

**Like The Guy From Krypton**  
**Photosynthesis: Energy from Sunlight**  
**What Is Photosynthesis?**

- Photosynthesis: “synthesis from light”
- The broad outline:
  - Plants take in CO<sub>2</sub> and release water and O<sub>2</sub>
  - Light is required
- Ruben and Kamen determined the source of O<sub>2</sub> released during photosynthesis by using radioisotope tracers.

Two pathways:

- Light reactions: light energy converted to chemical energy (in ATP and NADPH + H<sup>+</sup>)
- Light-independent reactions: use the ATP and NADPH + H<sup>+</sup> plus CO<sub>2</sub> to produce sugars

**How Does Photosynthesis Convert Light Energy into Chemical Energy?**

- Light is a form of electromagnetic radiation, which comes in discrete packets called photons and behave as particles.
- Light also behaves as if propagated as waves.
- Energy of a photon is inversely proportional to its wavelength.

When a photon meets a molecule it can be:

- *Scattered* or reflected
- *Transmitted* or pass through the molecule
- *Absorbed*—the molecule acquires the energy of the photon. The molecule goes from **ground state** to **excited state**.
- Photons can have a wide range of wavelengths and energy levels.
- Molecules that absorb specific wavelengths in the visible range of the spectrum are called pigments.
- Absorption spectrum: plot of wavelengths absorbed by a pigment
- Action spectrum: plot of biological activity as a function of the wavelengths of light the organism is exposed to

Several types of pigments absorb light energy used in photosynthesis:

- Chlorophylls: a and b
- Accessory pigments: absorb in red and blue regions, transfer the energy to chlorophylls—carotenoids, phycobilins

- When a pigment returns to ground state, some of the energy may be given off as heat, some may be given off as fluorescence.
- Fluorescence has longer wavelengths and less energy than the absorbed light energy. No work is done.
- If pigment can pass the energy to another molecule, there's no fluorescence.
- The energy can be passed to a reaction center where it is converted to chemical energy.
- Pigments are arranged in antenna systems.
- Pigments are packed together on thylakoid membrane proteins.
- Excitation energy is passed from pigments that absorb short wavelengths to those that absorb longer wavelengths, and ends up in the reaction center pigment.
- The reaction center molecule is chlorophyll a.
- The excited chlorophyll ( $\text{Chl}^*$ ) is a reducing agent (electron donor).
- A is the first in a chain of electron carriers on the thylakoid membrane—electron transport, a series of redox reactions.
- The final electron acceptor is  $\text{NADP}^+$

Two systems of electron transport:

- Noncyclic electron transport—produces  $\text{NADPH} + \text{H}^+$  and ATP
- Cyclic electron transport—produces ATP only
- Noncyclic electron transport: light energy is used to oxidize water  $\rightarrow \text{O}_2, \text{H}^+$ , and electrons
- $\text{Chl}^+$  is a strong oxidizing agent. It takes electrons from water, splitting the water molecule.
- Two photosystems required in noncyclic electron transport.
- Each photosystem consists of several chlorophyll and accessory pigment molecules.
- The photosystems complement each other, must be constantly absorbing light energy to power noncyclic electron transport.

Photosystem I

- Light energy reduces  $\text{NADP}^+$  to  $\text{NADPH} + \text{H}^+$
- Reaction center is chlorophyll a molecule  $\text{P}_{700}$ —absorbs in the 700nm range

Photosystem II

- Light energy oxidizes water  $\rightarrow \text{O}_2, \text{H}^+$ , and electrons

- Reaction center is chlorophyll a molecule P<sub>680</sub>—absorbs at 680nm
- The Z scheme models describes noncyclic electron transport.
- The reactions in the electron transport chain are coupled to a proton pump that results in the chemiosmotic formation of ATP.
- Cyclic electron transport: an electron from an excited chlorophyll molecule cycles back to the same chlorophyll molecule.
- A series of exergonic redox reactions, the released energy creates a proton gradient that is used to synthesize ATP.
- Photophosphorylation: light-driven production of ATP—a chemiosmotic mechanism.
- Electron transport is coupled to the transport of H<sup>+</sup> across the thylakoid membrane—from the stroma into the lumen.

### **How Is Chemical Energy Used to Synthesize Carbohydrates?**

- CO<sub>2</sub> fixation—CO<sub>2</sub> is reduced to carbohydrates.
- Enzymes in the stroma use the energy in ATP and NADPH to reduce CO<sub>2</sub>.
- Because the ATP and NADPH are not “stockpiled” these light-independent reactions must also take place in the light.
- Calvin and Benson used the <sup>14</sup>C radioisotope to determine the sequence of reactions in CO<sub>2</sub> fixation.
- They exposed Chlorella to <sup>14</sup>CO<sub>2</sub>, then extracted the organic compounds and separated them by paper chromatography.
- 3-second exposure of the Chlorella to <sup>14</sup>CO<sub>2</sub> revealed that the first compound to be formed is 3PG, a 3-carbon sugar phosphate.
- The pathway of CO<sub>2</sub> fixation is the Calvin cycle.
- CO<sub>2</sub> is first added to a 5-C RuBP; the 6-C compound immediately breaks down into two molecules of 3PG.
- The enzyme is rubisco—the most abundant protein in the world.

The Calvin cycle consists of 3 processes:

- Fixation of CO<sub>2</sub>
- Reduction of 3PG to G3P
- Regeneration of RuBP
- G3P: glyceraldehyde 3-phosphate
- Most is recycled into RuBP

- The rest is converted to starch and sucrose
- Covalent bonds in carbohydrates produced in the Calvin cycle represent the total energy yield of photosynthesis.
- This energy is used by the autotrophs themselves, and by heterotrophs—other organisms that cannot photosynthesize.

The Calvin cycle is stimulated by light:

- Proton pumping from stroma into thylakoids increases the pH which favors the activation of rubisco.
- Electron flow from photosystem I reduces disulfide bonds to activate Calvin cycle enzymes.

### **How Do Plants Adapt to the Inefficiencies of Photosynthesis?**

- Rubisco is an oxygenase as well as a carboxylase.
- It can add O<sub>2</sub> to RuBP instead of CO<sub>2</sub>, reduces amount of CO<sub>2</sub> fixed, and limits plant growth.
- Products: 3PG and phosphoglycolate

Photorespiration:

- The phosphoglycolate forms glycolate—moves into peroxisomes—converted to glycine.
- Glycine diffuses into mitochondria, 2 glycines are converted into glycerate + CO<sub>2</sub>
- Rubisco has 10 times more affinity for CO<sub>2</sub>.
- In the leaf, if O<sub>2</sub> concentration is high, photorespiration occurs. If CO<sub>2</sub> concentration is high, CO<sub>2</sub> is fixed.
- Photorespiration is more likely at high temperatures, such as hot days when stomata are closed.
- C<sub>3</sub> plants: first product of CO<sub>2</sub> fixation is 3PG. Palisade cells in the mesophyll have abundant rubisco.
- C<sub>4</sub> plants: first product of CO<sub>2</sub> fixation is oxaloacetate, a 4-C compound. Mesophyll cells contain PEP carboxylase.
- C<sub>4</sub> plants—corn, sugar cane, tropical grasses—can keep stomata closed on hot days, but photorespiration does not occur.
- In mesophyll cells, CO<sub>2</sub> is accepted by PEP (phosphoenolpyruvate) to form oxaloacetate.
- PEP carboxylase has no affinity for O<sub>2</sub>.

- Oxaloacetate diffuses to bundle sheath cells which have abundant rubisco.
- The oxaloacetate is decarboxylated (PEP returns to mesophyll cells), CO<sub>2</sub> enters the Calvin cycle.
- CAM plants—crassulacean acid metabolism
- Fix CO<sub>2</sub> with PEP carboxylase—at night—stomata can open with less water loss. Oxaloacetate is converted to malic acid.
- Day—malic acid goes to chloroplasts and is decarboxylated—CO<sub>2</sub> enters the Calvin cycle.

### **How Is Photosynthesis Connected to Other Metabolic Pathways in Plants?**

- Photosynthesis and respiration are closely linked by the Calvin cycle.
- Glycolysis in the cytosol, respiration in the mitochondria, and photosynthesis in the chloroplasts can occur simultaneously.
- Photosynthesis results in only 5 percent of total sunlight energy being transformed to the energy of chemical bonds.
- Understanding the inefficiencies of photosynthesis may be important as climate change drives changes in photosynthetic activity of plants.