PHOTOCHEMICAL REACTIONS

Whereas a mitochondrion releases energy from molecules, a chloroplast stores energy in molecules by capturing the energy of light and using it to assemble carbon dioxide and water into carbohydrate and other energy-rich compounds. This process is called photosynthesis (Greek: \textit{photo}, "light"; \textit{syn}, "together"; \textit{thesis}, "putting" or "placing"). Without photosynthesis, we would soon run out of food. We would also run out of oxygen, and the only life forms left on earth would be a few bacteria.

Color the heading \textbf{Net Reaction and titles and structures A through E}. Use two different shades of the same color for the oxygen in carbon dioxide and the oxygen in water.

The equation given here shows only the net change that results from photosynthesis. Six molecules of carbon dioxide and six molecules of water are used to produce one molecule of glucose, and six molecules of oxygen are released as a waste product. (Other carbohydrates can also be made, as well as amino acids, lipids, or anything else the plant needs.) The equation is deceptively simple and originally had scientists believing that photosynthesis was a simple process. We now know that it consists of a large number of complex chemical reactions and that all of the oxygen released in photosynthesis comes from water and all of the oxygen in carbohydrates comes from carbon dioxide.

The reactions of photosynthesis occur in two phases, the photochemical, or light-dependent, reactions, which must have light energy to drive them, and the thermochemical, or light-independent, reactions (see next plate), which use the high-energy molecules produced by the photochemical reactions but do not directly require light themselves. (At night, plants have to live by respiration, just as we do.) The photochemical reactions are believed to be carried out by molecules embedded in the thylakoid membranes (recall Plate 38), while the thermochemical reactions appear to occur in the stroma, the portion of the chloroplast outside the thylakoids.

Color the heading Photosystem I and titles F through L. Color the E arrows and structures F through L, but leave structures F', H', I', and J' for later.

The thylakoid membrane seems to have two groups of molecules, called photosystem I and photosystem II, each with different functions. Although both work simultaneously, we will have to discuss them one at a time. The first and most important event in either photosystem is the capture of light energy by a group of molecules acting as a sort of light-capturing antenna. These molecules are all brightly colored, so they are commonly referred to as pigments. They include two kinds of chlorophyll (three in some algae), which are responsible for the green color of plants, as well as several carotenes (yellow-orange) and xanthophylls (yellow). The absorbed light energy is passed along to a specialized molecule of chlorophyll a, which in photosystem I is called pigment 700 (from the wavelength in nanometers of light it absorbs most efficiently). The energy it receives from the other pigments is transferred to a single electron, which is raised to such a high energy level that it breaks free of the pigment 700 molecule and passes (along the electron pathway) through a series of electron transport molecules similar to those in the mitochondrion.

When two photons (units of light energy) are absorbed, two electrons are passed through these transport molecules and reduce a molecule of NAD (a close analogue of NADH; recall Plate 51) to NADPH, joined by one proton (hydrogen ion). Since this is a reduction and it is driven by light energy, it is called photoreduction.

Color the heading Photosystem II and structures F', H', I', and J'. Color titles and structures M through Q.

The light-capturing pigments of photosystem II channel the energy absorbed to a slightly different molecule of chlorophyll a, called pigment 680, which also transfers the energy to an electron and causes it to break free. That electron is passed through a different series of transport molecules specific to photosystem II, and it replaces the electron lost by pigment 700. (The illustration shows two electrons doing this, since two were required for the reduction of NADP, but they apparently go through one after the other.) The loss of electrons leaves the pigment 680 molecule with such a strong attraction for replacement electrons that it removes electrons from water, releasing protons (hydrogen ions) into the thylakoid interior and also releasing an oxygen atom (half of an oxygen molecule). This process is called photolysis.

Color the remainder of the plate.

According to the chemiosmotic hypothesis, each electron carries a proton from the stroma into the interior of the thylakoid (proton pathway) in the same manner as protons are transported in the mitochondrion (Plate 56). The flow of protons out of the thylakoid, through stalked \textit{CF}_{1} particles, phosphorylates ADP to ATP to provide energy for the thermochemical reactions that follow.
PHOTOCHEMICAL REACTIONS

NET REACTION:
CARBON
OXYGEN IN CARBON DIOXIDE

HYDROGEN:
OXYGEN IN WATER
LIGHT ENERGY

6CO₂ + 6H₂O → C₆H₁₂O₆ + 6O₂

PHOTOSYSTEM I
LIGHT-CAPTURING PIGMENTS
PIGMENT 700
TRANSPORT MOLECULE
ELECTRON PATHWAY
PROTON (H⁺)
PHOTOREDUCTION
NADP⁺/NADPH

PROTON PATHWAY
PHOTOPHOSPHORYLATION
CF₁ PARTICLE
CHEMIOSMOTIC FLOW
ADP + P₅/ATP

STROMA

PHOTOSYSTEM II
PIGMENT 680
PHOTOLYSIS
WATER
ELECTRON
OXYGEN

TO THERMOCHEMICAL REACTIONS

ATP

ADP + P₅

PHOSPHOLIPID BILAYER