1 # Photosynthesis

2 ## Nutritional Modes

- chemoautotrophs
- Photoautotrophs
- Heterotrophs
- Autoheterotrophs

3 ## Chloroplast Structure

- A typical mesophyll cell has 30-40 chloroplasts, each about 2-4 microns by 4-7 microns long
- Intermembrane space
- Thylakoids: sacs w lumen
- Stroma
- Chlorophyll inside the thylakoids

4 ## Leaf Structure & Orientation

- Palisade layer (mesophyll)
- Spongy mesophyll
- Vascular bundle
- Stomata
- Plant hormones allow leaf to orient to light
- Plant habit determines leaf arrangement

5 ## Electromagnetic Energy

- Wave particle duality
- All wavelengths radiated
- Photosynthetic pigments are receptors
- Chlorophyll a, chlorophyll b, carotenoids
- Ground state and excited state and thresholds
- 700 and 680

6

- The entire range of electromagnetic radiation is the **electromagnetic spectrum**.
- The most important segment for life is a narrow band between 380 to 750 nm, **visible light**.

7

- When light meets matter, it may be reflected, transmitted, or absorbed.
  - Different pigments absorb photons of different wavelengths.
  - A leaf looks green because chlorophyll, the dominant pigment, absorbs red and blue

light, while transmitting
and reflecting green
light.

8 Photosynthesis Equations

- $6CO_2$ + $12H_2O$ + EM energy→ $C_6H_{12}O_6$ + $6O_2$ + $6H_2O$
- CO_2 + H_2O + EM energy→ CH_2O + O_2 Calvin cycle turns 6 x

9 Source of O_2 released

- Science as a process and technology
- Originally thought to be from CO2
- Van Neil studied sulfanogens and deduced that H source could vary, but H was required
- CO_2 + $2H_2S$ -> CH_2O + H_2O + 2S
- Labeled ^{18}O in water & it was released in air
- Labeled ^{18}O in CO2 & it bound in sugar & H_2O

10 Endergonic Process

- Energy is required to REDUCE CO2
- Light is energy source (some λ)
- Light boosts potential energy of e- as moved from water to sugar
- Water splits, transferring e- to CO2, reducing it to sugar, CH2O

11 Photosynthesis is a redox reaction

It reverses the direction of electron flow in respiration.

- Water is split and electrons transferred with H^+ from water to CO_2, reducing it to sugar.
  - Polar covalent bonds (unequal sharing) are converted to nonpolar covalent bonds (equal sharing).
  - Light boosts the potential energy of electrons as they move from water to sugar.

12 Redox Reaction

13 Light Reactions

- Convert light energy to chemical bond energy in ATP and NADPH
- Occur in thylakoid membranes
- light energy absorbed by chlorophyll in the thylakoids drives the transfer of electrons and hydrogen from water to **$NADP^+$** (nicotinamide adenine dinucleotide phosphate), forming NADPH.
- NADPH, an electron acceptor, provides energized electrons, reducing power, to the Calvin cycle.
- Give off O2 as byproduct
- Generate ATP
- PHOTOPHOSPHORYLATION

14 Overview Photosynthesis

15 Calvin Cycle

- C fixation rx that reduce CO2 to carbohydrate
- Occur in the stroma
- Incorporate atmospheric CO2 into existing organic molecules by C fixation
- Reduction of CO2 to sugar require **products** of light rx, not light
- NADPH provides the reducing power
- ATP provides the chemical energy

16 Junction between light and Calvin

- Light rx in thylakoids of chloroplasts
- Calvin cycle rx occur in stroma
- As NADP+ and ADP contact thylakoid membranes, they pick up e- and phosphate and then transfer the energy and functional groups to the Calvin cycle

17 Light Harvesting

- Antenna complex: several hundred chlorophyll a, chlorophyll b and carotenoid molecules absorb photons and pass the energy to reaction center
- This process of resonance energy transfer is called inductive resonance
- Diff pigments w/n the antennal complex have diff absorption spectra

18 Pigment Absorption Spectra

- The light reaction can perform work with those wavelengths of light that are absorbed.
- In the thylakoid are several pigments that differ in their absorption spectrum.
  - **Chlorophyll *a*,** the dominant pigment, absorbs best in the red and blue wavelengths, and least in the green.
  - Other pigments with different structures have different absorption spectra.

19 Absorption Spectra

20 Action Spectrum

- Collectively, these photosynthetic pigments determine an overall **action spectrum** for photosynthesis.
  - An action spectrum measures changes in some measure of photosynthetic activity (for example, O_2 release) as the wavelength is varied.

21 Action Spectrum

- Differs from absorption by chlorophyll pigments because several molecules are absorbing light
- Accessory pigments expand the range of wavelengths:chloro b & carotenoids
- As resonance occurs, one molecule can transfer e-
- Rx ctr of chloro a is P700 and of chloro b is P680 they are identical but

are associated w diff proteins

22 Noncyclic Electron Flow

- Use both photosystems I and II
- Transforms energy stored in bonds of NADPH and ATP
- Occurs in thylakoid membrane
- Noncyclic flow pushes e- continuously from H2O, where they are at low potential energy, to NADPH, where they have high potential energy.
- Cyclic electron flow converts light energy to chemical energy in the form of ATP.
- Produces O2 as byproduct

23 Photosystem I

- P700 transfers e- to primary e- acceptor
- Primary e- acceptor transfers e- to ferredoxin (Fd)
- NADP+ reductase catalyzes redox rx that transfers these e- from Fd to NADP+ producing reduced coenyzme: NADPH
- Oxidized p700 need e- holes filled
- E- come from photosystem II

24 Photosystem II

- P680 rx ctr transfers excited e- to primary e- acceptor which transfers e- to plastoquinone (Pq)
- Cascade redox through molecules of cytochrome complex
- Cytochrome complex generates proton pump and phosphorylates one ATP (photophosphorylation)
- e- continue to flow and lose energy until they ground state of P700 where they replace missing e-
- Splitting of water extracts e- for P680

25 Cyclic Electron Flow

- Involves only photosystem I and generates ATP w/o producing NADPH or evolving O2
- e- that leave P700 return
- Photons are absorbed and transferred to P700 rx ctr
- P700 releases excited state e- to primary e- acceptor which passes potential energy to Fd which passes it down ETC to P700, making ATP
- e- drops to ground state of P700

26 Chemiosmosis comparison

1
- Mitochondria
- Food to ATP
- ETC in membrane
- Some e- carriers very similar in both
- H+ pumped intermembrane space

2 • Chloroplasts
• Light to ATP
• ETC in membrane
• ATP synthase both
• H+ pumped from stroma to thylakoid

27 **Calvin Cycle**

- G3PThe Calvin cycle regenerates its starting material after molecules enter and leave the cycle.
- CO_2 enters the cycle and leaves as sugar.
- ATP energy source; NADPH reducing agent adding e-
- 3C sugar: G3P glyceraldehyde 3-phosphate
- 3 molecules of CO2 enter cycle to produce

28 **Phase I: Carbon Fixation**

- 3 CO2 attached to 5-C sugar RuBP (ribulose biphosphate)
- Catalyed by rubisco: RuBP carboxylase (most abundant protein on Earth)
- Unstable 6 C intermediate splits to form 2 molecules of 3-phosphoglycerate
- 3 CO2 molecules 3 RuBP forms 6 molecules 3-phophoglycerate

29 **Phase 2: Reduction**

- Each molecule uses 1 ATP to produce 1,3 bisphosphoglycerate
- e- from NADPH reduce the carboxyl group to glyceraldehyd 3-phosphate
- G3P
- 3 molecules CO2 = 6 molecules G3P
- G3P same molecule formed split glucose
- Only one molecule is sugar rest regenerate RuBP

30 **Phase 3: Regeneration of RuBP**

- Uses 5 G3P molecules
- Requires 3 more ATP
- For each net synthesis of one G3P sugar,
- Calvin cycle uses 9 ATP and 6 NADPH

31 **Photorespiration**

- When hot, stomata close, no CO2 enters
- O2 builds up due to splitting of H2O by photosystem II

- RuBP can accept O_2 instead of CO_2
- Splits into 1 3C and 1 2C molecule
- 2C molecule goes to peroxisome which breaks down so it can enter mitochondrion releasing CO_2 from Krebs no ATP made

32 **C3 plants**

- First stable intermediate has 3C
- Agriculturally important rice, wheat, soybeans

33 **C4 Plants**

- Before Calvin rx, incorporate CO_2 into 4C cmpd
- Used by thousands species, corn and sugar cane, agricult. Grasses
- Works well in hot, arid climates
- Leaf anatomy spatially segregates Calvin cycle from initial incorporation of CO_2
- Bundle sheath cells Calvin occurs here
- Mesophyll cells

34 **How C4 Plants work**

- CO_2 is added to PEP (phosphoenolpyruvate) to form oxaloacetate
- PEP carboxlylase adds CO_2 to PEP
- No affinity for O_2
- Convert oxaloacetate to malate 4C
- In bundle sheath, malate releases CO_2 which rubisco picks up to make sugar

35 **CAM plants**

- Conserves H_2O in day
- Stomata open night, CO_2 take up and fixed in organic cmpd
- crassulacean acid metabolism
- Stored in vacuoles of mesophyll
- Daytime, light rx supply ATP and NADPH for Calvin cycle
- CO_2 released from organic acids and picked up by rubisco

36 **Review**

- Photosynthesis makes 160 billion metric tons carbohydrate/yr
- Light rx use photons to produce ATP and transfer e- from water to $NADP^+$ to make NADPH
- Make 3 C sugar G3P
- Sucrose is transplant form of carb in most plants
- Use about 50% of what is made-rest fuels food chain