

Chapter 10

Photosynthesis is the conversion of light energy to chemical energy that is stored in sugar and other organic molecules.

$6\text{CO}_2 + 12\text{H}_2\text{O} + \text{light energy} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 + 6\text{H}_2\text{O}$. Autotrophs are organisms that sustain themselves without eating anything derived from other human beings. They are known as producers. Heterotrophs obtain organic material by consuming the compounds produced by other organisms. Decomposers consume the remains of dead organisms. There are two stages of photosynthesis: the conversion of solar energy to chemical energy and the Calvin cycle, which is where chemical energy is transformed to organic molecules of food. Light reactions capture solar energy to form ATP and allow for the electron transfer from H₂O to NADP⁺, resulting in NADPH. The Calvin Cycle uses ATP and NADPH to form sugar from CO₂.

Chloroplasts are the sites of photosynthesis in cells. Mesophyll, which is the tissue in the interior of the leaf, is where the chloroplasts are found. The stomata are microscopic pores that allow CO₂ to enter and O₂ to exit. The stroma, which is where the Calvin Cycle occurs, is a dense fluid surrounded by an envelope of two membranes. Thylakoids, which is where light reactions occur, are sacs that are suspended in the stroma. Inside the thylakoids is the thylakoid space and grana are stacks of thylakoid. Chlorophyll is the green pigment in chloroplasts that absorbs light for photosynthesis.

The chloroplast splits H₂O into H₂ and O. The electron and hydrogen ions from it are transferred to CO₂, which is reduced to a sugar. The electrons increase in potential energy and require more energy, which is endergonic and supplied by light.

There are two processes to photosynthesis: light reactions and the Calvin Cycle. Light reactions convert the solar energy into chemical energy by splitting water into electrons, hydrogen ions, and oxygen. The light absorbed by the chlorophyll drives the electron and hydrogen ion to NADP⁺. Solar power then reduces NADP⁺ to NADPH by transferring the ion and electron. Photophosphorylation occurs, which is the generation of ATP from ADP and inorganic phosphorylation through chemiosmosis. Light energy is transferred to chemical energy in the form of NADPH and ATP. Light reactions do not produce sugar. The Calvin Cycle involves carbon fixation, which takes in CO₂ from the air and develops into organic compounds present in the chloroplast. NADPH reduces carbon to a carbohydrate by adding electrons. ATP is the energy used to convert CO₂ to CH₂O. The Calvin Cycle is the process that makes sugar, with the help of ATP and NADPH from light reactions.

Pigments absorb photons, which are discrete particles of light, and each absorb different wavelengths. In chloroplasts, there are three types of pigments: chlorophyll a, which directly participates in light reactions, chlorophyll b, an accessory pigment, and carotenoids, which is a group of accessory pigments. The action spectrum profiles the effectiveness of different wavelengths and confirms the best ones for photosynthesis. Photoprotection is the process of absorbing and dissipating excessive light energy that would otherwise damage chlorophyll or interact with O₂, forming oxidative molecules that are dangerous.

When a molecule absorbs a photon of light, a molecule's electron is elevated to an orbital with more potential energy. The ground state of an electron is its normal orbital. The excited state is an absorbed photon, which boosts the electron to an orbital of higher energy. Photons absorb only energy that is equal to the difference between the ground and excited

state. The excited state is very unstable and causes the electron to quickly drop back, releasing heat in an isolated molecule.

A photosystem is composed of a reaction-center complex surrounded by several light-harvesting complexes. The RCC is the organized association of proteins holding a special pair of chlorophyll a molecules. The LHC consist of various pigment molecules (chlorophyll a, chlorophyll b, and/or carotenoids) bound to proteins. Having a large number and variety of pigment molecules allows the photosystem to harvest light over a larger surface area. The LHC is essentially an "antenna" for the RCC. Pigment molecules absorb photons, and the energy is transferred from pigment molecule to pigment molecule within the LHC until passed to the RCC. The primary-electron acceptor is in the RCC and is a molecule capable of accepting electrons and being reduced. A pair of chlorophyll a molecules in the RCC enables the use of light energy to boost the electron to a higher energy level and transfer it to a different molecule, the PEA. The transfer of the electron from the RCC chlorophyll a pair to the PEA is the first step of light reactions. There are two types of photosystems, Photosystem I (P700 chlorophyll a pair) and Photosystem II (P680), which have different RCC.

Light energizes two photosystems to allow for ATP and NADPH synthesis because of the flow of electrons. Linear Electron Flow occurs during light reactions and is the flow of electrons through photosystems and thylakoid components. First, a photon strikes a pigment molecule in the LHC of PSII. The electron is raised to a higher energy level, but then drops back down, stimulating an electron in a nearby pigment. This continues until it reaches the P680 pair. The electron in the pair is transferred to the PEA, and P680 becomes P680⁺. An enzyme catalyzes the splitting of H₂O into two electrons, two hydrogen ions, and oxygen. The electron is supplied one by one to the P680⁺, replacing the electron that was transferred to the PEA. The hydrogen ions are released into the thylakoid lumen, and oxygen combines with another oxygen to form O₂. The photoexcited electron from the PSII PEA travels through the ETC to the PSI PEA. The exergonic electron drops to a lower level, supplying the energy for ATP synthesis. The electron passes through the cytochrome complex, the hydrogen ion is released into the lumen, and a proton gradient is formed for chemiosmosis. Light energy enters the PSI RCC causing the P700 excited electron to transfer to the PEA. The photoexcited electron goes through redox reactions from the PEA of PSI down the second ETC. NADP⁺ reductase catalyzes the transfer of electrons from Fd to NADP⁺. Two electrons are required for the reduction to NADPH. The energy level in it is greater than in water, making the electron more available for the Calvin Cycle. Hydrogen ions are also removed from the stroma.

The Cyclic Electron Flow is an alternate path for photoexcited electrons and uses PSI only. It is a short circuit, with the electron cycling back from Fd to the cytochrome complex and to the P700 in the PSI RCC. It does not generate NADPH and does not release O₂. ATP is, however, generated. It is photoprotective.

Chemiosmosis is a process that uses membranes to couple redox reactions to ATP production. The ETC pumps protons across the membrane as electrons pass through a series of electron carriers that are progressively more electronegative. It transforms redox energy to a proton motive force. ATP synthase complex couples hydrogen ion diffusion to ADP phosphorylation. In the mitochondria, the high energy electrons that move down the ETC are extracted from organic compounds. The electron source in chloroplasts is from H₂O, which uses light energy to drive the electron to the ETC. Mitochondrias use chemical energy whereas

chloroplasts use light energy. In the inner mitochondrial, the membrane pumps protons out of the matrix to the intermembrane space. In the chloroplast, the thylakoid membrane pumps protons from the stroma to the thylakoid space. For ATP synthesis in the mitochondria, protons fall down the concentration gradient from intermembrane space due to ATP synthase. In chloroplasts, hydrogen ions in the thylakoid space go through the ATP synthase complex to the stroma. In light reactions, the electron flow pushes electrons from H₂O to NADPH and stores PE. The current generates ATP and the thylakoid converts the light energy to chemical energy to be stored in ATP and NADPH.

The Calvin Cycle and the Citric Acid Cycle both regenerate its starting materials. The Citric Acid Cycle is catabolic and oxidizes Acetyl CoA to generate the energy to synthesize ATP. The Calvin Cycle is anabolic and builds carbohydrates from smaller molecules for energy. CO₂ enters the Calvin cycle and exits as a sugar. ATP is the source of energy and NADPH is the reducing power. G3P is produced, which is $\frac{1}{3}$ of glucose.

The first phase of the Calvin Cycle is carbon fixation. Each CO₂ molecule attaches one at a time to a five carbon sugar called RuBP and is catalyzed by rubisco. It forms a six carbon intermediate which is unstable and immediately splits into two 3-phosphoglycerate molecules. After comes reduction. Each 3-phosphoglycerate receives an additional phosphate group and becomes 1,3-bisphosphoglycerate. An electron from NADPH reduces the 1,3-bisphosphoglycerate and loses a phosphate group, becoming G3P. The electron reduces the carboxyl group on the 1,3-bisphosphoglycerate to aldehyde G3P, which stores more PE. For every three CO₂ that enter, 6 G3P are formed, but only one is a net carbon gain. One G3P is used for cell use, and the other five are used to regenerate RuBP. The last phase is the regeneration of the CO₂ acceptor, RuBP. The carbon skeletons of the five G3P molecules are rearranged to three molecules of RuBP.

CO₂, which is required for photosynthesis, enters the leaf via the stomata. H₂O, however, also exits through these pores, which poses a problem on hot days. In C₃ plants, a three carbon compound is first fixated. Then, rubisco binds to O₂ in a shortage of CO₂, causing a two carbon sugar to be released. Photorespiration occurs in light and consumes O₂, but generates no ATP and releases CO₂. It plays a protective role in plants by neutralizing otherwise damaging light reaction products. It, however, drains approximately 50% of the carbon fixed by the Calvin Cycle.

To fix this problem, C₄ plants fixate a four carbon compound. These plants have two distinct types of photosynthetic cells: bundle-sheath and mesophyll cells. Bundle-sheath cells are arranged in tight sheaths around leaf veins and mesophyll cells are between the bundle-sheath cells and leaf surface. The Calvin Cycle is confined to the chloroplasts of bundle-sheath cells, which is preceded by the CO₂ being incorporated into organic compounds in the mesophyll cells. PEP carboxylase is an enzyme found only in mesophyll cells. It adds CO₂ to PEP forming a four carbon oxaloacetate. The PEP has a higher affinity for CO₂ than rubisco does and has no affinity for O₂, resulting in carbon being efficiently fixed. Carbon is then fixed and mesophyll cells export the four carbon products to bundle-sheath cells through the plasmodesmata. Within the bundle-sheath cells, the four carbon compounds release CO₂, which is reassimilated into organic material by rubisco and the Calvin Cycle regenerates pyruvate. ATP is used to convert pyruvate to PEP, allowing the reaction to continue. CO₂ is