

This is an example outline of 2 lectures in BSC 2010. (Thanks to Dr. Ellington for sharing this information.)

Topic 11: PHOTOSYNTHESIS (17-18)

OBJECTIVES:

1. Be able to differentiate the functional roles of the light vs. the dark reactions in photosynthesis.
2. Know the difference between absorption spectrum and action spectrum.
3. Understand the process of photoexcitation as relates to the behavior of electrons.
4. Understand the organization of photosystems and reaction centers and how light excitation results in noncyclic electron flow. Understand the role of water in this process and the overall products of noncyclic electron flow which are essential to the dark reactions.
5. Be able to differentiate noncyclic from cyclic electron flow and understand the forces driving flow in particular directions.
6. Know the roles of ATP and NADPH in the standard C_3 (Calvin cycle) photosynthesis.
7. What is the role of Rubisco in this pathway?
8. Understand the phenomenon of photorespiration and how alternate modes of carbon dioxide fixation reduce photorespiration and/or water loss.

autotrophy- the organism generates its own food; forms of autotrophy

(1) **photosynthesis**- process by which the trapping of light energy is used to produce carbon compounds

(2) **chemosynthesis**- process by which the energy present in the bonds of inorganic compounds (such as hydrogen sulfide, H_2S) is used to produce compounds

heterotrophy- the organism obtains its food from its environment

Photosynthetic organisms- land plants, algae, unicellular protists like *Euglena*, cyanobacteria and purple sulfur bacteria; to a large extent the fundamental biochemical mechanisms are the same. We will focus on photosynthesis in plants.

fig. 10.2- photosynthesis involves gas exchange (inward movement of CO_2 and outward movement of O_2), light absorption and the biochemical events of energy conversion and the eventual fixation of CO_2 into carbohydrate. Typical site of these events is the leaf-

stomata- gas exchange valves located on the underside of leaves; formed by cells known as guard cells which increase or decrease size of aperture based on cell volume changes

mesophyl- interior portion of the leaf which contains the cells which carry on photosynthesis.

chloroplasts- actual site of photosynthesis; highly compartmented organelle consisting of outer & inner membrane, stroma and grana consisting of stacks of thylacoids.

fig. 10.4- overview of photosynthesis

- (1) **light reactions**- light energy is used to produce ATP and reducing power in the form of the reduced coenzyme known as NADPH; H_2O is split yielding oxygen.
- (2) **dark reactions** (aka **Calvin Cycle**)- the ATP and NADPH are used to “fix” CO_2 into C-C bonds ultimately forming sugar; produced ADP and $NADP^+$ are recycled back to the light reactions.

Light reactions

fig. 10.9 - dissolved in the thylacoid membranes are pigments known as chlorophyll a and chlorophyll b; each molecule has a chemical structure consisting of a porphyrin ring in which a Mg^{2+} atom is “coordinated” and a long hydrocarbon tail. Like all pigments these molecules absorb certain colors of light and reflect others.

fig. 10.5- visible spectrum; energy content is inversely proportional to wavelength

fig. 10.8 a & b-

-10.8 a: **absorption spectra for photosynthetic pigments**; absorbance is an index of the amount of light that a molecule absorbs. The absorption spectrum shows the relationship between light absorbance and light quality (wavelength); chlorophylls absorb strongly in both the blue and red regions but not in the green region (plants look green because of the reflected green light which was not absorbed; see fig. 10.6)

-10.8 b: **action spectra**; action spectra show the relationship between photosynthetic activity and light wavelength. Highest photosynthetic activity is in the same regions as highest light absorbance.

fig. 10.4- overview again

How does the absorption of light produce the forces that result in the splitting of water and the formation of ATP and NADPH?

Photoexcitation of chlorophyll- fig. 10.10; absorption of a photon of light causes an electron to move to a higher energy level. That is, it moves from the ground state to a higher energy (“excited”) state. When the excited electrons returns to ground state energy is dissipated in the form of heat and/or light (fluorescence).

However, when chlorophyll is present in thylacoids, the molecules are organized into **photosystems** (**photosystem** = light gathering “antenna” complex consisting of molecules of chlorophyll a and b and carotenoid pigment). Instead of dissipating the

energy by heat/fluorescence, the energy can be passed from one chlorophyll to another (fig. 10.11) until it reaches a molecule of chlorophyll a located in what is known as a **reaction center** (**reaction center** = site where light-driven photosynthesis takes place). This molecule of chlorophyll a transfers its excited electron to another molecule known the primary electron acceptor. This is a redox reaction.

Fig. 10.12

There are two kinds of photosystems- I and II ; reaction centers differ in terms of primary electron acceptor and associated proteins

- I- chlorophyll a molecule is known as P700 because it maximally absorbs at 700 nm [red] (its spectral properties are changed by the nature of the proteins it is near)
- II- chlorophyll a molecule is known as P680 (maximal absorption at 680 nm).

ATP and NADPH production by **noncyclic electron flow** (fig. 10.12).

1. P680 absorbs light energy and excites electron to higher orbital which is transferred to the primary electron acceptor; this renders the chlorophyll a strongly oxidizing agent.
2. water is oxidized by P680 ultimately yielding oxygen (reduces P680)
3. electrons in the primary electron acceptor are passed down an electron transport chain
4. this transfer results in pumping of protons from the stroma into the interior of the thylakoid (fig. 10.15); this creates a proton (pH gradient).
5. when protons flow down their gradient, they pass through an ATP synthase and ATP is produced. This is known as **photophosphorylation**; in this case **noncyclic photphosphorylation**.

Fig. 10.13- Shows a good mechanical analogy for how non-cyclic works

1. the electron is then transferred to P700 which is highly oxidized due to its loss of electron after light excitation.
2. the electron from P700 passes through a ferredoxin (Fd) and then NADP⁺ reductase uses the electrons to reduce NADP⁺ to NADPH.
3. Products of noncyclic electron flow- ATP and NADPH

ATP production by **cyclic electron flow** (fig. 10.14)

1. electrons from the primary electron acceptor in photosystem I go by the Fd back to the cytochrome complex of the electron transport chain; this generates additional ATP
2. no oxygen or NADPH is produced

fig. 10.16- summary of the light reactions

Carbon dioxide fixation by the Calvin cycle (fig. 10.17)

Calvin cycle- mechanism by which CO₂ is fixed (attached) to a larger carbon molecule; also known as C₃ photosynthesis

1. CO₂ is attached to a five carbon sugar RuBP by the enzyme Rubisco (RuBP carboxylase) to form 2 molecules of 3-phosphoglycerate
2. ATP phosphorylates both 3-phosphoglycerate molecules to two 1,3-bisphosphoglycerate molecules
3. Both 1,3-bisphosphoglycerate molecules are reduced to glyceraldehyde-3-P (G3P); one G3P molecule is used for sugar synthesis; the other G3P is converted back to RuDP at the cost of an ATP
4. the cycle must turn three times to produce one G3P molecule at a cost of 9 ATP and 6 NADPH; that is three molecules of CO₂ must be fixed to yield one net molecule of G3P
5. **To produce one molecule of glucose (6 carbons), the cycle must turn 6 times at a net cost of 18 ATP and 12 NADPH (all regenerated by the light phases).**

Dark and light reactions are linked; NADP⁺ + ADP produced in the dark reactions are used to make NADPH and ATP in the light reactions.

Photorespiration

on hot, dry days there is a tendency for the stomata to close to prevent excessive water loss; under these circumstances, carbon dioxide levels fall and oxygen levels rise. This leads to a phenomenon known as **photorespiration** (**photorespiration** = process by which the initial step of the Calvin cycles utilizes oxygen and literally siphons carbon from the traditional photosynthetic pathway)-

1. when [oxygen] > [carbon dioxide], Rubisco actually uses O₂ instead of CO₂ forming a two carbon and three carbon compounds
2. the two carbon compound is catabolized into CO₂; there is no net carbon fixation.

Alternative pathways of fixation.

1. C₄ plants- fig. 10.18; characteristic of grasses corn, sugar cane. There are two types of photosynthetic cells - bundle sheath (bundled around the veins) and mesophyll (randomly distributed near the leaf surface).
 - CO₂ is initially fixed in the mesophyll cells via an enzyme known as PEP carboxylase forming a four carbon compound known as oxaloacetate (hence the name C₄ plants).
 - this fixation takes place when stomata are closed; PEP carboxylase is more efficient than Rubisco under conditions of low [CO₂]
 - the four carbon compound (now malate) is transported to the bundle sheath cell where it is decarboxylated to pyruvate and CO₂.

- CO₂ is then used in standard Calvin cycle photosynthesis
- in effect the mesophyll cell functions as a trapping system for CO₂; it minimizes **photorespiration**

2. CAM plants (fig. 10.19)- crassulacean acid metabolism; found in succulents and cacti; stomata are closed during the day and open at night. At night CO₂ is fixed into a number of organic acids; during the day CO₂ is released from the organic acids and incorporated into sugars via the Calvin cycle. Strategy reduces water loss.

Fig. 10.20- linkage of light and dark phases of photosynthesis

Chemoautotrophy

It can be said that the ultimate source of energy in the living world is the sun. This is because the primary producers (autotrophs) use the energy in sunlight to fix carbon that the consumers (heterotrophs) ultimately eat. However, there are many places in which there is no sunlight yet CO₂ fixation takes place. The energy in hydrogen sulfide is used to fix carbon by numerous kinds of bacteria found in sediments. In places called hydrothermal vents, very large communities of animals live in the complete absence of light. They derive their nutrition from endosymbiotic bacteria that fix carbon dioxide using hydrogen sulfide as energy source.