Dr. Chris Kirmaier on **"Photosynthesis--It's Not Just About Plants"**

- (32 years as Research Professor of Chemistry at Washington University; a Master Gardener for 5 yr.; on M.G. Training Committee since 2008; an avid gardener, bird watcher, and orchid hobbyist)

Photosynthesis underlies nearly all life on earth. Dr. Kirmaier presented unusual examples of it from eons ago and in today's world and we learned how nature figured out solar energy long before man did.

One half of photosynthesis and half of the oxygen (O_2) we breathe comes from lakes, rivers, and oceans. The earth is 4.5 billion years old and 3 billion years ago **photosynthetic bacteria** (e.g., *Rhodobacter capsulatus*) had figured out how to use sunlight to live and grow.. These bacteria that are still around today have a pigment that is the predecessor of chlorophyll. They do a simple form of photosynthesis and cannot "split" water. In place of water, they use organic or inorganic compounds from their surroundings, such as hydrogen sulfide.

Over time, waning organic/inorganic resources began to force photosynthetic bacteria and photosynthesis to advance. By about 3 to 2.5 billion years ago, chlorophyll-containing photosynthetic bacteria appeared--called **cyanobacteria.** This was the birth of "modern" photosynthesis wherein water is consumed and split apart into oxygen and protons. Oxygen is given off as a waste product ("the poop of photosynthesis").

The overall process of photosynthesis is usually written:

Light Energy +6 H_2O + 6 CO_2 ---> $C_6H_{12}O_6$ (sugar) + 6 O_2 (oxygen)

Cyanobacteria were the organisms that oxygenated the earth over the next billion years or so. It took a long time for all the earth's bodies of water and all the earth's rocks to become oxygenated before there was free O_2 in the atmosphere. Cyanobacteria occupy an amazing range of ecological niches on earth, even at extremes of temperature and pH. Examples are seen at Yellowstone in springs where the temperature can be 170 degrees with a pH as low as 1 or 2.

Red and brown algae developed 1.2 billion years ago and **green algae** 0.75 billion years ago with more complex structures than the cyanobacteria. Algae are not plants or bacteria; (giant kelp is not a vascular plant but an algal one).

Green grows inside of rocks! There are many species of cyanobacteria and algae that live inside rocks. Typically, these live just below the rock's surface where they can gather in enough light. The pores of the rock hold enough water to support photosynthesis. Such organisms are common in desert environments, both hot and cold. The technical term for organisms that can colonize cavities within porous rocks is **cryptoendolithic**.

Another interesting example of an alga is *Emiliania huxleyi,* which lives in the upper sunlit portions of all but the polar oceans and was discovered in mud samples by Thomas Huxley in the late 1800s. These organisms cover themselves with sculptured shells called coccoliths (balls of $CaCO_3$, the substance of egg shells, snail shells, sea shells, coral reefs, chalk, limestone, marble, and most calcium supplements). This alga can form massive blooms in the oceans that are visible from space. Over hundreds of millions of years, the discarded coccoliths provided a continual rain down to the ocean floor. Eons ago, as the polar ice caps formed and the oceans receded, cliffs came into view, e.g., the White Cliffs of Dover that are comprised mainly of coccoliths and also from coral reef detritus.

Vascular plants emerged about 423 million years ago and are found even in Antarctica. Modern plants and algae carry out photosynthesis with essentially the same mechanism crafted in the ancient cyanobacteria 2.5-3 billion years ago. Much of the inside of the plant cell is occupied by microscopic chloroplasts. Inside the chloroplasts are millions of rechargeable chlorophyl l "batteries", or solar cells (each about 20,000 times smaller than the diameter of a human hair), organized in solar panels. It is at the chlorophyll "battery" inside the chloroplast that light is absorbed, resulting in the energy used to split water (among other uses) that supports, directly or indirectly, most of life on earth.

An interesting aside: Photosynthesis--Plant or Animal?

Sea slugs (salt water snails that have no shell) exist worldwide and can come in exotic and flamboyant colors. Only in the last 10-12 years it has been realized that a few special ones are "solar-powered". One example is *Elysia chlorotica*, common on the east coast of the U.S. This sea slug is born a tannish brown. The juvenile eats algae for 2-3 weeks, sucking out the contents of the algae and digesting and discarding all but the chloroplasts that become suffused throughout the animal's extensive digestive system. The chloroplasts turn the body a brilliant green. The animal never has to eat again throughout its lifespan of 10 months because it uses the previously ingested algal chloroplasts to drive photosynthesis. It also adds algal chromosomes to its DNA through a process known as "horizontal gene transfer" between the alga and the animal. This gives the animal the ability to send "command and control signals" to the chloroplasts and keep them alive and functioning in the sea slug's body. It's an amazing story with much yet to be learned. Google "solar-powered sea slugs" to read more. Fun for kids! A nice article written about the original discovery of this by Dr. Mary Rumpo is:

http://www.newscientist.com/article/dn16124-solarpowered-sea-slug-harnesses-stolen-plant-genes.html

Timeline of Photosynthesis on Earth

This is part of a Feature "The Color of Plants on Other Worlds" from the April 2008 issue of Scientific American.

Photosynthesis evolved early in Earth's history. The rapidity of its emergence suggests it was no fluke and could arise on other worlds, too. As organisms released gases that changed the very lighting conditions on which they depended, they had to evolve new colors.

4.6 billion years ago -- Formation of Earth

3.4 billion years ago -- First photosynthetic bacteria
They absorbed near-infrared rather than visible light and produced sulfur or sulfate compounds rather than oxygen. Their pigments (possibly bacteriochlorophylls) were predecessors to chlorophyll.

2.4–2.3 billion years ago -- First rock evidence of atmospheric oxygen

2.7 billion years ago -- Cyanobacteria
These ubiquitous bacteria were the first oxygen producers. They absorb visible light using a mix of pigments: phycobilins, carotenoids and several forms of chlorophyll.

1.2 billion years ago -- Red and brown algae
These organisms have more complex cellular structures than bacteria do. Like cyanobacteria, they contain phycobilin pigments as well as various forms of chlorophyll.

0.75 billion years ago -- Green algae
Green algae do better than red and brown algae in the strong light of shallow water. They make do without phycobilins.

0.475 billion years ago -- First land plants
Mosses and liverworts descended from green algae. Lacking vascular structure (stems and roots) to pull water from the soil, they are unable to grow tall.

0.423 billion years ago -- Vascular plants
These are literally garden-variety plants, such as ferns, grasses, trees and cacti. They are able to grow tall canopies to capture more light.