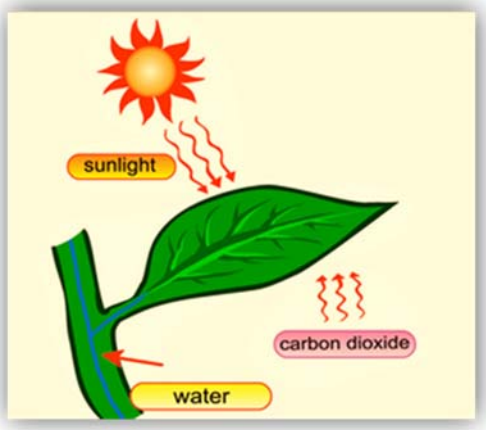

PHOTOSYNTHESIS - THE WHAT, WHERE, HOW, AND WHY OF IT

Unit Overview

Photosynthesis is probably the most important chemical reaction in the world. Without it life as we know it could not exist. In this lesson we will define it and look at the structures where it occurs. We will see in a simplified manner how it occurs. Then we will find out why it is so important for us to study it.

What is Photosynthesis?

QuickTime Photosynthesis (02:18)

Photosynthesis is the process by which plants, algae, and some bacteria use the energy of light, water, and carbon dioxide to make sugar. The word itself can give us clues as to its definition. The prefix “photo” refers to light and the remainder of the word “synthesis” means to make or put together. So photosynthesis is putting together with light. Of course this is a bit of a simplification. Research is still going on to study this very complex process. We will look at just the basic process.

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Plants and Bacteria that Photosynthesize

Where Does Photosynthesis Take Place?

Photosynthesis can only occur is plants, algae, and some bacteria because only those organisms contain **chlorophyll**, an essential chemical to trap the energy of light. Since we are more familiar with plants, we will focus on where photosynthesis occurs in plants. The leaves of plants are the factories where photosynthesis occurs. Different parts of the leaf have different functions or jobs to do. Examine the diagram on the next page as the parts of the leaf are discussed. The outermost layer is the cuticle which is a waxy coating that keeps the leaf from drying out. The upper and lower dermis layers are for protection, just like your skin protects the tissues underneath it. The stoma is an opening on the lower surface of the leaf that allows

gases to move into and out of the leaf. The guard cells open and close the stoma. The vascular bundles are the transportation system for the liquids; these bundles are seen as the veins in a leaf. Water and dissolved minerals are carried into the leaf by the xylem. Dissolved sugars and other nutrients are carried from the leaf by the phloem. The mesophyll consists of thin-walled cells that contain the **chloroplasts**, and it is within the chloroplasts that the chlorophyll is found. The palisade mesophyll cells are closely packed at the upper surface of the leaf and contain many chloroplasts. This is where most photosynthesis occurs. The spongy mesophyll cells are loosely arranged allowing for gases to circulate as they go in and out of the stomata (plural for stoma).

QuickTime Chloroplasts (01:29)

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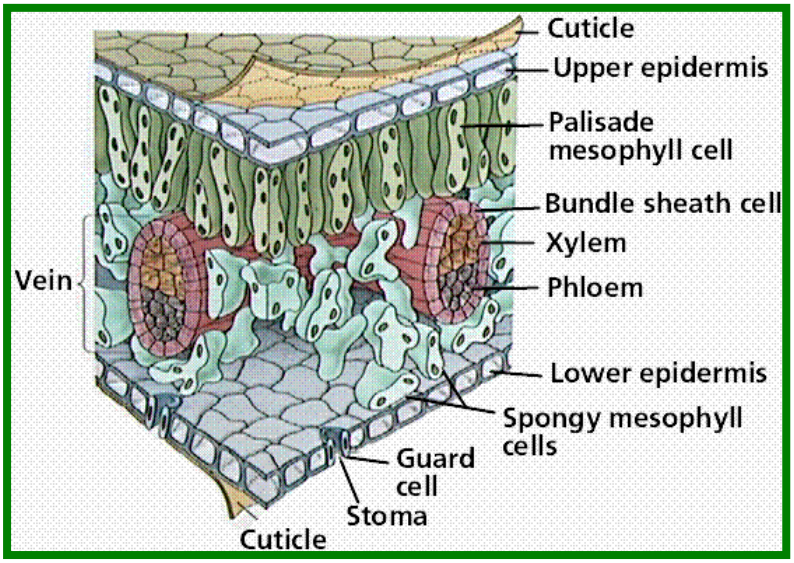
Leaf Structures



How Does Photosynthesis Occur?

The key to the process of photosynthesis is chlorophyll. Chlorophyll is a green **pigment**. A pigment is any substance that absorbs light. Light is composed of different wavelengths, and each wavelength is seen by our eyes as a different color. The various colors in light are those of the rainbow - red, orange, yellow, green, blue, and violet. Different pigments absorb different wavelengths of light and reflect the rest. That is why we associate the word pigment with color. For example, all paints contain pigments that give them their specific color. The color reflected is the color of the pigment; so red paint has in it a pigment that absorbs all light except red light and that is the light that is reflected and seen by our eyes. White objects reflect all light, and black objects absorb all light, reflecting none. Since chlorophyll is green, it is a pigment that absorbs all colors except for green and yellow. The green and yellow wavelengths are reflected. Since the epidermis of a leaf is transparent so light can shine through it, we seen the green of the chloroplasts which gives all leaves their green color.

The chlorophyll molecule is arranged in a circle or ring so that electrons can flow easily around it. In case you do not know, electrons are tiny negative particles that buzz around the nucleus or center of all atoms. Under certain circumstances electrons can move from one atom to another. Some plants have additional pigments called **carotenoids** that can also move electrons. The word carrot comes from the fact that carrots contain carotenoids. Can you guess what color carotenoids are? Yes, they are orange! Why are moving electrons so important?

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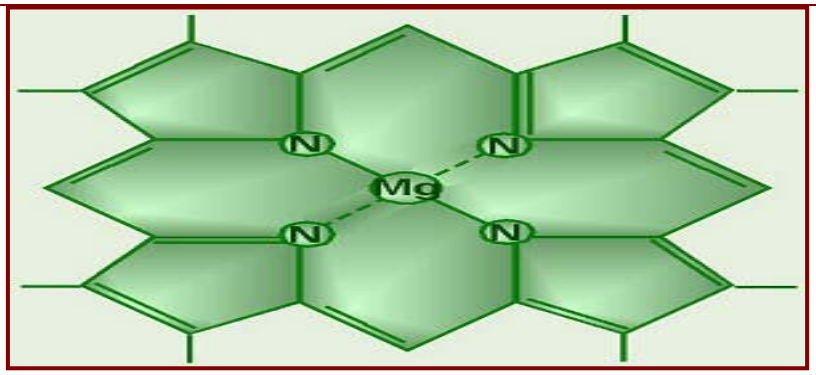

Chlorophyll structure where the light reaction occurs.

The wonder of photosynthesis is that it takes sunlight, which except for keeping us warm cannot be used by us, and transforms it into **chemical energy**, which is energy stored in the molecules of a substance. (Molecules are simply atoms hooked together in various combinations.) This stored chemical energy is used as food either directly or indirectly by all living beings. Without photosynthesis no living being would be able to able to grow or reproduce or even exist! Chlorophyll and carotenoids use sunlight by using the energy in light to move electrons. Carotenoids are known as accessory pigments because they help by directing electrons toward the chlorophyll. We say that the electrons are excited because they quickly move around the chlorophyll molecules until they reach a central area called the reaction site where photosynthesis occurs.

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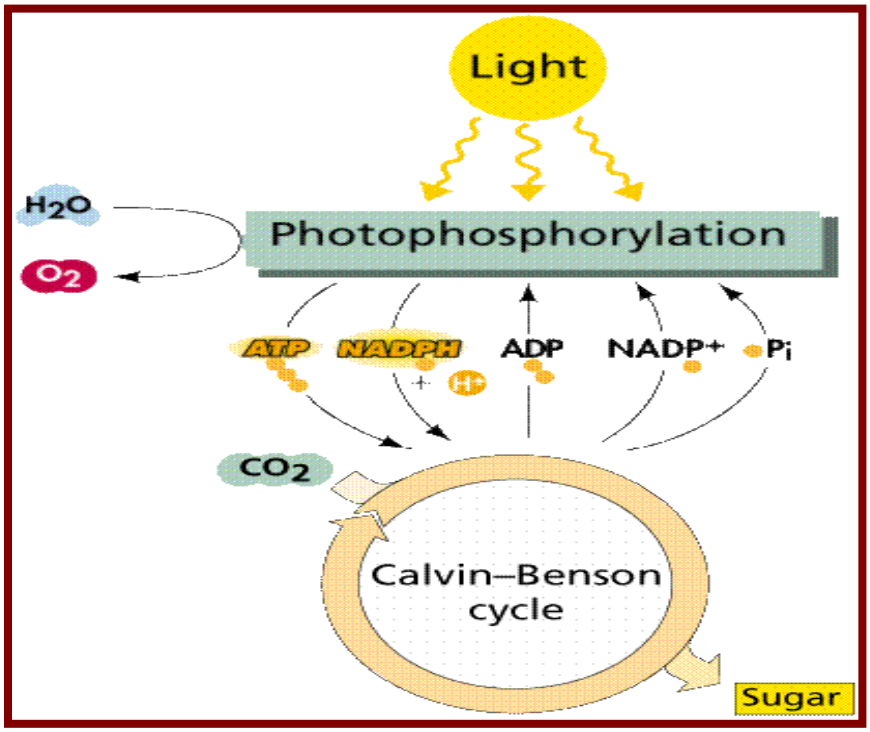

Photosynthesis occurs in two parts: a light reaction and a dark reaction. The **light reaction** as the name suggests requires direct sunlight. During this reaction the plant uses water, H_2O, to create two types of high energy molecules that are abbreviated ATP and NADPH. These are very complex molecules made from other less energized molecules known as ADP and $NADP^+$. The water is brought to the leaf from the roots of the plant through the xylem tissues. The energy needed for the reaction comes from those energetic little electrons. A fancy-sounding name for this process is photophosphorylation, but we can just remember that it is the light reaction.

Oxygen, O_2, is also produced. This is important because we need oxygen to breathe as do animals. Do you know that the plant itself needs oxygen to use the food it makes during photosynthesis but that it makes a lot more oxygen than it uses? For example, on one sunny summer day an acre of corn produces enough oxygen for 130 people! An average-sized tree produces enough oxygen to keep 3 people alive!

The second reaction is known as the **dark reaction**, because it can occur without sunlight directly. It uses the ADP and NADPH made from the first reaction and carbon dioxide, CO_2, to produce a simple sugar called glucose, $C_6H_{12}O_6$. The carbon dioxide enters from the air through the stomata, the holes in the lower surface of the leaf. This process is known as carbon fixation (Calvin-Benson cycle in the diagram) because it puts the carbon in a useable form. Once glucose is made, it can be changed in the plant into other sugars, starches, and cellulose. These are called carbohydrates and are an important part

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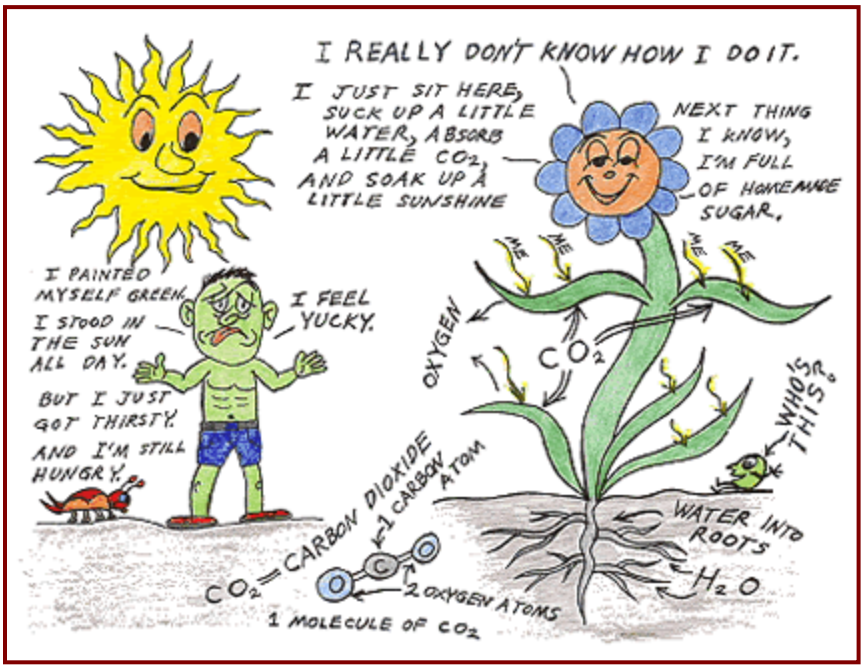
of the food for plants and animals. In addition, proteins and fats can also be made. Carbohydrates, proteins, and fats are basic nutrients needed by living things.



We should be very appreciative of plants for without them we would soon run out of oxygen and food. Another important benefit of plants is that they use carbon dioxide during photosynthesis and therefore, help reduce the threat of global warming caused by the build up in part of carbon dioxide in the atmosphere. We have studied the photosynthesis in plants but we must not forget that algae and some bacteria also photosynthesize. Many of these are found in the ocean as **phytoplankton**, tiny organisms that can photosynthesize. The ocean covers 70% of the Earth's surface. Although these organisms are tiny, they are very abundant. This makes them a very important source of food for marine life and users of carbon dioxide, just like the land plants.

QuickTime The Effects of Global Warming on Coastal Biomes (00:50)

Scientists often like to write chemical reactions in a short-hand way called a chemical equation. The basic equation for photosynthesis is fairly simple and can be shown as:

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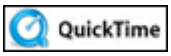
$$6H_2O + 6CO_2 \rightarrow C_6H_{12}O_6 + 6O_2$$

This is read as six molecules of water plus six molecules of carbon dioxide produce one molecule of glucose (a sugar) plus six molecules of oxygen. This equation combines both the light and dark reactions into one. The actual process of photosynthesis involves many intermediate steps and can consist of at least 80 different reactions, but we will let the biologists and research scientists worry about those for now. We will stick with what is needed to get the reaction going and what is formed. Of course we dare not forget that sunlight and chlorophyll are also essential. Because the chlorophyll is a **catalyst**, a substance that is needed for the reaction but is not used up, it is not included in the reaction. However, we could rewrite the reaction and put the chlorophyll above the yields sign (the arrow) to show its importance. We could also include the sunlight as the energy put into the reaction. Then the equation would look like this:

$$\text{Sunlight} + 6H_2O + 6CO_2 \xrightarrow{\text{chlorophyll}} C_6H_{12}O_6 + 6O_2$$



Photosynthesis Reaction (04:57)

Why is Photosynthesis Important?

Of course the most obvious answer to this question is that without photosynthesis we would have no food, not only us, but animals and plants as well. Plants use the food they make in order to release the stored chemical energy in the food to carry on all their life processes, such as growing and reproducing. They do not use all the food they make, so other organisms can use it. For example, we can eat the corn from a corn plant. We are actually eating the seeds that the corn plant produces during the process of reproduction. A cow might eat the corn and then later, we may eat the cow. Either way, we benefit from the food produced during photosynthesis.

Let's not forget the production of oxygen. As stated before, the plant does use some oxygen while using part of the food it makes, but it makes much more oxygen than it uses so animals and humans can use this oxygen. We need oxygen for the same reason that plants do – to release the chemical energy in the food we eat so that we can carry on our life processes. This

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process is known as **respiration.** It is the reverse of photosynthesis. Part of that energy is used just to keep our bodies at about 98.6 degrees Fahrenheit.

Another important purpose of photosynthesis is to keep the supply of carbon dioxide balanced so that global warming can be slowed. All the large forests in the world and the phytoplankton in the ocean are very helpful in this regard.

But there are other reasons. What about the clothes we wear? If they are cotton or linen, they are made from fibers taken from plants. Cotton comes from the cotton plant, and linen is made from the fibers in the flax plant. If they are wool, they come from the hair of sheep or goats. These animals could not survive without the energy and nutrients stored in the plants that they eat. If the fiber is a synthetic like nylon, Dacron, polyester, or acrylic, these are made from petroleum and that too is made from plants.

Petroleum is also used for fuel. Along with coal and natural gas, it is known as a **fossil fuel** because it has been formed over many, many years from the remains of dead plants that have been subjected to extreme heat and pressure deep within the earth. So without plants we would have no fossil fuels. That means no way to power our automobiles or four-wheelers or motorcycles or airplanes and no way for many of us to heat our homes. Fuel oil comes from petroleum. Even if we burn wood, is that not a product of trees? If your home is heated with electricity, remember that most power plants burn coal or oil, both fossil fuels, to produce electricity. Another fuel that is being used more and more is ethanol. This can be derived from petroleum, but it can also be made by fermenting corn. Much of our gasoline has a small percentage of ethanol made from corn added to it. This allows us to use less petroleum so that the United States is less dependent upon foreign sources of oil. This gasoline is sometimes called gasohol. Industries also need fuel to power their machines.

A **fuel** is a material that releases energy in the forms of heat and light when burned. Where does this energy come from? If it is a fossil fuel, it was stored as chemical energy in the plant from which the fuel was made during the process of photosynthesis. Plants (and some bacteria and algae) are marvelous factories for converting the energy of sunlight into chemical energy that can be stored indefinitely. They store away sunshine for later use. The worrisome fact is that as we burn these fuels we are releasing energy from sunlight that was stored over a long time period, and we are doing it quickly. Will we run out of energy? In addition, carbon dioxide and various air pollutants, like nitrogen oxides, are also being released.

If that is not enough reason to value plants for carrying on photosynthesis, let's take a look at the buildings around us. Many parts of these buildings come directly or indirectly from plants. If

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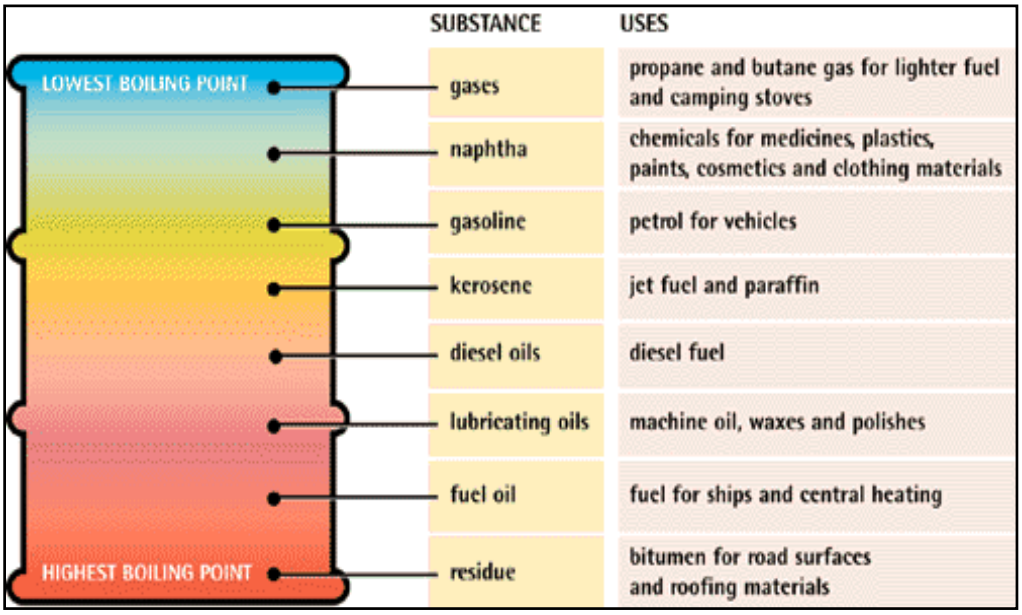
you live in a house made of lumber that is a direct product from trees. What about building materials inside your house? Plastics, paints, some flooring, and sealants are made from petroleum or coal. Your roof may have asphalt shingles on it, another product of petroleum. The carpets in your house are made from fibers like your clothing. Are you beginning to be thankful for plants?

What's in a Barrel of Oil?



Some of the many products we get from petroleum.

There are other reasons to be thankful for photosynthesis. Today scientists are unlocking more and more secrets about how it occurs. Remember it is a very complex process. Perhaps through this knowledge scientists can develop plants that trap the energy of light more efficiently and produce a greater yield of crops to feed the world's growing population. Most plants are not very efficient at doing this. For example, a corn field traps only about 1% to 2% of the sunshine during photosynthesis. Sugar cane is more efficient at about 8%, but uncultivated plants that you might find along the roadside, for example, trap a mere .2% of the sunlight. Another reason that photosynthesis is not very efficient is that on very hot days, photosynthesis can stop or slow down. That is because not only does carbon dioxide enter the plant through stomata, but water as water vapor leaves the plant through these openings. This process is known as **transpiration** To keep the plant from loosing too much water and thus wilting, the stomata close if the temperature soars. No more carbon dioxide can enter, so photosynthesis slows or stops altogether.

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Knowing more about photosynthesis can help us improve our environment. New herbicides, materials that kill plants, could be developed that work on only certain plants by interfering with their photosynthesis because the way photosynthesis occurs in plants can be slightly different. These herbicides would not be hazardous to the rest of the environment. Learning more about photosynthesis may even help us develop smaller and faster computers. Remember that the process involves moving electrons and that is what electronics is all about. Even diseases like skin cancer may be easier to treat if we understand more about photosynthesis. Perhaps we can use this knowledge to design better solar collectors. One scientist is working on placing films on roofing shingles that will absorb different wavelengths of light and then convert that light to electricity. This should be more efficient than our present day collectors and perhaps cheaper, too. Uncovering the mysteries that still exist about photosynthesis can lead to great things. **Bioremediation** is any process using microorganisms to return a polluted environment back to its original state. We can use bacteria in the presence of light to remove toxins from water. Oil spills are often bio remediated by adding fertilizer to stimulate the bacteria to decompose the oil molecules.

Fun Facts Related to Photosynthesis

Why do some plants stay green even during the hottest, driest periods in summer and others wither or turn brown? While many plants shut down photosynthesis when their stomata close, some like crabgrass, corn, and sugar cane can use very low levels of carbon dioxide and stay green by continuing to perform photosynthesis.

How can desert plants photosynthesize in such heat? Many desert plants close their stomata during the day to conserve water, but open them at night. During the night, the carbon dioxide enters the plant and is stored in a chemical reaction that releases it during the day so that photosynthesis can occur.

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Why do leaves change color in the fall? We have already said that it is the presence of chlorophyll that gives leaves their green color. When the amount of light begins to lessen during the autumn months, chlorophyll in the leaves begins to break down. Then the yellows and orange pigments that were in the leaves all along begin to show up. They had been masked by the green of the chlorophyll during spring and summer. The reds and purples are a result of glucose being trapped in the leaves. The bright sunlight and cool nights of autumn cause the glucose to change into other chemicals that give off these colors. Some leaves like oaks are brown. This is due to waste materials in the leaves. Many oaks also keep their leaves for most of the winter.

What causes the reds and yellows in these leaves? Is it the same reason for both?

Now answer questions 1 through 30.

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