Light and photosynthetic pigments

Properties of light. How chlorophylls and other pigments absorb light.

Introduction

If you've ever stayed out too long in the sun and gotten a sunburn, you're probably well aware of the sun's immense energy. Unfortunately, the human body can't make much use of solar energy, aside from producing a little Vitamin D (a vitamin synthesized in the skin in the presence of sunlight).

Plants, on the other hand, are experts at capturing light energy and using it to make sugars through a process called photosynthesis. This process begins with the absorption of light by specialized organic molecules, called **pigments**, that are found in the chloroplasts of plant cells. Here, we'll consider light as a form of energy, and we'll also see how pigments – such as the chlorophylls that make plants green – absorb that energy.

What is light energy?

Light is a form of electromagnetic radiation, a type of energy that travels in waves. Other kinds of electromagnetic radiation that we encounter in our daily lives include radio waves, microwaves, and X-rays. Together, all the types of electromagnetic radiation make up the **electromagnetic spectrum**.

Every electromagnetic wave has a particular **wavelength**, or distance from one crest to the next, and different types of radiation have different characteristic ranges of wavelengths (as shown in the diagram below). Types of radiation with long wavelengths, such as radio waves, carry less energy than types of radiation with short wavelengths, such as X-rays.

A light wave (or any other form of electromagnetic radiation) has evenly spaced crests and troughs. The distance from crest to crest, or, equivalently, from trough to trough, is defined as the wavelength.

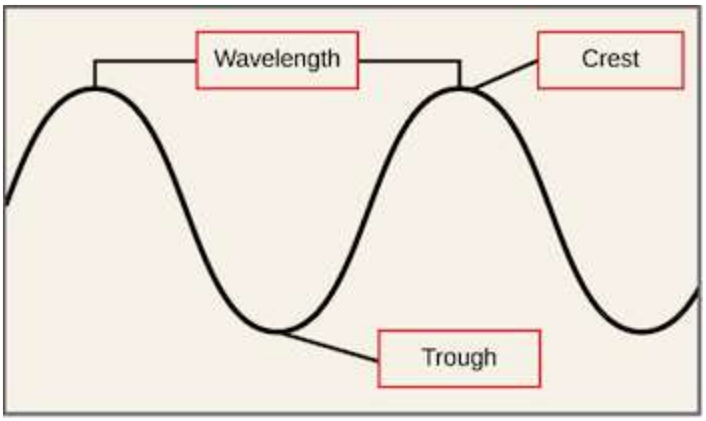
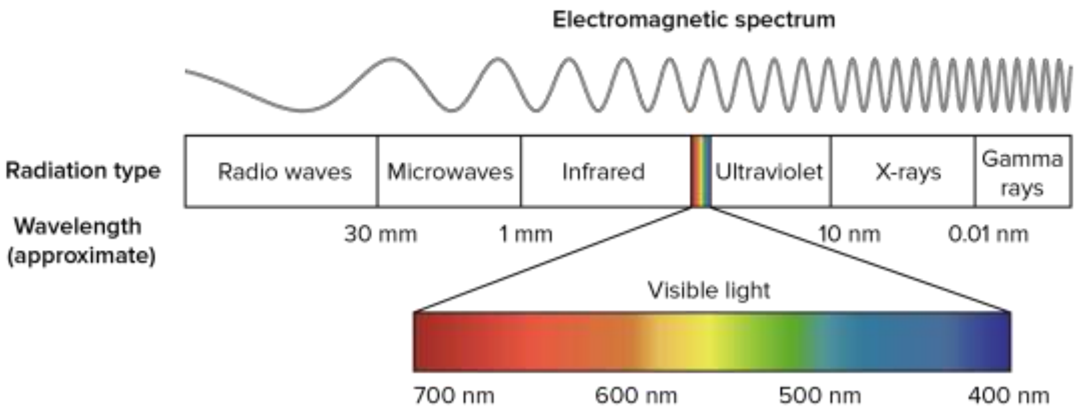


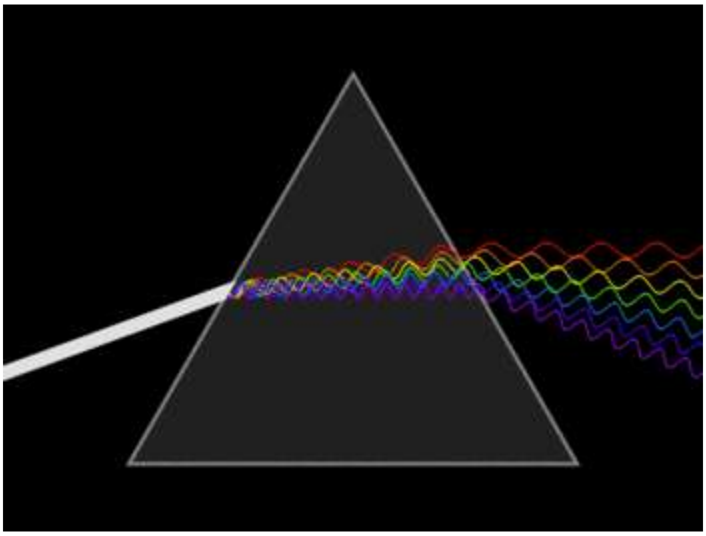
Image of a wave, showing the crests, trough, and wavelength (crest-to-crest distance).

Image modified from: "The light-dependent reactions of photosynthesis: Figure 2," by OpenStax College, Biology (CC BY 3.0).



The electromagnetic spectrum is the entire range of wavelengths of electromagnetic radiation. A longer wavelength is associated with lower energy and a shorter wavelength is associated with higher energy. The types of radiation on the spectrum, from longest wavelength to shortest, are: radio, microwave, infrared, visible, ultraviolet, X-ray, and gamma ray. Visible light is composed of different colours, each having a different wavelength and energy level. The colours, from longest wavelength to shortest, are: red, orange, yellow, green, blue, indigo, and violet.

The **visible spectrum** is the only part of the electromagnetic spectrum that can be seen by the human eye. It includes electromagnetic radiation whose wavelength is between about 400 nm and 700 nm. Visible light from the sun appears white, but it's actually made up of multiple wavelengths (colours) of light. You can see these different colours when white light passes through a prism: because the different wavelengths of light are bent at different angles as they pass through the prism, they spread out and form what we see as a rainbow. Red light has the longest wavelength and the least energy, while violet light has the shortest wavelength and the most energy.



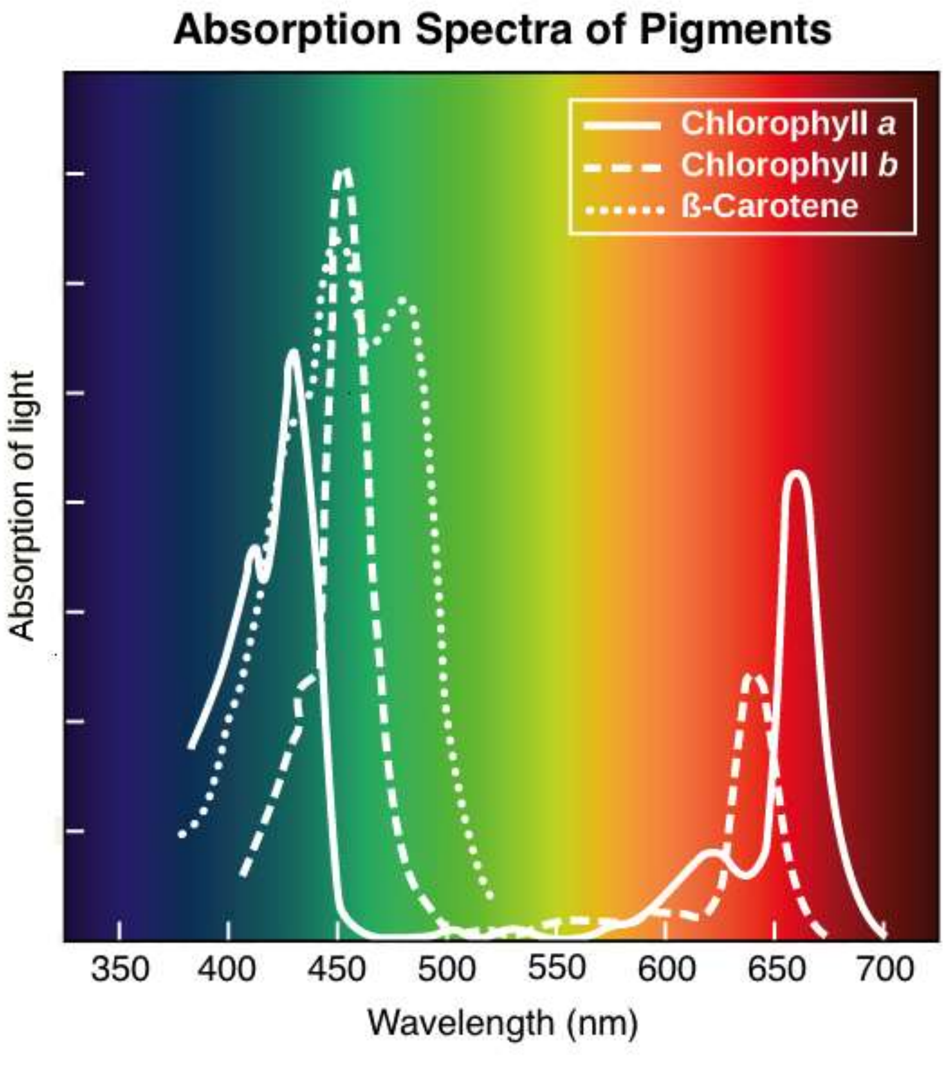
This animation provides a simplified, conceptual view of how various wavelengths that make up white light bend differently as they pass through a prism, resulting in the formation of a rainbow.

Although light and other forms of electromagnetic radiation act as waves under many conditions, they can behave as particles under others. Each particle of electromagnetic radiation, called a **photon**, has certain amount of energy. Types of radiation with short wavelengths have high-energy photons, whereas types of radiation with long wavelengths have low-energy photons.

Pigments absorb light used in photosynthesis

In photosynthesis, the sun's energy is converted to chemical energy by photosynthetic organisms. However, the various wavelengths in sunlight are not all used equally in photosynthesis. Instead, photosynthetic organisms contain light-absorbing molecules called **pigments** that absorb only specific wavelengths of visible light, while reflecting others.

The set of wavelengths absorbed by a pigment is its **absorption spectrum**. In the diagram below, you can see the absorption spectra of three key pigments in photosynthesis: chlorophyll *a*, chlorophyll *b*, and β-carotene. The set of wavelengths that a pigment doesn't absorb are reflected, and the reflected light is what we see as colour. For instance, plants appear green to us because they contain many chlorophyll *a* and *b* molecules, which reflect green light.



Each photosynthetic pigment has a set of wavelength that it absorbs, called an absorption spectrum. Absorption spectra can be depicted by wavelength (nm) on the x-axis and the degree of light absorption on the y-axis. The absorption spectrum of chlorophylls includes wavelengths of blue and orange-red light, as is indicated by their peaks around 450-475 nm and around 650-675 nm. As a note, chlorophyll *a* absorbs slightly different wavelengths than chlorophyll *b*. Chlorophylls do not absorb wavelengths of green and yellow, which is indicated by a very low degree of light absorption from about 500 to 600 nm. The absorption spectrum of β-carotene (a carotenoid pigment) includes violet and blue-green light, as is indicated by its peaks at around 450 and 475 nm.

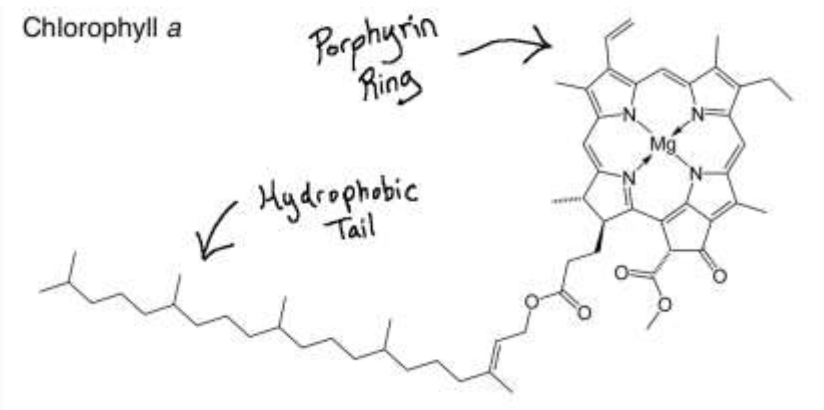
Optimal absorption of light occurs at different wavelengths for different pigments.

Most photosynthetic organisms have a variety of different pigments, so they can absorb energy from a wide range of wavelengths. Here, we'll look at two groups of pigments that are important in plants: chlorophylls and carotenoids.

Chlorophylls

There are five main types of chlorophylls: chlorophylls *a*, *b*, *c* and *d*, plus a related molecule found in prokaryotes called bacterio-chlorophyll. In plants, **chlorophyll *a*** and **chlorophyll *b*** are the main photosynthetic pigments. Chlorophyll molecules absorb blue and red wavelengths, as shown by the peaks in the absorption spectra above.

Structurally, chlorophyll molecules include a hydrophobic ("water-fearing") tail that inserts into the thylakoid membrane and a **porphyrin ring** head (a circular group of atoms surrounding a magnesium ion) that absorbs light[1].



A chlorophyll *a* molecule has a hydrophobic tail that inserts into the thylakoid membrane and a porphyrin head that captures light energy.

Image modified from "Chlorophyll-a-2D-skeletal," by Ben Mills (public domain)

Although both chlorophyll *a* and chlorophyll *b* absorb light, chlorophyll *a* plays a unique and crucial role in converting light energy to chemical energy (as you can explore in the light-dependent reactions article). All photosynthetic plants, algae, and cyanobacteria contain chlorophyll *a*, whereas only plants and green algae contain chlorophyll *b*, along with a few types of cyanobacteria[2,3].

Because of the central role of chlorophyll *a* in photosynthesis, all pigments used in addition to chlorophyll *a* are known as **accessory pigments**—including other chlorophylls, as well as other classes of pigments like the carotenoids. The use of accessory pigments allows a broader range of wavelengths to be absorbed, and thus, more energy to be captured from sunlight.

Carotenoids

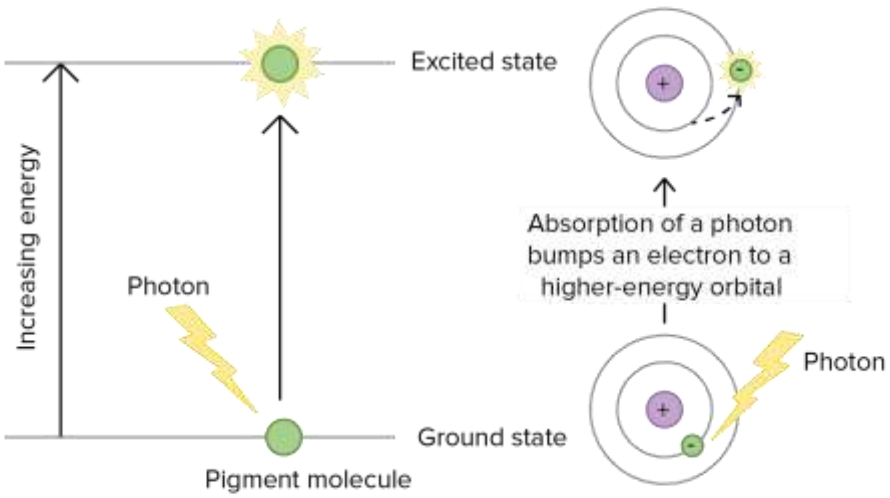
Carotenoids are another key group of pigments that absorb violet and blue-green light (see spectrum graph above). The brightly coloured carotenoids found in fruit—such as the red of tomato (lycopene), the yellow of corn seeds (zeaxanthin), or the orange of an orange peel (β-carotene)—are often used as advertisements to attract animals, which can help disperse the plant's seeds.

In photosynthesis, carotenoids help capture light, but they also have an important role in getting rid of excess light energy. When a leaf is exposed to full sun, it receives a huge amount of energy; if that energy is not handled properly, it can damage the photosynthetic machinery. Carotenoids in chloroplasts help absorb the excess energy and dissipate it as heat.

What does it mean for a pigment to absorb light?

When a pigment absorbs a photon of light, it becomes **excited**, meaning that it has extra energy and is no longer in its normal, or **ground**, state. At a subatomic level, excitation is when an electron is bumped into a higher-energy orbital that lies further from the nucleus.

Only a photon with just the right amount of energy to bump an electron between orbitals can excite a pigment. In fact, this is why different pigments absorb different wavelengths of light: the "energy gaps" between the orbitals are different in each pigment, meaning that photons of different wavelengths are needed in each case to provide an energy boost that matches the gap.



When a pigment molecule absorbs light, it is raised from a ground state to an excited state. This means that an electron jumps to a higher-energy orbital (an orbital that is further from the nucleus).

An excited pigment is unstable, and it has various "options" available for becoming more stable. For instance, it may transfer either its extra energy or its excited electron to a neighbouring molecule. We'll see how both of these processes work in the next section: the light-dependent reactions.