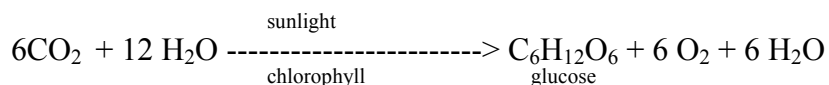


LIGHT AND PHOTOSYNTHESIS PART 1 - LIGHT

There is no more important biochemical process on the planet than photosynthesis. Although this sounds like hyperbole, it is true. First, plants that photosynthesize convert energy from the sun into glucose, a form of stored, chemical energy. As an animal, you eat plants or you eat animals that do eat plants. Therefore, the source of the vast majority of stored chemical energy on this planet comes from photosynthesis. Not only that, but plants produce oxygen as a byproduct. Without plants, there would not be any significant level of oxygen on the planet earth. The earth was essentially without oxygen until plants evolved.

Summary Equation for Photosynthesis

Photosynthesis is not a single chemical equation. Instead, it is a series of complex chemical reactions. However, it is sometimes convenient to represent photosynthesis by a summary equation.



In essence, carbon dioxide from the atmosphere combines with water in the presence of sunlight and the green pigment chlorophyll to form glucose, oxygen and water.

From where does the carbon dioxide come? It is produced by plants and animals through a process known as respiration. Much of the early atmosphere of the earth was also carbon dioxide. Water, of course, comes from rain, the ground, and some plants are even capable of pulling water vapor out of the atmosphere. Notice that oxygen is considered a “byproduct” of photosynthesis.

The Source of Oxygen on Earth

Most people can tell you the source of oxygen on earth is green plants. What they often cannot tell you is the majority of the oxygen is produced, not by terrestrial plants, but plants in the ocean. The ocean has an abundance of microscopic life forms collectively referred to as plankton. There are two basic types of plankton: zooplankton (microscopic animals) and phytoplankton (microscopic plants). Fully ninety percent of the oxygen produced on earth by plants is produced by phytoplankton.

Light from the Sun

In order to really comprehend photosynthesis, it is necessary to understand light in general and sunlight in particular. What is light? Look at the structure of the atom once again. Electrons occupy discrete positions around the nucleus of the atom. They have enough energy to be located at one energy level or another. These discrete amounts of energy electrons possess are called quanta. An electron is therefore found in one energy level or another or is in transit to that energy level.

LIGHT AND PHOTOSYNTHESIS PART 1 - LIGHT

Assume an electron obtains additional energy, enough to propel it to the next energy level. Once there, it can remain there, or it can return to its original level. To return to its original level, it must lose the energy it obtains. It does that by releasing a photon, a particle of energy.

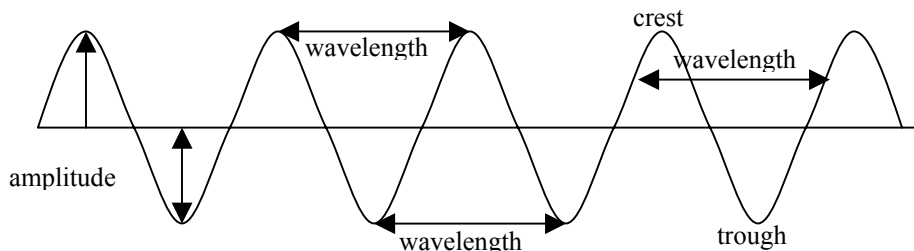
Dual Nature of Light

It is this photon we consider to be light. Take for example a fluorescent light. Electrons are energized in the tube by an electrical current. Those electrons are bounced to a higher energy level and then return to their original position. Photons are being shed from the fluorescent fixture. These photons bounce off objects in the room and eventually strike the surface of your retina to stimulate a nerve impulse to be sent to your brain. Thus you “see” objects by reflected photons off those objects!

Photons have two properties. They can behave just like a bouncing ball – the particulate nature of light, or they can behave simultaneously like a wave – just like a sound wave or a wave at the beach, but in this case, a light wave.

Wave Properties

Assume you are at a beach on a totally calm day. Unusual as it may seem, sometimes the water is so still, there is no wave action, and the surface looks totally smooth. This is our “base line” for waves. On other days, you see waves. It would give you an appearance much like that shown in the diagram.



The height of a wave from the baseline is called amplitude. The same can be said for the “depth” of a wave. The “peak” of a wave is called the crest. The bottom of a wave is called a trough. The distance from one crest to the succeeding crest is called a wavelength. The same can be said for the distance from one trough to the succeeding trough. Also, a wavelength can be the distance from any point on one wave to the succeeding point on the next wave.

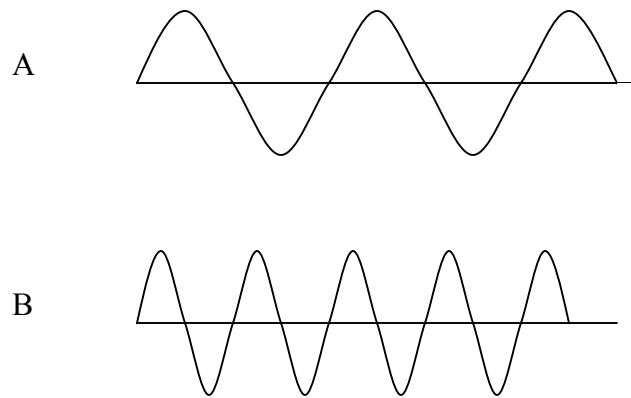
Frequency

The frequency of a wave is defined as the wavelength per time interval. It can be represented by a formula.

$$f = \lambda/t$$

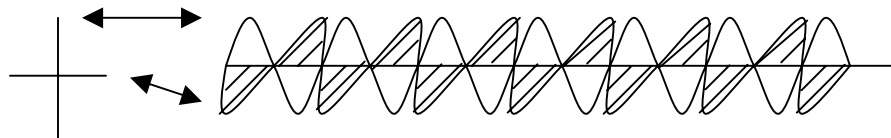
The Greek letter “ λ ” (lambda) stands for wavelength, “ t ” for time in seconds, and “ f ” is frequency.

LIGHT AND PHOTOSYNTHESIS PART 1 - LIGHT



Here are two waves. Which has the higher frequency, A or B? Which has the longest wavelength, A or B? A has the longer wavelength and B is the higher frequency (more wavelengths/time interval).

If you could see sunlight, and you cannot, it would look somewhat like a “+” sign coming straight at you. Sunlight is composed of two waves: one electric wave and one magnetic wave, perpendicular to each other.



The sun produces both electric and magnetic waves of varying frequencies (and wavelengths). The sun is producing electromagnetic radiation of very high frequency and very low frequency, and everything in between. This array of frequencies is called the electromagnetic spectrum.

In this course, we will concentrate on several frequencies (or wavelengths) of electromagnetic radiation: gamma rays, x-rays, ultraviolet rays, visible light, infrared rays, microwaves, TV and radio waves.

LIGHT AND PHOTOSYNTHESIS PART 1 - LIGHT

Gamma Rays

Gamma rays are very high frequency waves and are, thus, considered very penetrating waves. Only large earthen berms, massive concrete walls, and lead shields do a sufficient job of blocking gamma rays. Gamma rays are also mutagenic. Unfortunately, 99.9% of all mutations are harmful – some even lethal. One percent of those mutations are either not harmful or they can be beneficial – mutations to the good. As a matter of fact, the building in which you are sitting is not sufficient to stop gamma rays. You are therefore being bombarded by gamma rays at this moment. The question becomes, are you mutating with your exposure to gamma rays. The answer is probably, but as long as it doesn't affect your sperm and egg, not big problem. You've also had a little time to get use to the gamma radiation from the sun – 4.5 billion years. The sun's gamma radiation (and all other forms of radiation from our sun) is called background radiation. It's this background radiation that has driven evolution on earth for 4.5 billion years. One way of looking at things is to remind you that you are all mutants – the products of 4.5 billion years of, we hope, “beneficial” mutations. Your major concern is when you are exposed to doses of gamma rays in excess of background radiation.

X-Rays

These are the next highest frequency of electromagnetic radiation. X-rays, of course, are very penetrating as well. Think about where an x-ray technician stands when they take your x-ray. They are also mutagenic. Also, like gamma rays, the real danger comes to sperm and egg cells and even the developing fetus in the womb. Any mutation of the fetus that occurs is due to a teratogen. X-rays are both mutagenic and teratogenic.

UV Radiation

These are the rays that tan you. When you lay out in the sun, *when* you get skin cancer, it is due to UV radiation. It is mutagenic. Notice the statement was not *if* you get skin cancer. One reason is the sun's rays are more direct the closer you are to the equator. They are more dispersed above the Tropic of Cancer and the Tropic of Capricorn. Another reason skin cancer is so epidemic is the layer of the atmosphere that protects us from excessive UV radiation, the ozone layer, is diminishing. Ozone is tri-atomic oxygen. It prevents the majority of the UV radiation from penetrating the earth's atmosphere. There are holes in the ozone layer developing over the poles. This phenomenon has been attributed to the use of chlorofluorocarbons (CFC) as propellants in aerosol containers, freon (a CFC) in air conditioners, and from emissions from the internal combustion engine.

Visible Spectrum

The next highest frequency of light from the sun falls within the spectrum of light humans can see. It is called the visible spectrum. The discussion of the visible spectrum will be postponed until later. However, it is also mutagenic.

LIGHT AND PHOTOSYNTHESIS PART 1 - LIGHT

Infrared Radiation

The next highest energy from the sun is in the infrared range. This form of radiation can best be demonstrated by turning on the eye of an electric stove until it glows cherry red. This “reflected” radiation is infrared. You also notice it when you walk past a brick building after the sun goes down and feel the heat radiating off the side of the building. It is also mutagenic. Humans produce infrared radiation from their body. Infrared glasses have allowed people who suffer from night blindness to see well enough in the dark to be able to function in that environment.

Microwaves

The sun also produces microwaves. They are also mutagenic, along with the other frequencies of light. That’s why older versions of microwave ovens used to have signs posted around them they may interfere with pacemakers, etc. The first versions of microwave ovens often leaked due to improper door closures. Microwaves today are most often used in communication, particularly long distance communication.

TV and Radio Waves

No, the sun doesn’t broadcast the top 10 hits, but it does produce electromagnetic (and mutagenic) radiation in the same wavelength as TV and radio stations. That often causes interference with those stations, since the sun’s radiation comes across as static.

Visible Light Revisited

Only a very narrow portion of the electromagnetic spectrum is visible to the human eye. That combination of frequencies that make up the visible spectrum is often referred to as “white” light. Pass that combination of frequencies through a triangular piece of glass called a prism, and the frequencies are separated by the prism and visible as individual colors – the colors of the rainbow. The components of visible light are red, orange, yellow, green, blue and violet. (Some people like to insert indigo between blue and violet to give the mnemonic ‘ROY G BIV’.) Red is the lowest frequency of the visible spectrum (and thus has the longest wavelength) and violet is the highest frequency of the visible spectrum (and thus the shortest wavelength).

Why You See Red

When you see someone with a red colored garment, the shirt or blouse usually starts out without any color. The color is obtained by embedding dye particles in the fabric. The dye particle, although smooth to the naked eye, is actually very rugged and ragged in appearance. When “white” light from the sun hits it, the various frequencies are trapped by the dye particle and only one escapes – red. That red frequency then stimulates the cone cells in your eye (the color cells), and you “see” red.

What About White Clothing?

When you see someone in a white outfit, the “white” light of the sun hits it. No frequency is absorbed and therefore, all the visible components of light are bounced off and stimulate your cone cells. The presence of all visible components stimulating the cone cells results in your seeing white. White clothing is much cooler than dark colored clothing.

LIGHT AND PHOTOSYNTHESIS

PART 1 - LIGHT

What About Black?

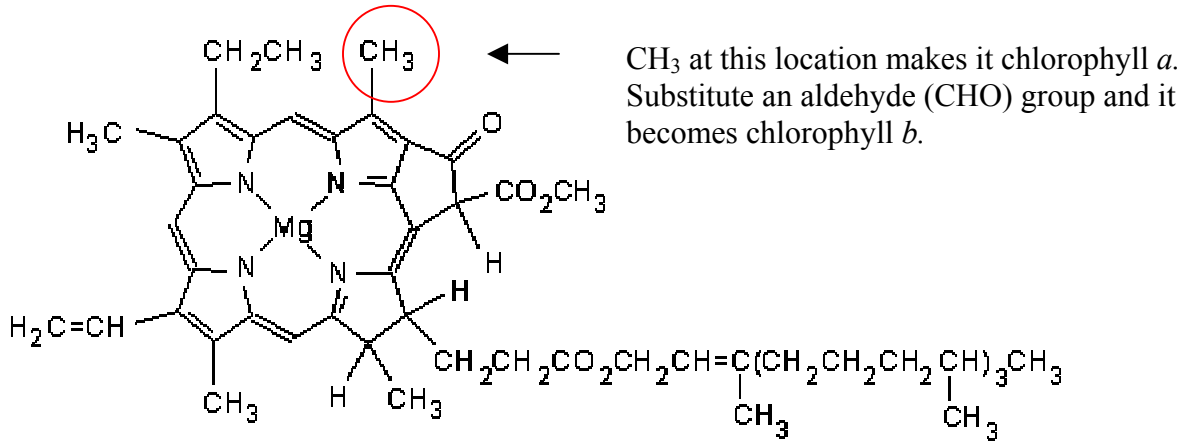
Black clothing absorbs all parts of the visible spectrum and bounce nothing off. The absence of light is dark. Dark colored clothing is actually warmer than light colored clothing, hence the “Panama Suit” which is white...it’s hot in Panama!

Which Frequency Is Important in Photosynthesis?

The question becomes “which wavelength (frequency) of light is the most important in photosynthesis. At first, it is tempting to say green since plants are green. Upon further consideration, you may deduce this is incorrect. Green is the least efficient wavelength in photosynthesis – that’s why plants bounce it off and you see green. Instead, red and blue are the most efficient wavelengths of light for the photosynthetic process.

Chlorophyll

What traps red and blue wavelengths? The answer is the green pigment called chlorophyll. Remember that chlorophyll is found in the thylakoids of the chloroplasts. What you may not know is there are five types of chlorophyll. There’s chlorophyll *a*, chlorophyll *b*, chlorophyll *c*, chlorophyll *d*, and chlorophyll *e*. All green plants contain chlorophyll *a*. All plants contain at least two chlorophylls. Most higher plants, like the trees in your yard, the grass in your lawn, and flowers, contain chlorophylls *a* and *b*. The brown seaweed that often washes up on the beach contains chlorophylls *a* and *c*. Other plants contain *a* and *d*, and others contain *a* and *e*. You may often classify plants based on the types of chlorophylls present.



LIGHT AND PHOTOSYNTHESIS

PART 1 - LIGHT

Primary Pigments of Photosynthesis

Chlorophylls are considered the primary pigments of photosynthesis. However, nature does not waste much and the other wavelengths of visible light are important. These other wavelengths are trapped by other pigments in plants – the accessory pigments.

- I. Primary Pigments of Photosynthesis
 - a. Chlorophylls (Water Insoluble – found in thylakoids)
- II. Accessory Pigments
 - a. Water Insoluble – found in thylakoids
 - i. Carotenoids
 1. carotenes (orange)
 2. xanthophylls (yellow-orange)
 - b. Water Soluble – found in cell sap of central vacuole
 - i. Phycobilins
 1. phycocyanin (blue-green)
 2. allophycocyanin (blue-green)
 3. phycoerythrin (red)
 - ii. flavonoids – found in higher plants – block harmful UV radiation
 1. red
 2. violet
 3. blue
 - iii. flavonols
 1. yellow
 2. ivory

Fall Colors in Leaves

Most of you have seen leaves change colors present in the fall of the year. What many people don't understand is those colors were there at the beginning of the year, all during the spring and summer, and only in the fall do the other colors really begin to "show through". Until the fall, the amount of chlorophyll in the leaf masks all the other pigments. However, in the fall, chlorophyll degenerates and the hidden fall colors begin to appear in the leaf. The curiosity is what causes the chlorophyll to degenerate. There are three things most people associate with the fall season: change in temperature, change in day length, and change in moisture content. The most important parameter on chlorophyll degeneration is ground moisture. The more water in the soil (and the plant) the greater the display of colors.