PHOTOSYNTHESIS

AN INTRODUCTION TO PHOTOSYNTHESIS

The processes of all organisms—from bacteria to humans—require energy. To get this energy, many organisms access stored energy by eating; that is, by ingesting other organisms. All of the stored energy in the food can be traced back to photosynthesis. Photosynthesis is essential to all life on earth; both plants and animals depend on it. It is the only biological process that can capture energy that originates in outer space (sunlight) and convert it into chemical compounds (carbohydrates) that every organism uses to power its metabolism. In brief, the energy of sunlight is captured and used to energize electrons, which are then stored in the covalent bonds of sugar molecules. The energy extracted today by the burning of coal and petroleum products represents sunlight energy captured and stored by photosynthesis almost 200 million years ago. Plants, algae, and a group of bacteria called cyanobacteria are the only organisms capable of performing photosynthesis . Because they use light to manufacture their own food, they are called photoautotrophs (literally, “self-feeders using light”). Other organisms, such as animals, fungi, and most other bacteria, are termed heterotrophs (“other feeders”) because they must rely on the sugars produced by photosynthetic organisms for their energy needs. A third very interesting group of bacteria synthesize sugars, not by using sunlight’s energy, but by extracting energy from inorganic chemical compounds; hence, they are referred to as chemoautotrophs. The importance of photosynthesis is not just that it can capture sunlight’s energy. A lizard sunning itself on a cold day can use the sun’s energy to warm up. Photosynthesis is vital because it evolved as a way to store the energy in solar radiation (the “photo-” part) as high-energy electrons in the carbon-carbon bonds of carbohydrate molecules (the “-synthesis” part). Those carbohydrates are the energy source that heterotrophs use to power the synthesis of ATP via respiration. Therefore, photosynthesis powers 99 percent of Earth’s ecosystems. When a top predator, such as a wolf, preys on a deer, the wolf is at the end of an energy path that went from nuclear reactions on the surface of the sun, to light, to photosynthesis, to vegetation, to deer, and finally to wolf.

MAIN STRUCTURES AND SUMMARY OF PHOTOSYNTHESIS

In multicellular autotrophs, the main structures that allow photosynthesis to take place include chloroplasts, thylakoids, and chlorophyll. Photosynthesis is a multi-step process that requires sunlight, carbon dioxide (which is low in energy), and water as substrates. After the process is complete, it releases oxygen and produces glyceraldehyde-3-phosphate (GA3P), simple carbohydrate molecules (which are high in energy) that can subsequently be converted into glucose, sucrose, or any of dozens of other sugar molecules. These sugar molecules contain energy: the energized carbon that all living things need to survive. Therefore, according to the chemical equation for photosynthesis, carbon dioxide and water produce sugar and oxygen when exposed to sunlight. Although this equation looks simple, the many steps that take place during photosynthesis are actually quite complex. Before learning the details of how photoautotrophs turn sunlight into food, it is important to become familiar with the structures involved.

Photosynthesis Equation

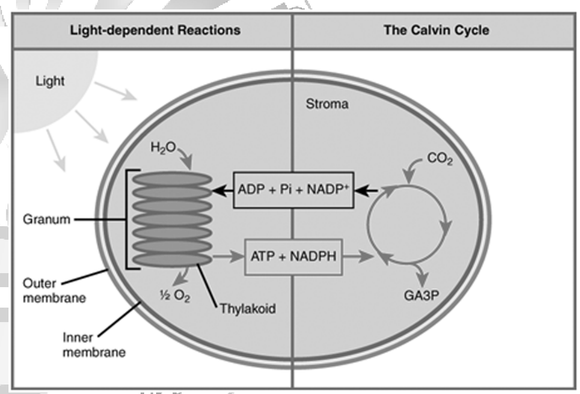
Carbon dioxide +	Water $\xrightarrow{\text{SUNLIGHT}}$	Sugar +	Oxygen
$6CO_2$	$6H_2O$	$C_6H_{12}O_6$	$6O_2$

Chemical Equation for Photosynthesis

In plants, photosynthesis generally takes place in leaves, which consist of several layers of cells. The process of photosynthesis occurs in a middle layer called the mesophyll. The gas exchange of carbon dioxide and oxygen occurs through small, regulated openings called stomata (singular: stoma), which also play roles in the regulation of water balance. The stomata are typically located on the underside of the leaf, which helps to minimize water loss. Each stoma is flanked by guard cells that regulate the opening and closing of the stomata by swelling or shrinking in response to osmotic changes. In all autotrophic eukaryotes, photosynthesis takes place inside an organelle called a chloroplast. For plants, chloroplast-containing cells exist in the mesophyll. Chloroplasts have a double membrane envelope (composed of an outer membrane and an inner membrane). Within the chloroplast are stacked, disc-shaped structures called thylakoids. Embedded in the thylakoid membrane is chlorophyll, a pigment that absorbs certain portions of the visible spectrum and can capture energy from sunlight. This pigment gives plants their green color and is ultimately responsible for the initial interaction between light and plant material, as well as numerous proteins that make up the electron transport chain. The thylakoid membrane encloses an internal space called the thylakoid lumen. A stack of thylakoids is called a granum , and the liquid-filled space surrounding the granum is called stroma or "bed" (not to be confused with stoma or "mouth," an opening on the leaf epidermis).

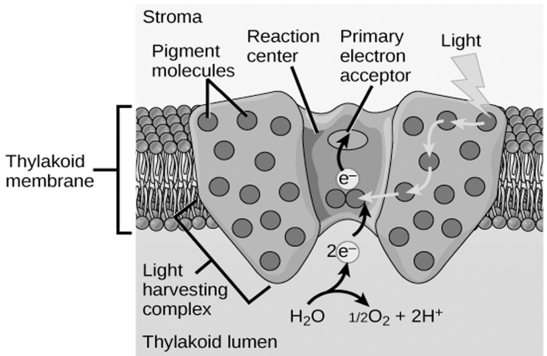
The Two Parts of Photosynthesis

Photosynthesis takes place in two sequential stages: the light-dependent reactions and the light-independent reactions . In the light-dependent reactions, energy from sunlight is absorbed by chlorophyll; that energy is converted into stored chemical energy in the form of NADPH (nicotinamide adenine dinucleotide phosphate) and ATP (adenosine triphosphate). Protein complexes and pigment molecules work together to produce both NADPH and ATP.

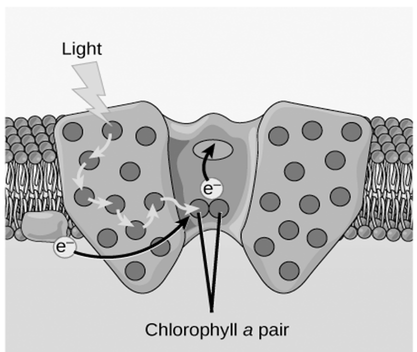


In the light-independent reactions, the chemical energy harvested during the light-dependent reactions drives the assembly of sugar molecules from carbon dioxide. Therefore, although the light-independent reactions do not use light as a reactant, they require the products of the light-dependent reactions to function. In addition, several enzymes of the light-independent reactions are activated by light. The light-dependent reactions utilize certain molecules to temporarily store the energy: These are referred to as energy carriers. The energy carriers that move energy from light-dependent reactions to light-independent reactions can be thought of as "full" because they are rich

(a) Photosystem II (P680)



(b) Photosystem I (P700)



in energy. After the energy is released, the "empty" energy carriers return to the light-dependent reaction to obtain more energy. Moreover, the actual step that converts light energy into chemical energy takes place in a multiprotein complex called a photosystem, two types of which are found embedded in the thylakoid membrane: photosystem II (PSII) and photosystem I (PSI) . The two complexes differ on the basis of what they oxidize (i.e., the source of the low-energy electron supply) and what they reduce (i.e., the place to which they deliver their energized electrons).

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