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PHOTOSYNTHESIS

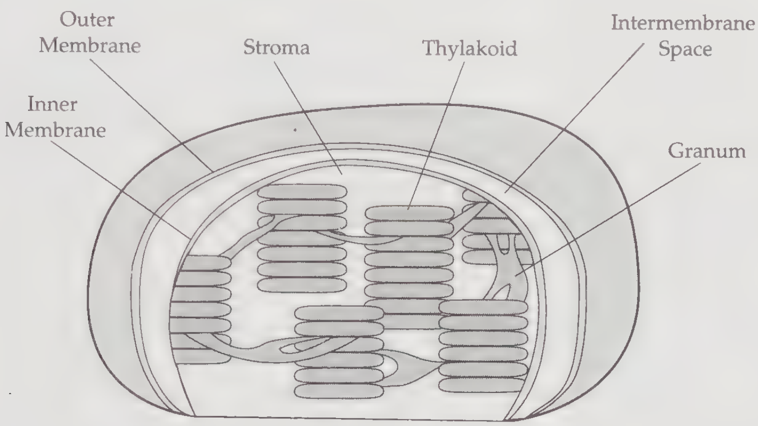
To survive, all organisms need energy. Herbivores get energy by eating plants, and carnivores by eating herbivores or other carnivores. The foundation of all ecosystems and the source of the energy in these ecosystems and on planet earth as a whole is *photosynthesis*. Plants are *autotrophs*, or self-feeders, that generate their own chemical energy from the energy of the sun through photosynthesis. There are also many prokaryotic photosynthetic organisms such as cyanobacteria (blue-green algae) that contribute significantly to global productivity. The chemical energy that plants get from the sun is used to produce glucose that can be burned in mitochondria to make ATP, which is then used to drive all of the energy-requiring processes in the plant, including the production of proteins, lipids, carbohydrates, and nucleic acids. Animals eat plants to extract this energy for their own metabolic needs. In this way, photosynthesis supports almost all living systems.

Photosynthesis occurs in plants in the *chloroplast*, an organelle that is specific to plants. In cyanobacteria, a prokaryote, there are no chloroplasts, and photosynthesis occurs throughout the cytoplasm. Chloroplasts are found mainly in the cells of the *mesophyl*, the green tissue in the interior of the leaf. The leaf contains pores in its surface called *stomata* that allow carbon dioxide in and oxygen out to facilitate photosynthesis in the leaf. The chloroplast has an inner and outer membrane, and within the inner membrane is a fluid called the *stroma*. In addition, the interior of the chloroplast contains a series of membranes called the *thylakoid membranes* that form stacks called *grana*.

DON'T MIX THESE UP ON TEST DAY

The *stomata (stomates)* are pores in the surface of a leaf through which carbon dioxide enters and oxygen exits the plant.

The *stroma* is the dense fluid within the chloroplast in which carbon dioxide is converted into sugars.



Chloroplast

Photosynthesis can be summarized with this equation:

$$6CO_2 + 12H_2O + \text{light} \longrightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O$$

Photosynthesis involves the reduction of CO_2 to a carbohydrate. It can be characterized as the reverse of respiration, in that reduction of CO_2 to produce glucose occurs instead of oxidation of glucose to make CO_2. One by-product of photosynthesis is oxygen; this makes photosynthesis of keen interest to all of us air-breathers since it is the source of the oxygen that we need to survive. Photosythesis has two main parts, the *light reaction* and the *Calvin cycle*. The light reaction occurs in the interior of the thylakoid, while the Calvin cycle occurs in the stroma. Plants are green because they reflect green light the most. The pigments involved in photosynthesis absorb the most strongly in the red and blue wavelengths.

Light Reactions

The first part of photosynthesis is made up of light reactions, in which light energy is used to generate ATP, oxygen, and the reducing molecule NADPH. The molecule that captures light energy to start photosynthesis is a pigment called *chlorophyll* found within the thylakoid membranes of the chloroplast. Chlorophyll is used by two complex systems called *Photosystem I* and *Photosystem II* in the thylakoid membrane. When photons strike chlorophyll, electrons are excited and transferred through the photosystems to a reaction center. The light reactions, which can collectively be called *photophosphorylation*, are grouped into two types of reactions using two photosystems: *cyclic* and *noncyclic photophosphorylation*.

Cyclic reactions are conducted by Photosystem I and contribute to ATP production but do not produce NADPH. When chlorophyll in Photosystem I is excited, the excited electrons pass through a system of electron carriers that pump protons to build a proton gradient. This proton gradient is used to make ATP (sound familiar?). At the end of the chain, the electron is given back to chlorophyll to be excited once again, making this reaction cyclic.

GREEN POWER

The ATP produced by photosynthesis is used to make glucose. Like animals, plants burn glucose in glycolysis and aerobic respiration to make ATP for all other energy needs.

Noncyclic photophosphorylation requires both photosystems and produces ATP, NADPH, and O_2, molecular oxygen. The noncyclic reactions begin with excitation of chlorophyll in Photosystem II. This excited chlorophyll uses water as an electron donor, producing protons and oxygen. Photosystem II then sends these excited electrons through a chain of redox factors that use the energy to pump protons that will be used to make ATP. At the bottom of the redox chain, the electrons are donated to Photosystem I, which will excite the electrons and use their energy to make NADPH.

A proton gradient is produced by both the cyclic and noncyclic reactions. The proton gradient in photosynthesis involves pumping protons into the interior of the thylakoids. This proton gradient is used to make ATP by a process similar to the way that a proton gradient is used to make ATP in mitochondria. Protons flow down this chloroplast proton gradient back out into the stroma through an ATP synthase to produce ATP. The NADPH and ATP produced during the light reactions are used to complete photosynthesis in the Calvin cycle, using carbon from carbon dioxide to make sugars. The oxygen produced in the light reactions is released from the plant as a byproduct of photosynthesis. This oxygen helps to maintain the oxygen atmosphere of earth that organisms need for aerobic respiration. Photosynthesis can take credit for the atmosphere rich in oxygen found today.

Calvin Cycle

The Calvin cycle, also known as the "dark cycle," creates carbohydrates using the energy of ATP and the reducing power of NADPH produced in the light reactions. The carbon used in the creation of carbohydrates comes from atmospheric carbon dioxide, CO_2, so the process is sometimes called *carbon fixation*. CO_2 first combines with, or "is fixed to," ribulose bisphosphate, a five-carbon sugar with two phosphate groups attached. The resulting six-carbon compound is promptly split, resulting in the formation of two molecules of 3-phosphoglycerate, a three-carbon compound. The 3-phosphoglycerate is then phosphorylated by ATP and reduced by NADPH, which leads to the formation of glyceraldehyde 3-phosphate. This molecule can then be utilized as a starting point for the synthesis of glucose.

IN THE DARK

The "dark cycle" does not necessarily take place in the dark, but can if provided ATP, NADPH, and CO_2.