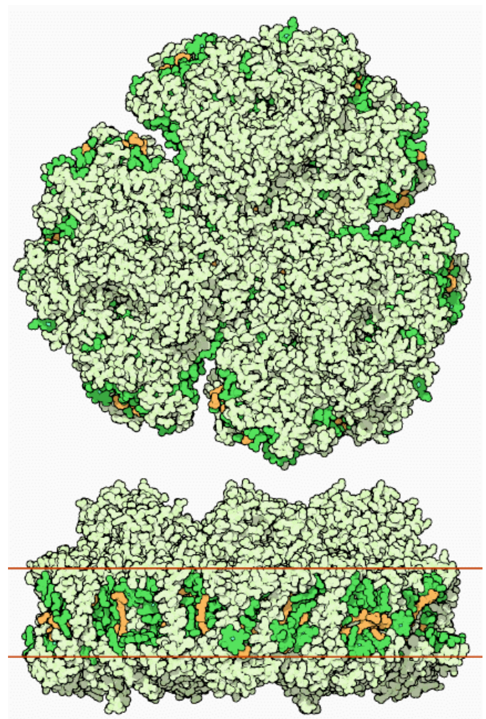
October 2001: Photosystem I

Look around. Just about everywhere that you go, you will see something green. Plants cover the Earth, and their smaller cousins, algae and photosynthetic bacteria, can be found in nearly every corner. Everywhere, they are busy converting carbon dioxide into sugar, creating living organic molecules out of air using the energy of sunlight as power. This process, termed photosynthesis, provides the material foundation on which all life rests.

Capturing Light



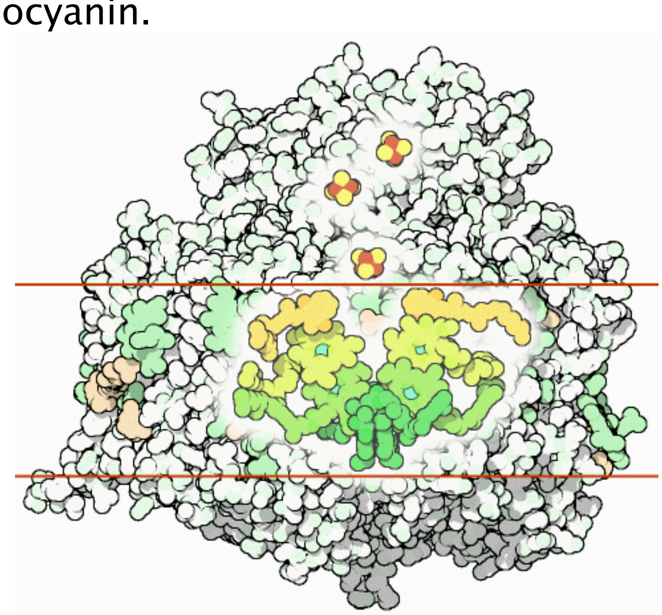
At the center of photosynthesis is a class of proteins termed photosynthetic reaction centers. These proteins capture individual light photons and use them to provide power for building sugar. The example shown here is photosystem I (PDB entry 1jb0), one of the two large reaction centers used in cyanobacteria, algae and plants. Photosystem I is a trimeric complex that forms a large disk. In cells, the complex floats in a membrane (the membrane is indicated by the two red lines in the lower picture) with the large flat faces exposed above and below the membrane.

Colorful Cofactors

Each of the three subunits of photosystem I is a complex of a dozen proteins, which together support and position over a hundred cofactors. Some of these cofactors, shown here in green and orange, are exposed around the edge of the complex and many others are buried inside. Cofactors are small organic molecules that are used to perform chemical tasks that are beyond the capabilities of pure protein molecules. The cofactors in photosystem I include many small, brightly-colored molecules such as chlorophyll, which is bright green, and carotenoids, which are orange. The colors are, in fact, the reason that these molecules are useful: the colors are an indication that the cofactors absorb other colors strongly. For instance, chlorophyll absorbs blue and red light, leaving the beautiful greens for us to see. The energy from these absorbed colors is then captured to perform photosynthesis.

The Electron Transfer Chain

The heart of photosystem I is an electron transfer chain, a chain of chlorophyll (shown in green), phylloquinone (shown in orange) and three iron-sulfur clusters (yellow and red at the top). These cofactors convert the energy from light into energy that the cell can use. The two chlorophyll molecules at the bottom capture the light first. When they do, an electron is excited into a higher energy state. Normally this electron would quickly decay, releasing heat or releasing a new photon of slightly lower energy. But before this has a chance to happen, photosystem I passes this electron on, up the chain of cofactors. At the top, the electron is transferred to a small ferredoxin protein (not shown here), which then ferries it on to the other steps of photosynthesis. At the bottom, the hole left by this wandering electron is filled by an electron from another protein, plastocyanin.



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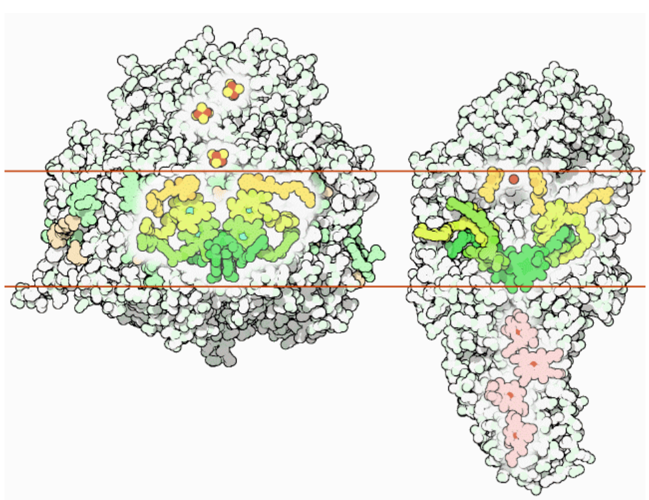
This may seem rather mundane until you see the trick that the photosystem is performing. The proteins at both ends of this process, ferredoxin and plastocyanin, are carefully chosen. Because of the special design of their own cofactors, it is more difficult to add an electron to ferredoxin than it is to plastocyanin--normally, the flow would be in the opposite direction. But photosystem I uses the energy from light to energize the electron, moving it in a difficult direction. Then, since the electron is placed in such an energetic position, it can be used to perform unfavorable duties such as the production of sugar from carbon dioxide.

Photosynthetic Cousins

Different photosystems are used by different photosynthetic organisms. Higher plants, algae, and some bacteria have the photosystem I shown here and a second one termed photosystem II. A low resolution structure of photosystem II is available in PDB entry 1fe1 (not shown here). Photosystem II uses water instead of plastocyanin as the donor of electrons to fill the hole left when the energized electron is passed up the chain. When it grabs electrons from a water molecule, photosystem II splits the water and releases oxygen gas. This reaction is the source of all of the oxygen that we breathe. Some photosynthetic bacteria contain a smaller photosynthetic reaction center, such as the one shown on the right (PDB entry 1prc). As in photosystem I, a stack of chlorophyll and other cofactors transfer a light-energized electron up to an energetic electron carrier.



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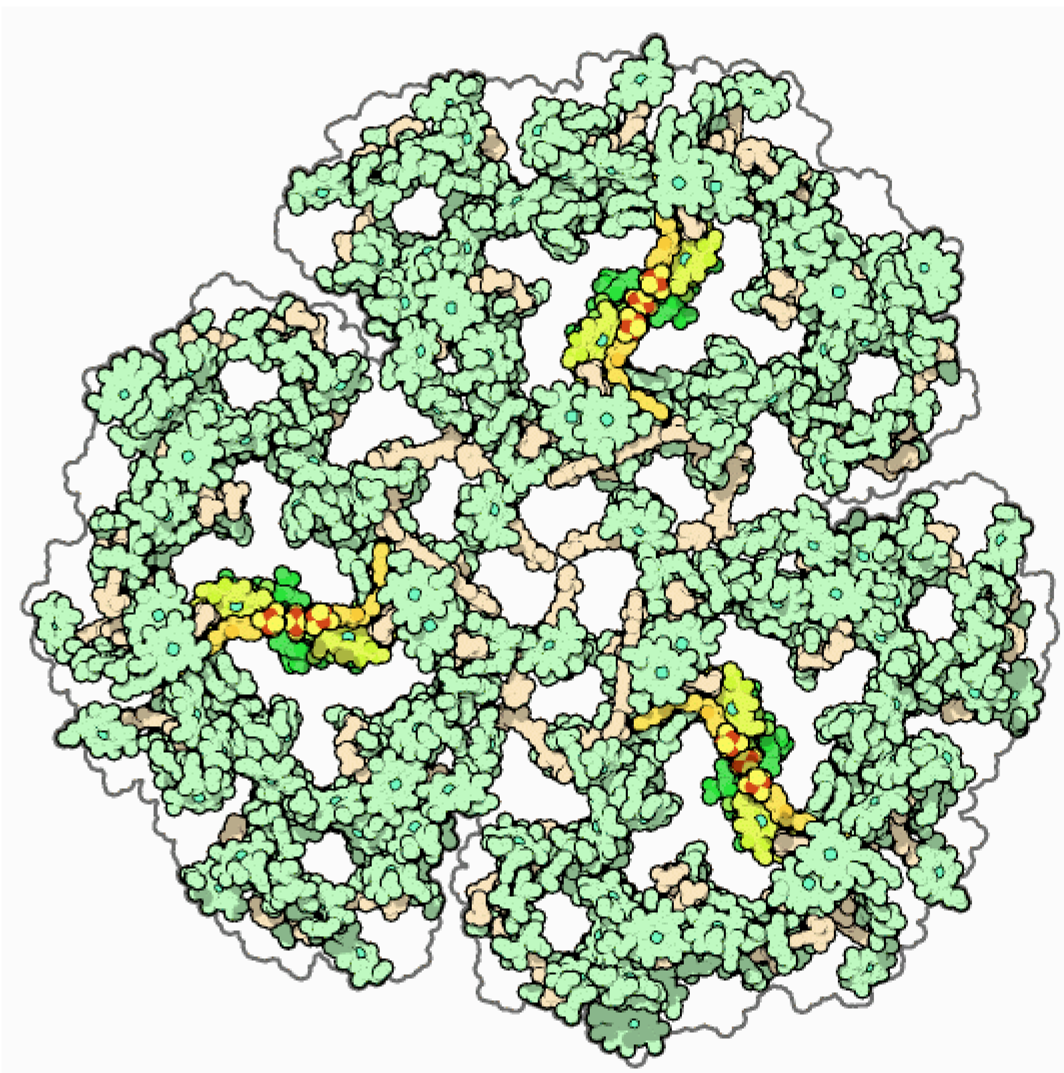
Harvesting Light

Of course, plants do not rely on the slim chance of a photon running into one tiny chlorophyll molecule in the middle of the reaction center. As with all things in life, cells have found an even better way. Photosystem I, shown here looking from the top, contains an electron transfer chain, colored here in bright colors, at the center of each of the three subunits. Each one is surrounded by a dense ring of chlorophyll and carotenoid molecules that act as antennas. In this picture, the protein is transparent so that only the cofactors are seen. These antenna molecules each absorb light and transfer energy to their neighbors. Rapidly, all of the energy funnels into the three reaction centers, where is captured to create activated electrons.



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Exploring the Structure

You can look at the many photosystem I cofactors of the electron transfer chain and the antenna in PDB entry 1jb0. Only one of the three subunits is included in the file, but you will find that this is complicated enough. If you display only the cofactors, you will get a picture like the one shown here. This picture shows the electron transfer chain at the center, drawn in spacefilling spheres. Two special chlorophyll molecules, residues 1140 and 1239, are also shown in spheres and colored green. These two chlorophyll molecules act as a bridge between the reaction center in the middle and the many molecules in the surrounding antenna. The many antenna cofactors are shown here in bond representation with small spheres for the magnesium ions at the center of each chlorophyll.