Warm-up

- **Objective:**
  - Explain how photosynthesis converts light energy into chemical energy.
- **Warm-up:**
  - In the light reactions, what is the electron donor? Where do the electrons end up?

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)**
    - get their energy from "self"
    - get their energy from sunlight
    - build organic molecules (food) from CO_2
    - make energy & synthesize sugars through photosynthesis

Energy needs of life

- **Heterotrophs**
  - consumers
  - animals
  - fungi
  - most bacteria
- **Autotrophs**
  - producers
  - plants
  - photosynthetic bacteria (blue-green algae)

How are they connected?

Heterotrophs

making energy & organic molecules from ingesting organic molecules

glucose + oxygen → carbon dioxide + water + energy

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

exergonic

Autotrophs

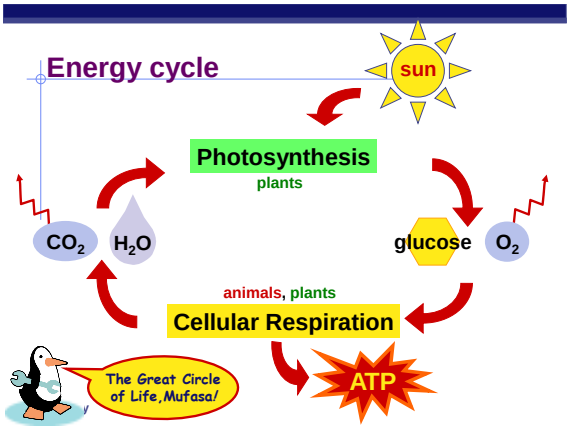
making energy & organic molecules from light energy

carbon dioxide + water + energy → glucose + oxygen

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

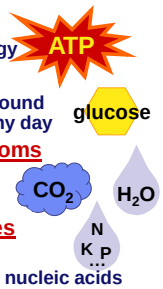
endergonic

Energy cycle



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 & also saved for a rainy day
  - 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

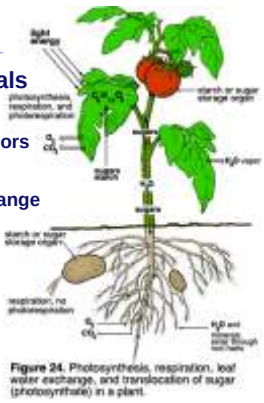
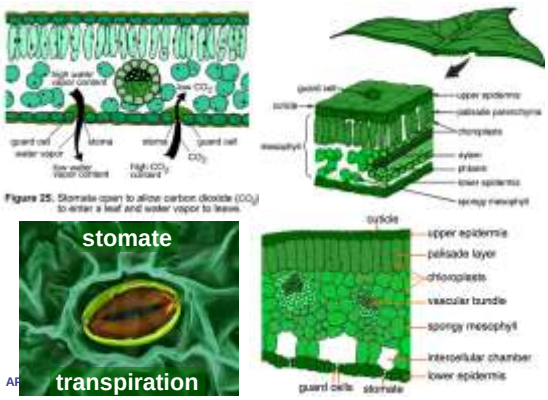
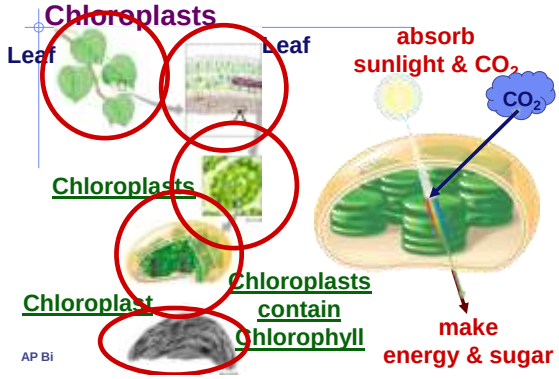


Figure 24. Photosynthesis, respiration, leaf water exchange, and translocation of sugar (photosynthate) in a plant.

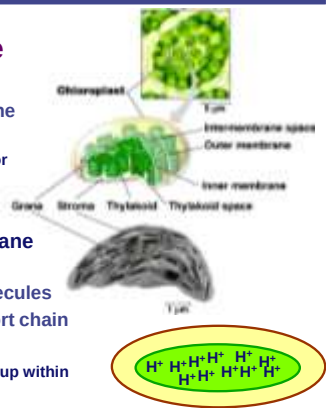


Chloroplasts



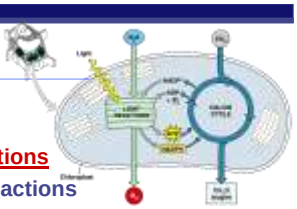
Plant structure

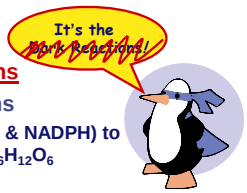
- Chloroplasts
  - double membrane
  - stroma
    - fluid-filled interior
  - thylakoid sacs
  - grana stacks
- Thylakoid membrane contains
  - chlorophyll molecules
  - electron transport chain
  - ATP synthase
    - H^+ gradient built up within thylakoid sac



Photosynthesis

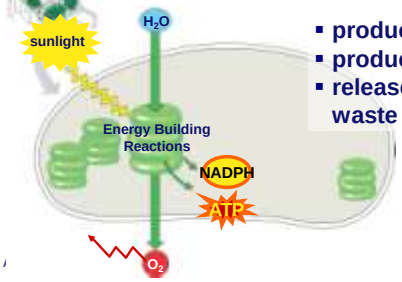
- Light reactions
  - light-dependent reactions
  - energy production reactions
    - convert solar energy to chemical energy
    - ATP & NADPH
- Calvin cycle
  - light-independent reactions
  - sugar production reactions
    - uses chemical energy (ATP & NADPH) to reduce CO_2 & synthesize $C_6H_{12}O_6$





Light Reactions

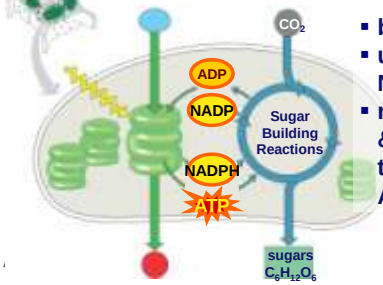
H_2O + light energy → ATP + NADPH + O_2



- produces ATP
- produces NADPH
- releases O_2 as a waste product

Calvin Cycle

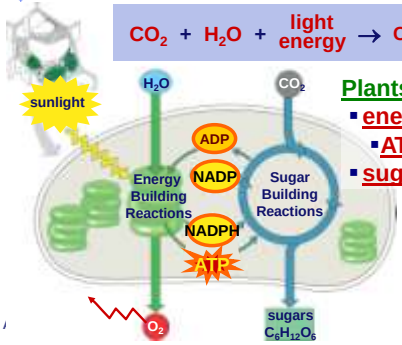
CO_2 + ATP + NADPH → $C_6H_{12}O_6$ + ADP + NADP



- builds sugars
- uses ATP & NADPH
- recycles ADP & NADP back to make more ATP & NADPH

Putting it all together

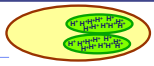
CO_2 + H_2O + light energy → $C_6H_{12}O_6$ + O_2



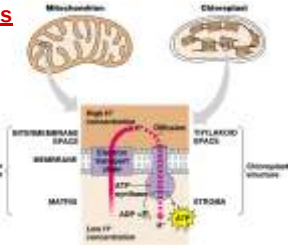
Plants make both:

- energy
- ATP & NADPH
- sugars

Light reactions



- Electron Transport Chain
  - like in cellular respiration
  - membrane-bound proteins in organelle
  - electron acceptors
    - NADPH
  - proton (H^+) gradient across inner membrane
    - Where's the double membrane?
  - ATP synthase enzyme

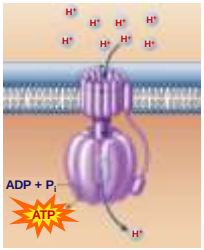


The ATP …..

photosynthesis: **sunlight** → moves the electrons

respiration: **breakdown of $C_6H_{12}O_6$** → runs the pump

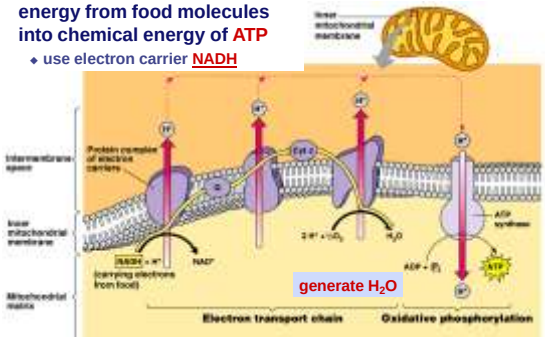
- moves the electrons
- runs the pump
- pumps the protons
- forms the gradient
- drives the flow of protons through ATP synthase
- attaches P_i to ADP
- forms the ATP



… that evolution built

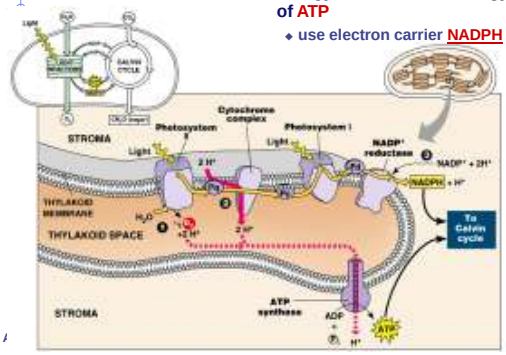
ETC of Respiration

- Mitochondria transfer chemical energy from food molecules into chemical energy of ATP
  - use electron carrier NADH

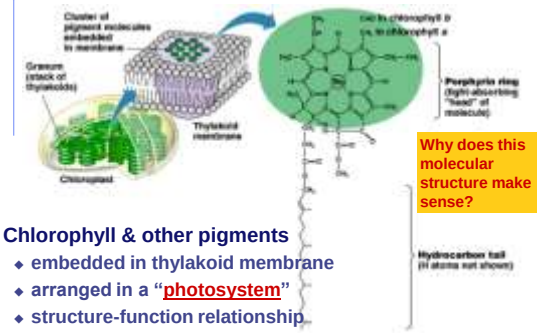


ETC of Photosynthesis

- Chloroplasts transform light energy into chemical energy of ATP
  - use electron carrier NADPH



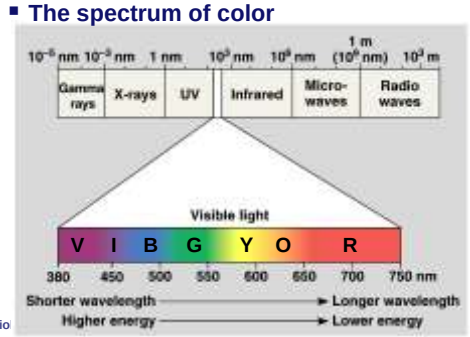
Pigments of photosynthesis



- Chlorophyll & other pigments
  - embedded in thylakoid membrane
  - arranged in a "photosystem"
  - structure-function relationship

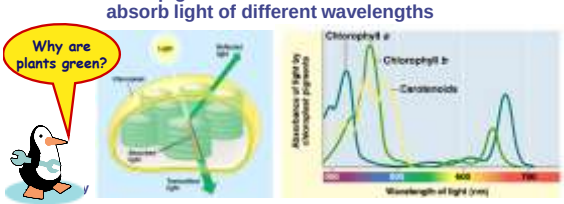
A Look at Light

- The spectrum of color



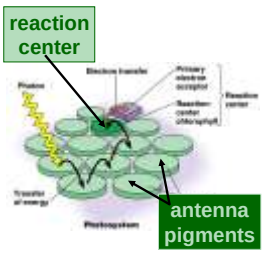
Light: absorption spectra

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

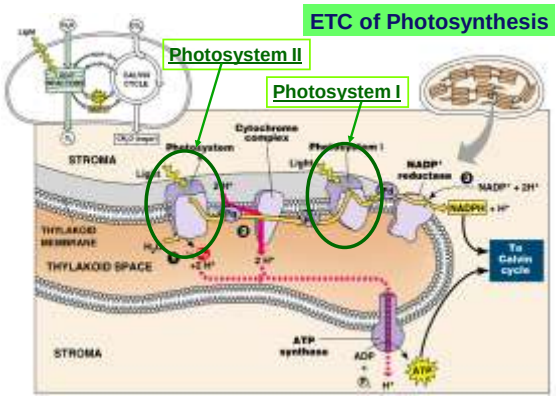


Photosystems of photosynthesis

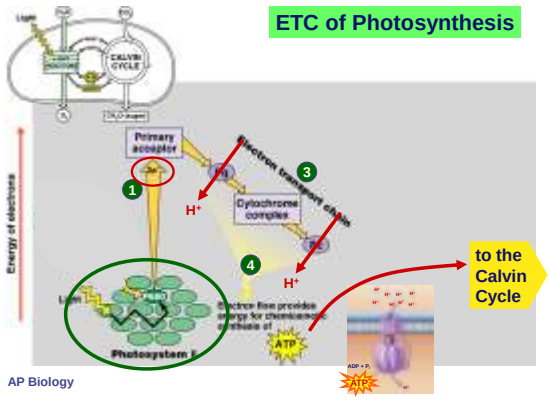
- 2 photosystems in thylakoid membrane
  - collections of chlorophyll molecules
  - act as light-gathering "antenna complex"
  - Photosystem II
    - chlorophyll *a*
    - P_{680} = absorbs 680nm wavelength red light
  - Photosystem I
    - chlorophyll *b*
    - P_{700} = absorbs 700nm wavelength red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



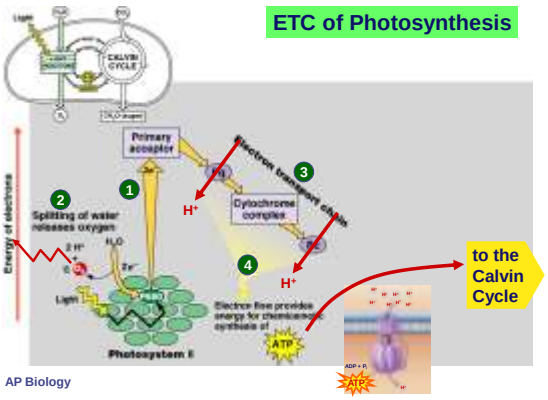
ETC of Photosynthesis



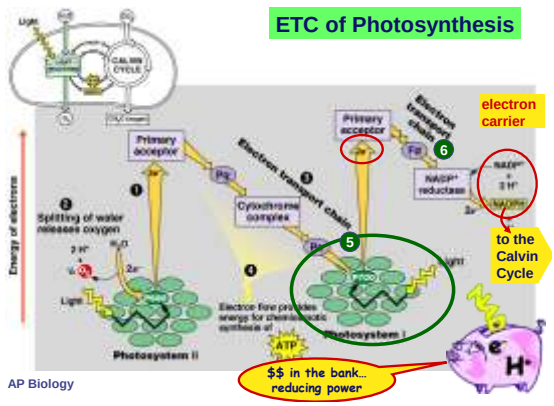
ETC of Photosynthesis



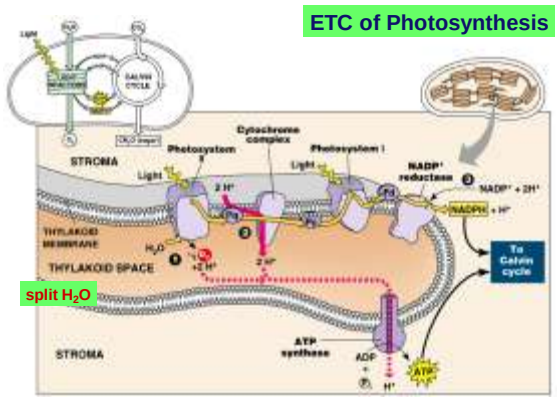
ETC of Photosynthesis



ETC of Photosynthesis



ETC of Photosynthesis



ETC of Photosynthesis

- ETC produces from light energy
  - 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

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

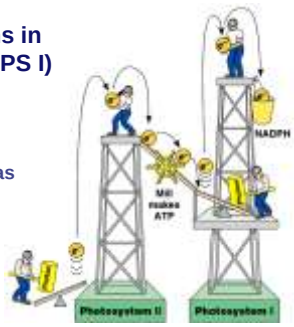
Experiment 2

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

Proved O_2 came from H_2O not CO_2 = plants split H_2O

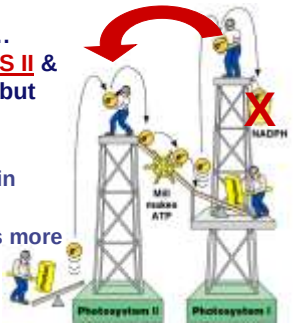
Noncyclic Photophosphorylation

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



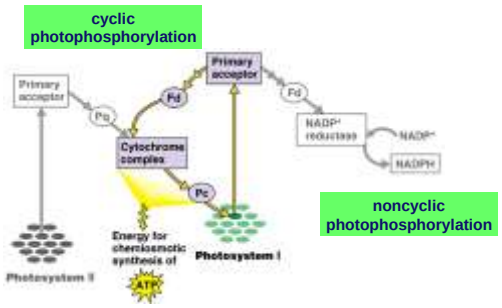
Cyclic photophosphorylation

- 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



Photophosphorylation

cyclic photophosphorylation



noncyclic 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

Any Questions??

Stomates