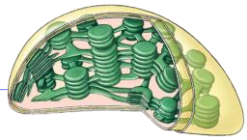
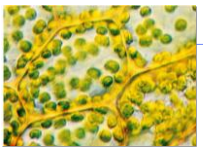


Photosynthesis: Life from Light and Air



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

ATP

glucose

CO_2 H_2O N K P …

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

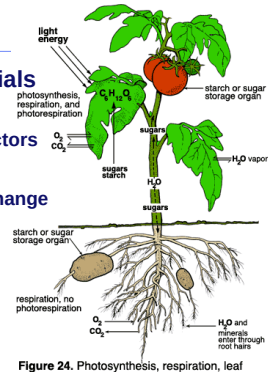
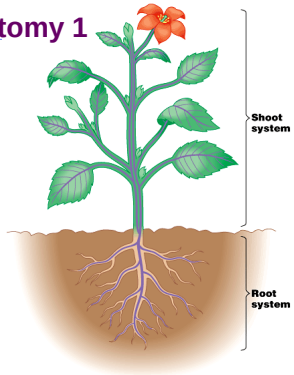


Figure 24. Photosynthesis, respiration, leaf water exchange, and translocation of sugar (photosynthate) in a plant.

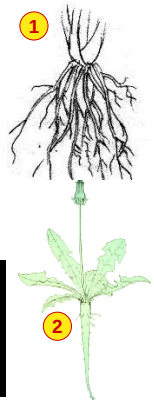
Basic plant anatomy 1

- root
  - root tip
  - root hairs



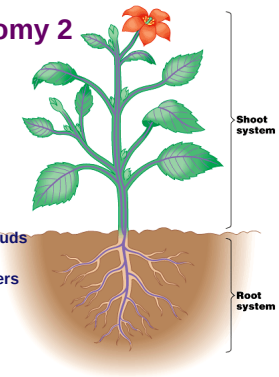
Roots

- Roots anchor plant in soil, absorb minerals & water, & store food
  - fibrous roots (1)
    - mat of thin roots that spread out
    - monocots
  - tap roots (2)
    - 1 large vertical root
    - also produces many small lateral, or branch roots
    - dicots
  - root hairs (3)
    - increase absorptive surface area



Basic plant anatomy 2

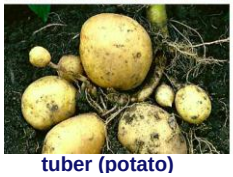
- root
  - root tip
  - root hairs
- shoot (stem)
  - nodes
    - internodes
  - buds
    - terminal or apical buds
    - axillary buds
    - flower buds & flowers



Modified shoots

stolons (strawberries)

rhizome (ginger)

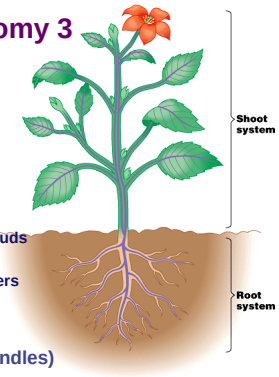


tuber (potato)

bulb (onion)

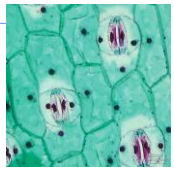
Basic plant anatomy 3

- root
  - root tip
  - root hairs
- shoot (stem)
  - nodes
    - internodes
  - buds
    - terminal or apical buds
    - axillary buds
    - flower buds & flowers
- leaves
  - mesophyll tissue
  - veins (vascular bundles)

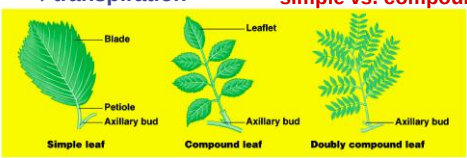


Leaves

- Function of leaves
  - photosynthesis
    - energy production
    - CHO production
  - gas exchange
  - transpiration



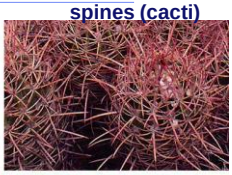
simple vs. compound



Modified leaves

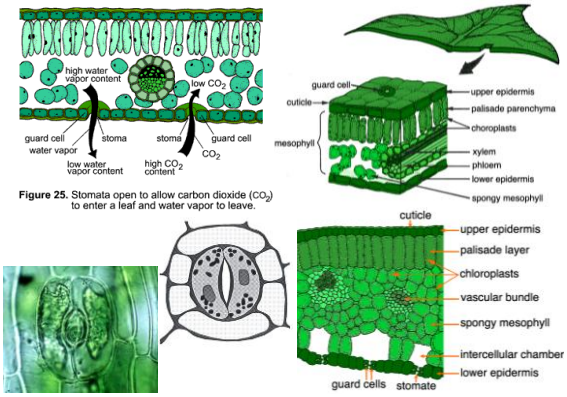
tendrils (peas)

spines (cacti)



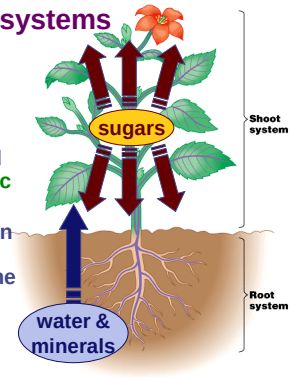
succulent leaves

colored leaves (poinsetta)



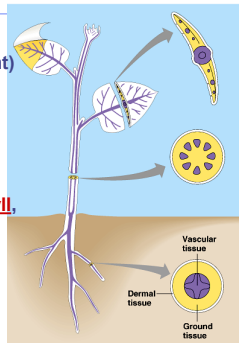
Interdependent systems

- Both systems depend on the other
  - roots depend on sugars produced by photosynthetic leaves
  - shoots depend on water & minerals absorbed from the soil by roots



Plant TISSUES

- Dermal
  - epidermis ("skin" of plant)
  - single layer of tightly packed cells that covers & protects plant
- Ground
  - bulk of plant tissue
  - photosynthetic mesophyll, storage
- Vascular
  - transport system in shoots & roots
  - xylem & phloem

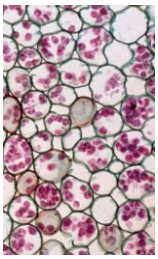


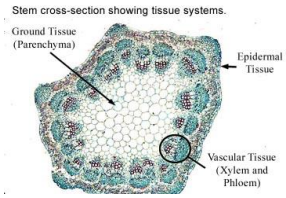
Plant CELL types in plant tissues

- Parenchyma
  - "typical" plant cells = least specialized
  - photosynthetic cells, storage cells
  - tissue of leaves, stem, fruit, storage roots
- Collenchyma
  - unevenly thickened primary walls
  - support
- Sclerenchyma
  - very thick, "woody" secondary walls
  - support
  - rigid cells that can't elongate
  - dead at functional maturity

Parenchyma

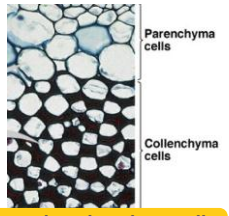
- Parenchyma cells are unspecialized, thin, flexible & carry out many metabolic functions
  - all other cell types in plants develop from parenchyma





Collenchyma

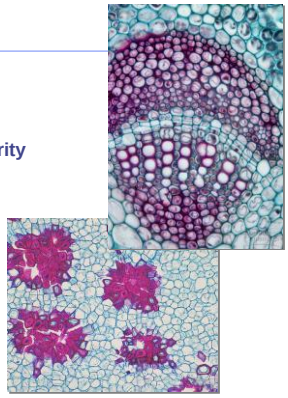
- Collenchyma cells have thicker primary walls & provide support
  - help support without restraining growth
  - remain alive in maturity



the strings in celery stalks are collenchyma

Sclerenchyma

- Thick, rigid cell wall
  - lignin (wood)
  - cannot elongate
  - mostly dead at maturity
- Cells for support
  - xylem vessels
  - xylem tracheids
  - fibers
    - rope fibers
  - sclereids
    - nutshells
    - seed coats
    - grittiness in pears



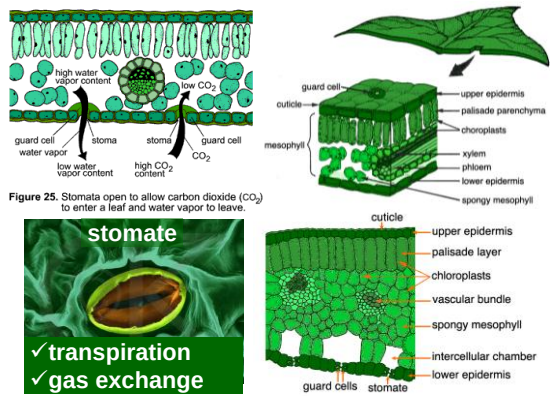
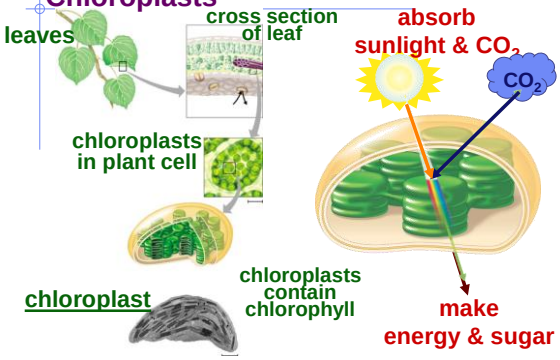
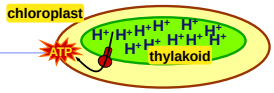


Figure 25. Stomata open to allow carbon dioxide (CO_2) to enter a leaf and water vapor to leave.

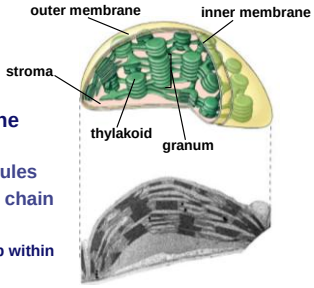
Chloroplasts



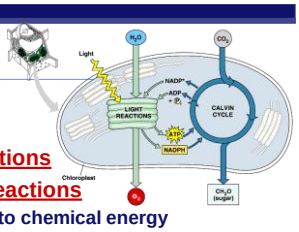
Plant structure



- 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



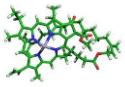
Photosynthesis

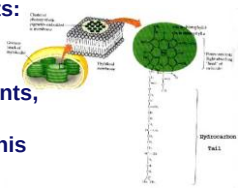


- Light reactions
  - light-dependent reactions
  - energy conversion reactions
    - convert solar energy to chemical energy
    - ATP & NADPH
- Calvin cycle
  - light-independent reactions
  - sugar building reactions
    - uses chemical energy (ATP & NADPH) to reduce CO_2 & synthesize $C_6H_{12}O_6$

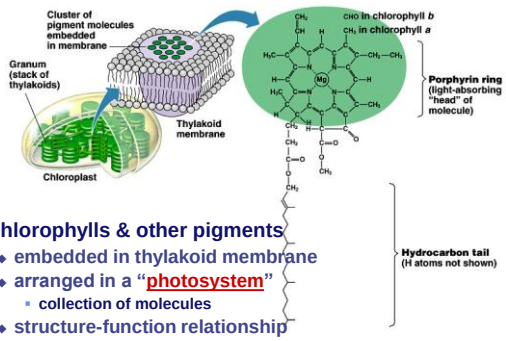
Photosynthesis Pigments

- Light energy has to be trapped by something in the plant cells
- Two main groups of photosynthetic pigments: Chlorophylls and Carotenoids
- Light energy hits pigments, excites electrons in pigments, and passes this energy through an ETC





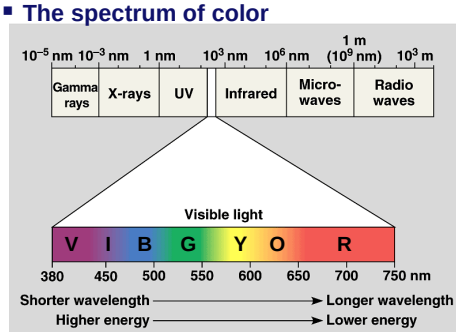
Pigments of photosynthesis



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

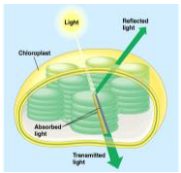
A Look at Light

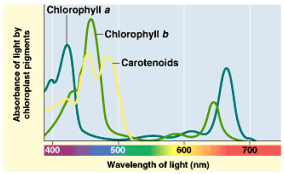
- The spectrum of color



Light: absorption spectra

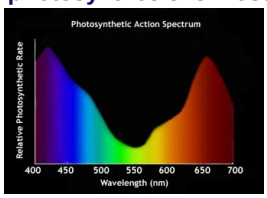
- Photosynthesis gets energy by absorbing wavelengths of light
  - chlorophyll *a*
    - absorbs best in red & blue wavelengths & least in green
  - accessory pigments with different structures absorb light of different wavelengths
    - chlorophyll b, carotenoids, xanthophylls



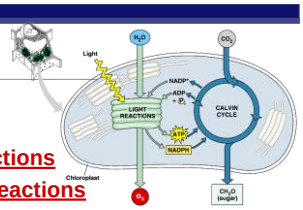


Light: action spectra

- While absorption spectra show everywhere light is absorbed by a given pigment…
- Action spectra are graphs that show where photosynthesis is most efficient

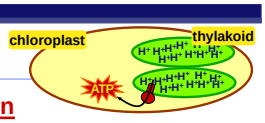


Photosynthesis

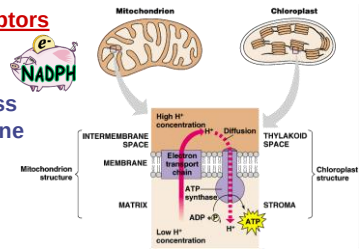


- Light reactions
  - light-dependent reactions
  - energy conversion reactions
    - convert solar energy to chemical energy
    - ATP & NADPH
- Calvin cycle
  - light-independent reactions
  - sugar building reactions
    - uses chemical energy (ATP & NADPH) to reduce CO_2 & synthesize $C_6H_{12}O_6$

Light reactions



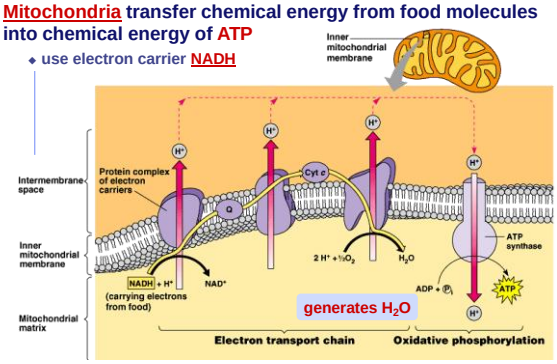
- **Electron Transport Chain**
  - like in cellular respiration
  - proteins in organelle membrane
  - electron acceptors
    - NADPH
  - proton (H^+) gradient across inner membrane
  - ATP synthase enzyme



ETC of Respiration

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

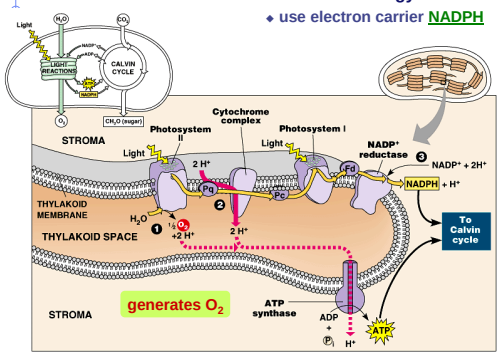
- use electron carrier NADH



ETC of Photosynthesis

Chloroplasts transform light energy into chemical energy of ATP

- use electron carrier NADPH

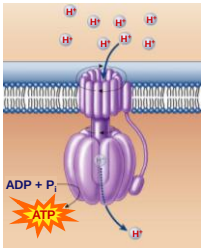


ATP Building

photosynthesis: **sunlight**

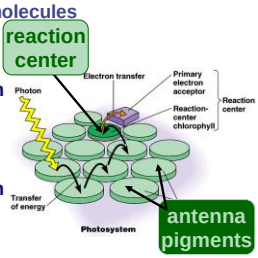
respiration: **breakdown of $C_6H_{12}O_6$**

- 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

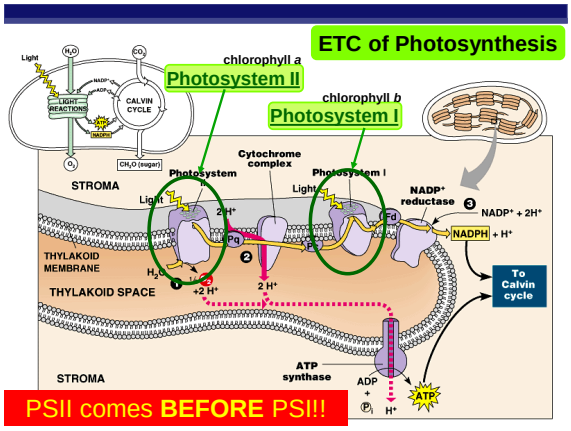


Photosystems of photosynthesis

- 2 photosystems in thylakoid membrane = most efficient way to harness energy
  - 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



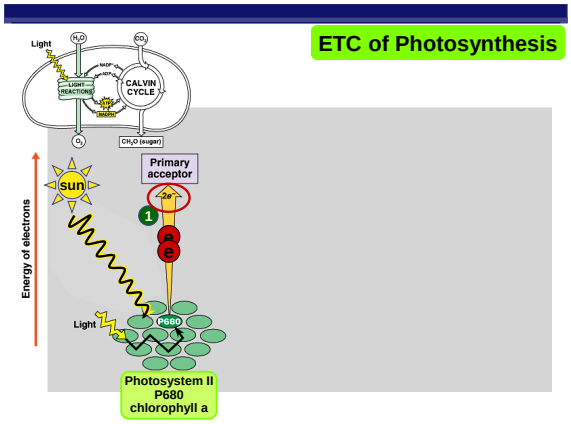
ETC of Photosynthesis

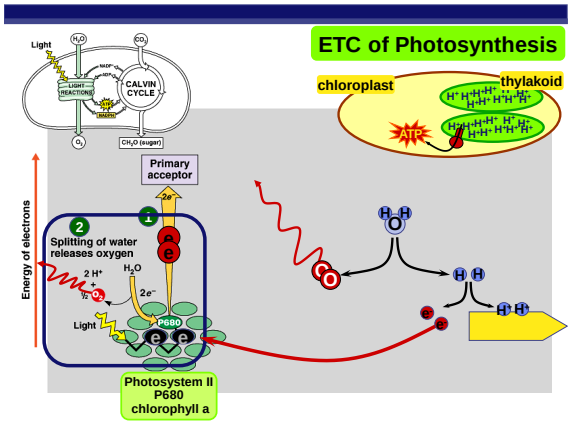


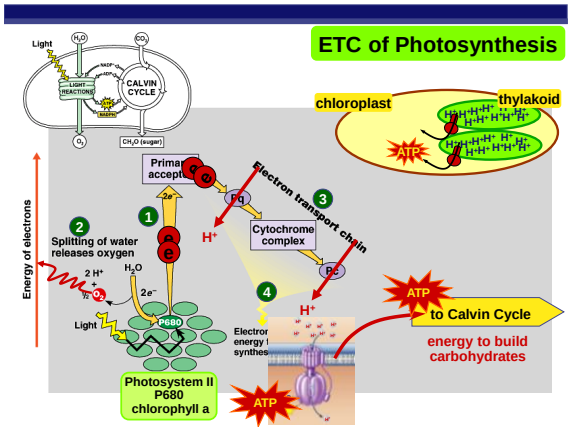
PSII comes **BEFORE** PSI!!

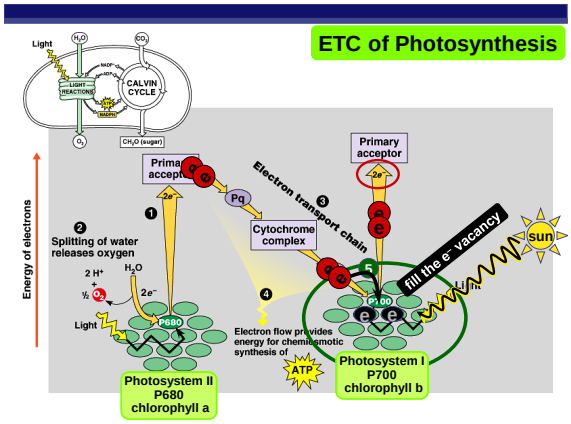
ETC of Photosynthesis

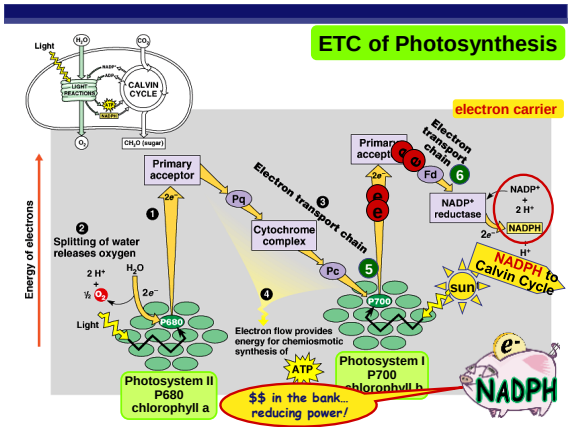
- ETC uses light energy to produce
  - ATP & NADPH
    - go to Calvin cycle (light-independent reactions)
- PS II absorbs light
  - excited electron passes from chlorophyll to "primary electron acceptor"
  - need to replace electron in chlorophyll
  - enzyme extracts electrons from H_2O & supplies them to chlorophyll
    - splits H_2O
    - O combines with another O to form O_2
    - O_2 released to atmosphere
    - Builds an H+ concentration gradient INSIDE the thylakoid sacs
    - and we breathe easier!



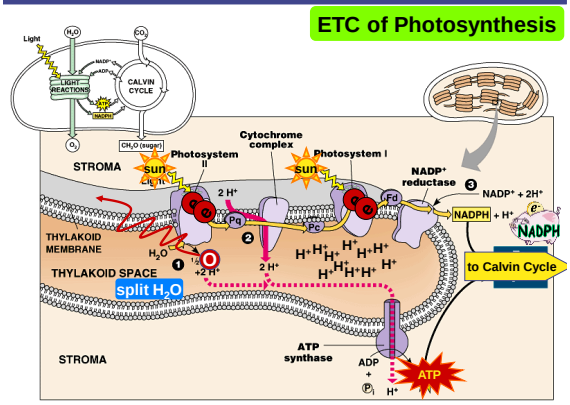








ETC of Photosynthesis



Experimental evidence

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

Experiment 1

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

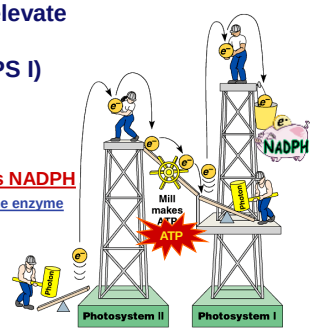
Experiment 2

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

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

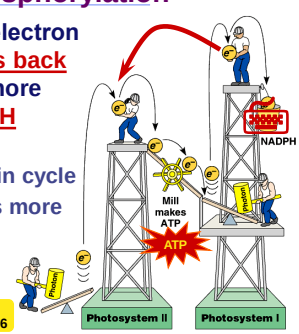
Noncyclic Photophosphorylation

- Light reactions elevate electrons in 2 steps (PS II & PS I)
  - PS II generates energy as ATP
  - PS I generates reducing power as NADPH
    - Does this through the enzyme NADP reductase



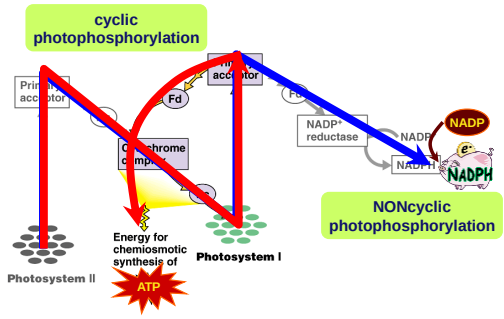
Cyclic photophosphorylation

- 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



- Detailed Overview: http://www.youtube.com/watch?v=hj_WKgnL6MI
- Fun: http://www.youtube.com/watch?v=x-t0sGyjfto

Photosynthesis Light Rxns summary: Answer on your own paper and turn in!

- 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