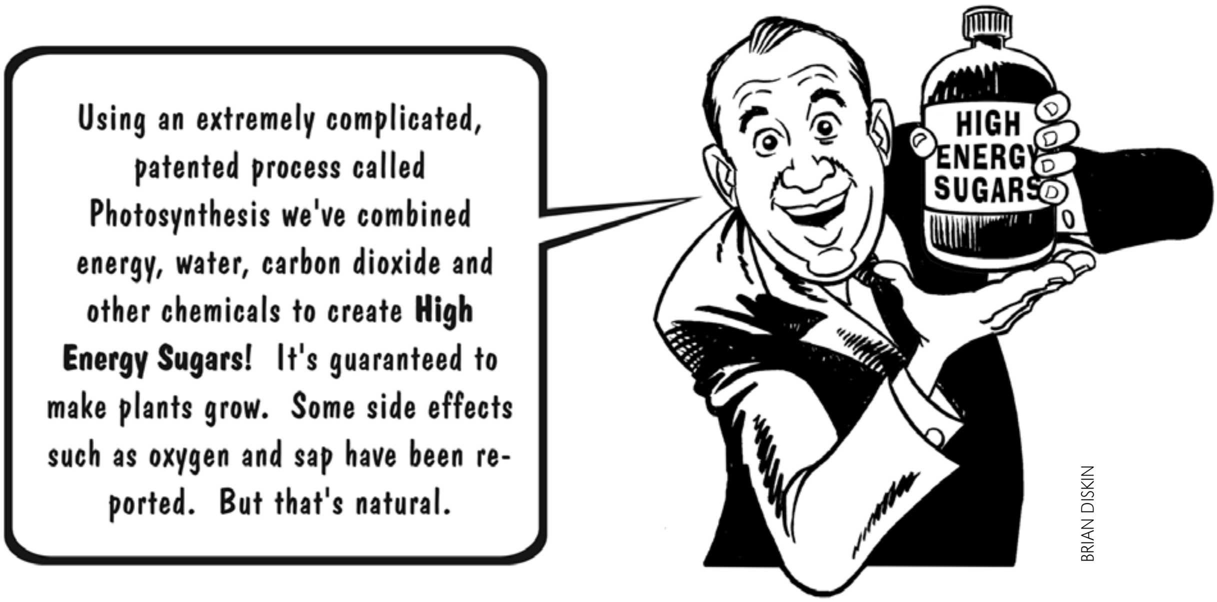
Q: How does photosynthesis work?



A: Energy transformations are an important part of the functioning of ecosystems, and a key part of those energy transformations is photosynthesis. *Photosynthesis* is the process by which plants, bacteria, and other organisms use the energy of sunlight to manufacture food in the form of sugar. If it weren't for photosynthesis, the energy source (sunlight) for all ecosystems would be useless. In other words, we'd all die, even though we might have really nice tans. In a Science 101 column last year, "How does the human body turn food into useful energy?" (March 2006, p. 60), I discussed how humans use food for energy, so it only makes sense that we should address how we get that food in the first place, via photosynthesis. In doing so, I'll stick with photosynthesis as it occurs in green plants. In addition to providing food for animals that eat plants and for the plants themselves, photosynthesis provides another valuable service. The process removes carbon dioxide from the air (a waste product for animals) and replaces it with oxygen, something animals need in order to survive.

A Simple Process?

You can represent the overall process of photosynthesis in a simple way. Plants take in carbon dioxide and water and produce glucose (a sugar) and oxygen. As a chemical equation, this looks like the following:

$$\text{carbon dioxide} + \text{water} \xrightarrow[\textit{produces}]{} \text{glucose} + \text{oxygen}$$

or

$$6CO_2 + 6H_2O \xrightarrow[\textit{produces}]{} C_6H_{12}O_6 + 6O_2$$

The numbers refer to how many molecules of each type take part in the reaction and how many atoms of each type (carbon, hydrogen, and oxygen) are in each molecule. Anyway, this looks like a simple procedure. Carbon dioxide is available in the atmosphere, and plants are good at absorbing water, so why can't plants (or any other organisms, for that matter) just combine carbon dioxide and water to produce glucose and oxygen? For the answer to that, simply look at your nearest bottle of sparkling water. It contains lots of water and lots of dissolved carbon dioxide, but you won't notice the spontaneous generation of sugar and oxygen in that sparkling water. Obviously, just bringing the proper ingredients together doesn't produce the desired result. So, though the overall process of photosynthesis might look simple, the details must not be simple.

Examining the Details

If you head to the internet or your favorite textbook to learn about the details of photosynthesis, you will likely find that the vocabulary becomes overwhelming in a hurry. In fact, you can soon see nothing but the vocabulary words and become confused in short order. One reason for this is that photosynthesis is quite complicated, and the other is that many biology references are overly fond of vocabulary. To avoid this problem, I'm going to stick to the basics of photosynthesis and focus primarily on the energy transformations involved. In fact, I'm going to begin by recalling a basic energy concept that I've addressed in earlier columns. After the energy discussion, I'll talk briefly about the plant structures involved in photosynthesis. First though, the energy.

If you have a ball sitting at the top of a hill, all it takes is a little nudge for the ball to roll down the hill, enabling you to use its energy for some useful or not-so-useful purpose. If that ball is not at the top of a hill, though, you might have to first give the ball some energy before you can get energy out of it. (See Figure 1.)

Relating this concept to plants, a plant uses two high-energy molecules to create sugars. Those molecules are adenosine triphosphate (ATP) and "reduced" nicotinamid adenosine dinucleotide phosphate (NADPH). You can think of these two molecules as balls at the top of their respective hills—they are poised to provide the energy needed to create sugar out of carbon dioxide. The problem is that plants don't just have these molecules sitting around (although they do have the chemicals necessary to produce the high-energy molecules). Enter light. In a complex process, plants use light energy to transform a couple of low-energy molecules—adenosine diphosphate (ADP) and nicotinamid adenosine dinucleotide phosphate (NADP)—into the high-energy molecules it needs. Figure 2, page 62, shows the transfers of energy involved in this process.

What's interesting is that the difference between the low-energy molecules and the high-energy molecules is relatively small. ATP has one more phosphate group (a phosphorous atom plus four oxygen atoms, with a couple of extra electrons) than ADP, and NADPH is the same as NADP with the exception of one additional hydrogen atom that's missing an electron. These differences in energy are a result of the different numbers of electrons and their positions in relation to the atoms. This is common in chemistry. Simply changing how close an electron is to the nucleus of an atom changes the total energy of an atom, just as changing the distance a ball is from the surface of the Earth changes the energy of the situation. Of course, these tiny energy differences add up to a considerable amount, because we're dealing with millions of ATP and NADPH molecules.

I should end by saying that you will run across the molecules ADP, ATP, NADP, and NADPH in lots

Figure 1.

Sometimes you have to expend energy to get energy.

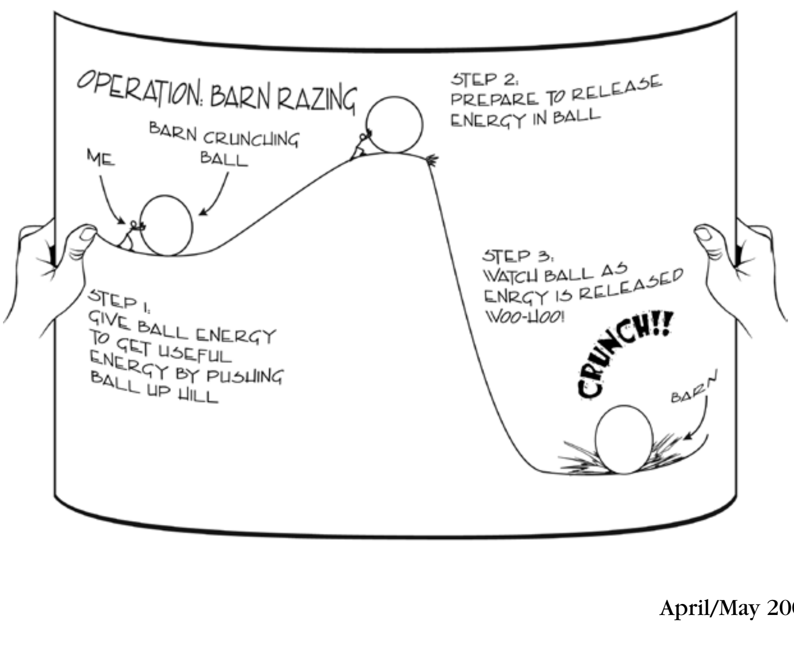


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Figure 2.

Energy transfers in photosynthesis.

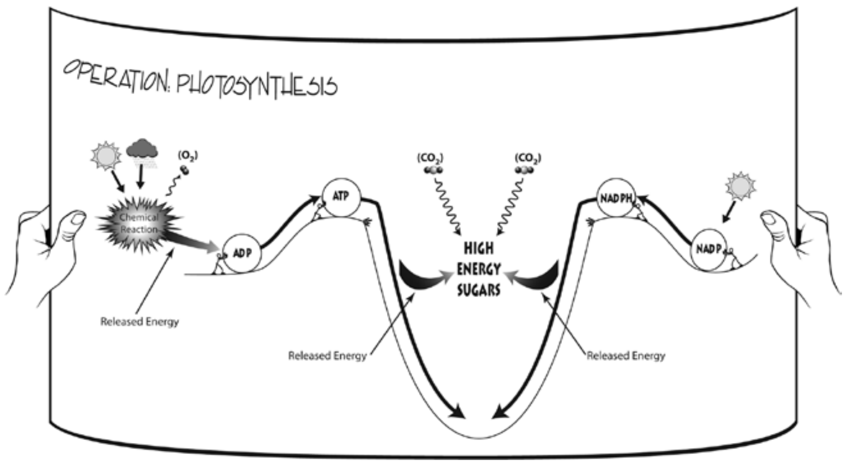

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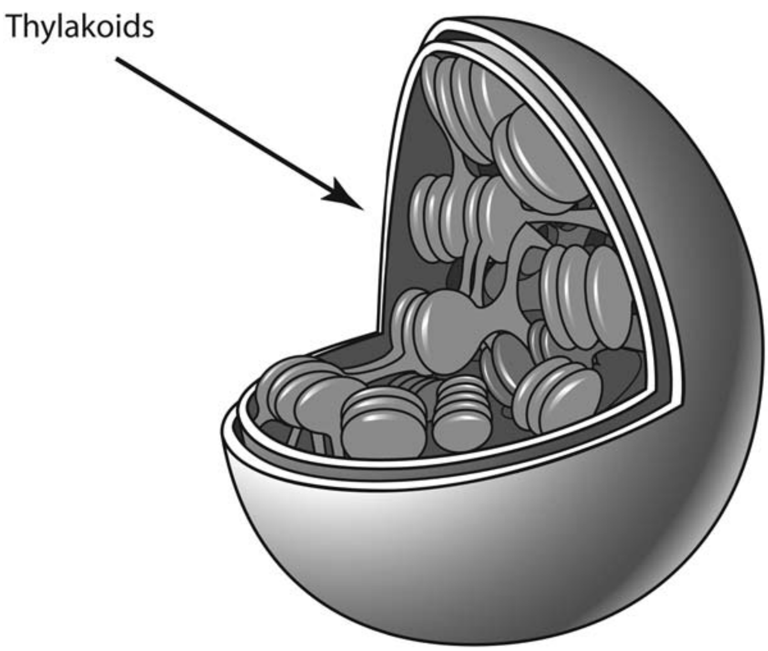
Figure 3.

Photosynthesis occurs in sacs called thylakoids inside chloroplasts.



of chemical reactions that take place in living organisms. As with photosynthesis, following the energy transformations will help you understand the overall processes in those reactions.

The Plant Factory

As I said, the complete process of photosynthesis is pretty darned complicated. There are lots of plant parts involved, lots of different molecules involved, and many chemical pathways. If you keep the overall energy transfer in mind, though, you should have an easier time wading through a more complex explanation. Here is a brief overview of how and where photosynthesis occurs.

Using Light

Plants have a pigment called *chlorophyll* that absorbs light in the red-orange and blue-violet parts of the spectrum. Chlorophyll reflects green light, which is why plants are green. Parts of the chlorophyll known as *antennae* absorb the light energy and funnel the light energy to what are called *reaction centers*, where another energy transfer takes place by the movement of electrons from molecule to molecule. Plants that thrive without a lot of sunlight have a larger number of antenna sites to gather enough light for photosynthesis under such conditions.

The main chemical reactions of photosynthesis take place in plant structures called *chloroplasts*, and specifically in something called the *thylakoids*. Thylakoids are flat sacs that contain the chemicals such as NADP and ADP that are necessary for photosynthesis to occur (Figure 3).

Gases In, Gases Out

Plants don't breathe the way humans do, and gases don't pass easily through the waxy parts of leaves, but leaves have special sites known as *stomata* that can open and close. Carbon dioxide enters through the stomata, and oxygen leaves (no pun intended) in the reverse direction. Plants lose lots of water in this process, so the ability to gather lots of water is a good thing for plants. Special tubes known as *xylem* transport water efficiently from the roots of a plant to the leaves.

Photosynthetic Products

Plants use the sugar products of photosynthesis to produce carbohydrates. These carbohydrates are converted to useful energy that plants use to grow and reproduce, and they also serve as the main food source that animals use for all bodily functions. I should also end by giving thanks to our friends the plants, without which we'd starve and run out of oxygen. Thanks, plants.

Resources

Robertson, B. 2006. How does the human body turn food into useful energy? *Science and Children* 43(6): 60–61.

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