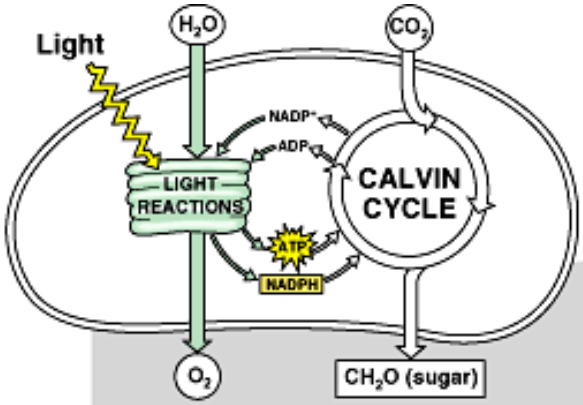
H_2

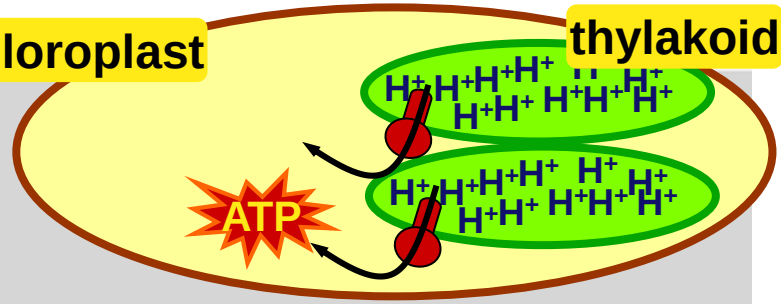
e^- e^-

H^+ H^+

Photosystem II
P680
chlorophyll a

ETC of Photosynthesis





Energy of electrons

Primary acceptor

e e

2e⁻

1

2

Splitting of water releases oxygen

2 H⁺ + ½ O_2

H_2O

2e⁻

e e

Light

P680

Photosystem II
P680
chlorophyll a

H⁺

Pq

Cytochrome complex

Pc

Electron transport chain

3

4

H⁺

Electron energy to synthesis

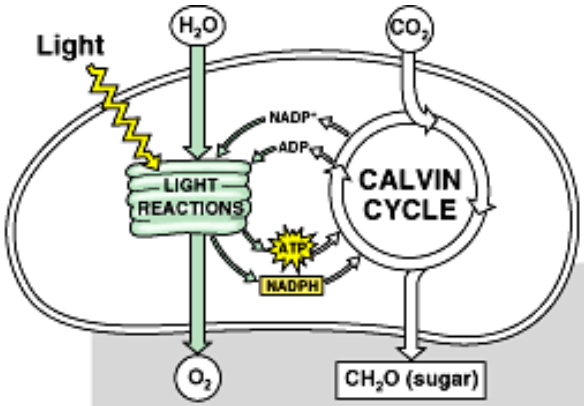
ATP

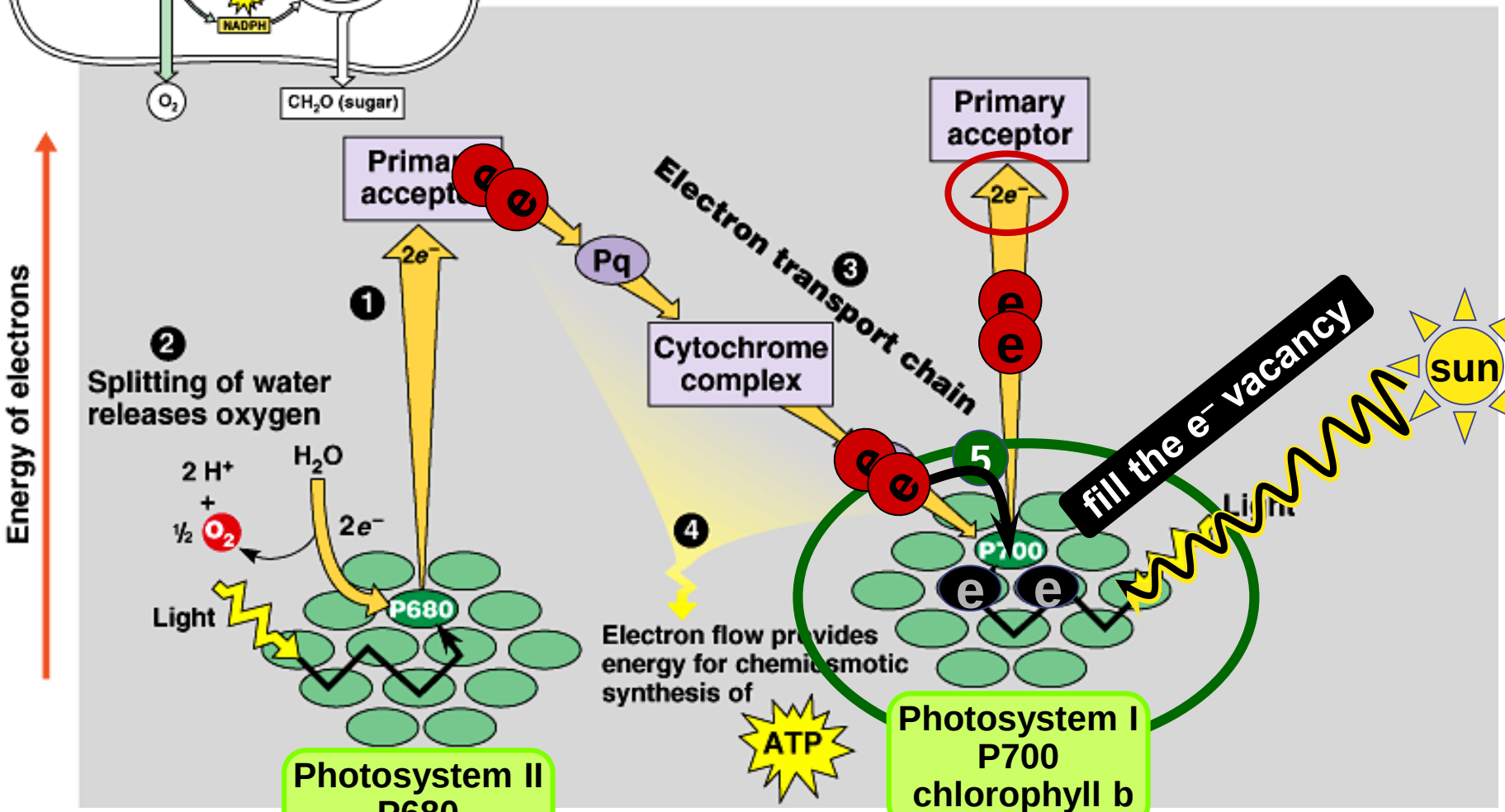
ATP

to Calvin Cycle

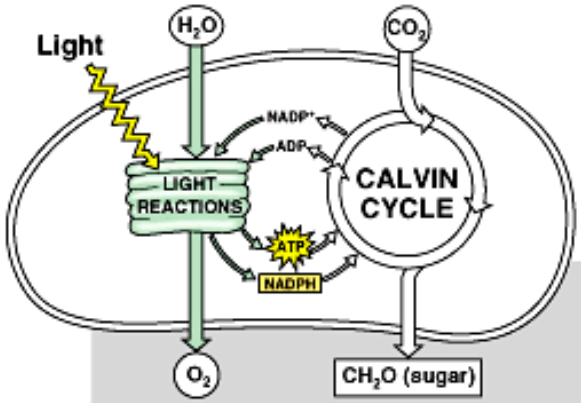
energy to build carbohydrates

ETC of Photosynthesis





ETC of Photosynthesis



electron carrier

Energy of electrons

Primary acceptor

Pq

Cytochrome complex

Pc

Primary acceptor

Fd

NADP+ reductase

NADP+ + 2 H+

NADPH

+ H+

Electron transport chain

Electron transport chain

❶ $2e^-$

❷ Splitting of water releases oxygen

2 H+ + ½ O_2

H_2O

$2e^-$

Light

P680

❸

❹ Electron flow provides energy for chemiosmotic synthesis of ATP

❺

P700

❻

$2e^-$

$2e^-$

e e e e

sun

NADPH to Calvin Cycle

Photosystem II P680 chlorophyll a

Photosystem I P700 chlorophyll b

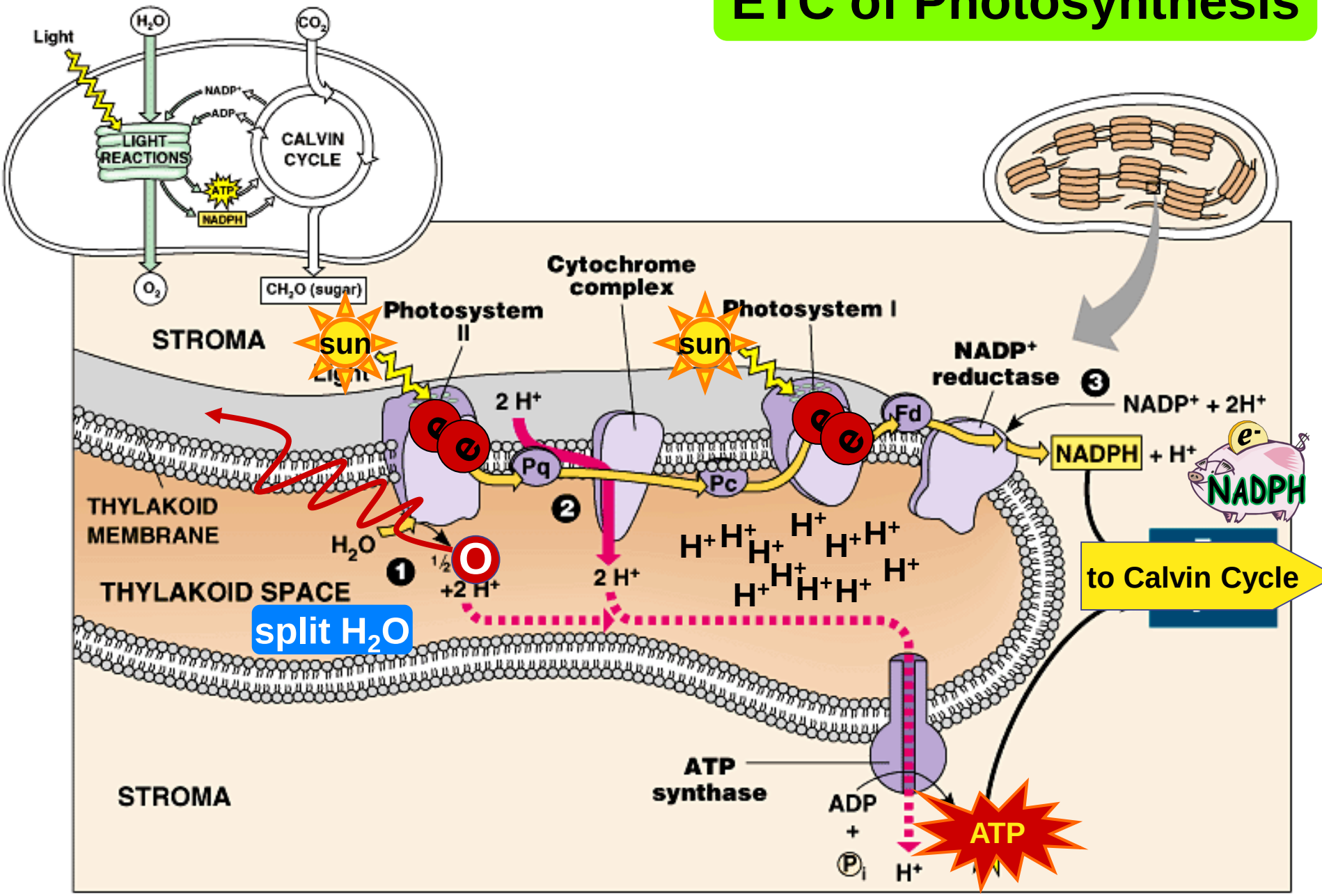
$$ in the bank… reducing power!

e-

NADPH

AP Biology

ETC of Photosynthesis



ETC of Photosynthesis

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

Experimental evidence

- Where did the O_2 come from?
  - radioactive tracer = O_{18}

Experiment 1

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

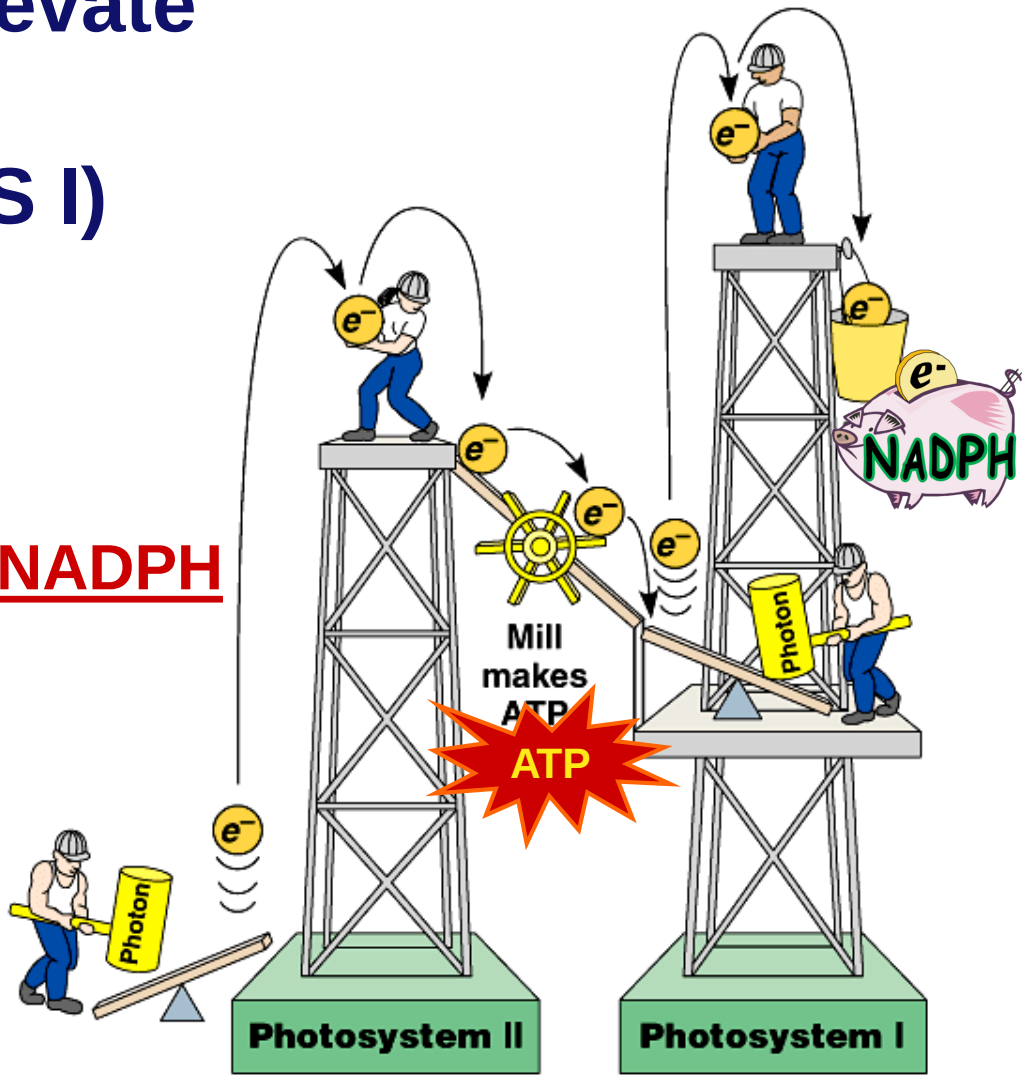
Experiment 2

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

Proved O_2 came from H_2O <u>not</u> CO_2 = plants split H_2O*!*

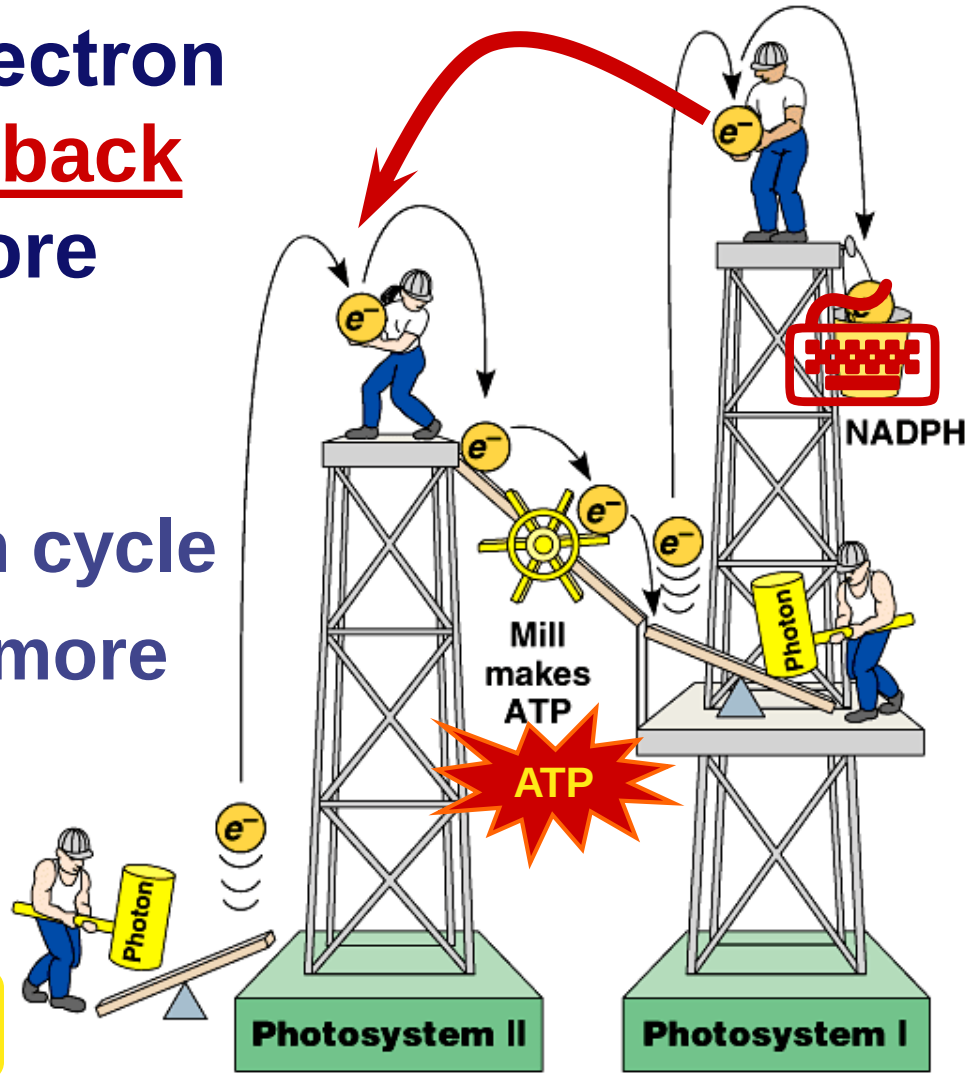
Noncyclic Photophosphorylation

- Light reactions elevate electrons in 2 steps (PS II & PS I)
  - PS II generates energy as ATP
  - PS I generates reducing power as NADPH



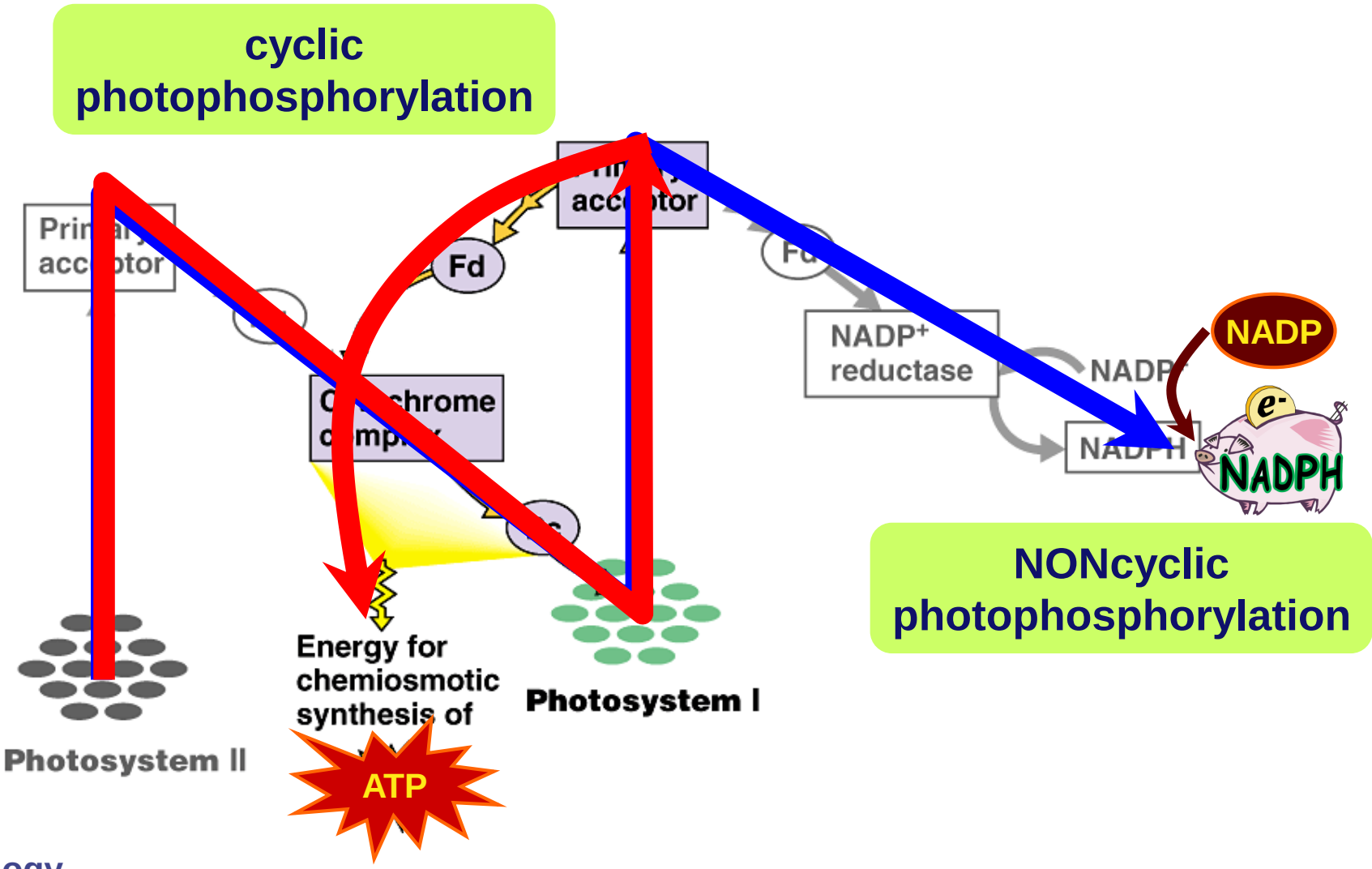
Cyclic photophosphorylation

- If PS I can't pass electron to NADP…it cycles back to PS II & makes more ATP, but no NADPH
  - coordinates light reactions to Calvin cycle
  - Calvin cycle uses more ATP than NADPH



18 ATP + 12 NADPH → 1 $C_6H_{12}O_6$

Photophosphorylation



Photosynthesis summary

- Where did the 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

You can grow if you Ask Questions!

Ghosts of Lectures Past (storage)

Stomates