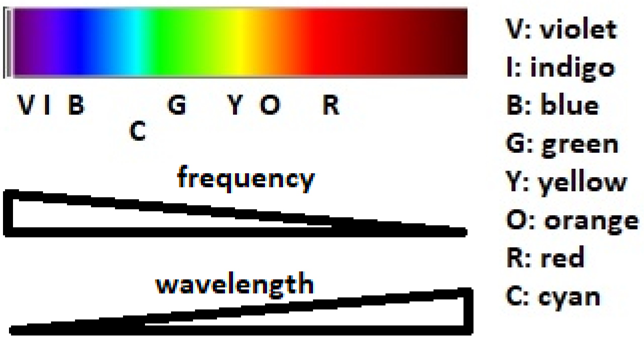
Color Vision

Accelerated charges radiate electromagnetic waves, which carry energy as they travel through space. This energy is shared equally by electric and magnetic fields. The electromagnetic spectrum covers many frequencies and is comprised of radio waves, microwaves, terahertz waves, infrared, visible light, ultraviolet, X-rays and gamma rays. Frequency is inversely proportional to wavelength, i.e, the lower the frequency, the higher is the wavelength. Of interest here is the visible spectrum that spans wavelengths from 380 nanometers (nm) to 760 nm.

Radiations of these wavelengths are detected by the human eye and are hence, seen as visible light. The lowest wavelength (highest frequency) appears violet while the highest wavelength (lowest frequency) appears red. Combining all the colors of these wavelengths results in white light. Conversely, passing white light through a prism will split white light into these different colors of the visible spectrum. The visible spectrum is popularly known by the acronym VIBGYOR (violet-indigo-blue-green-yellow-orange-red), which are the seven major colors of this spectrum in increasing order of wavelength.

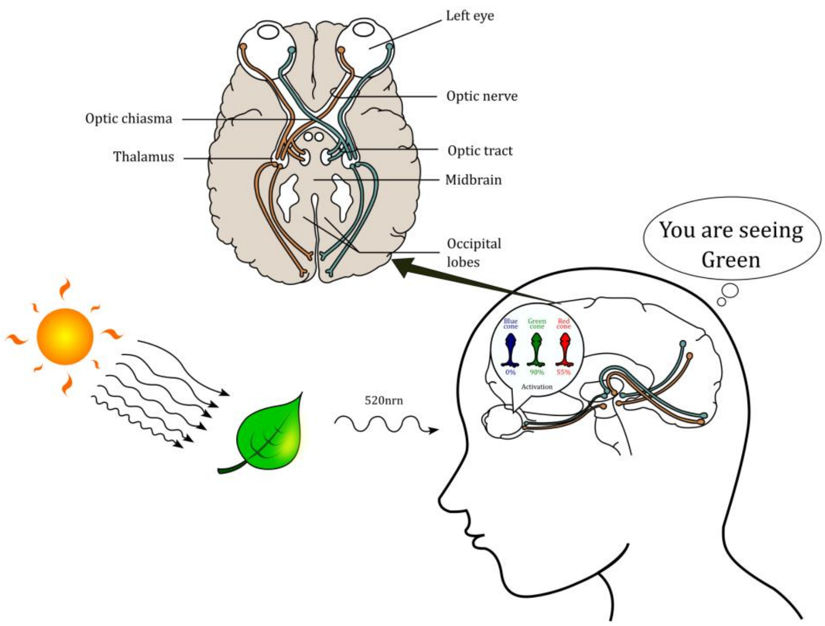


Visible spectrum

Einstein introduced the photon as a quantum of light that has both energy and momentum. Photons are electrically neutral. All photons of light of a particular wavelength have the same energy and momentum, regardless of the intensity of the radiation. Photons show wave-like and particle-like properties.

Color vision is the ability to distinguish the wavelengths in the visible spectrum after the incoming light reacts with different types of cone receptors in the eye. In humans, there are three types of cones that are sensitive to three different spectra: short (S), medium (M) and long (L) cones. Visual information is sent from retinal ganglion cells via the optic nerve to the thalamus, and then to the primary visual cortex at the back of the brain.

Cone type	Name	Range (nm)	Peak wavelength (nm)
S	β (B)	400-500	420-440
M	γ (G)	450-630	534-555
L	ρ (R)	500-700	564-580



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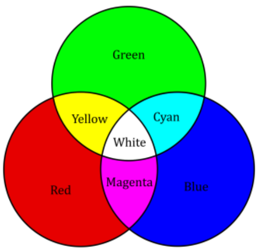
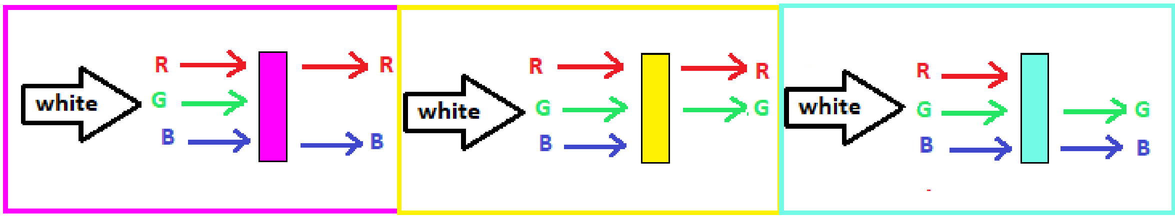
Color theory offers some guidance about mixing of colors and was originally based on three primary colors, red, yellow and blue. The RGB (red-green-blue) color model is considered additive. Behavior of light mixtures (spotlighting, theatrical lighting, digital media) is said to be additive because it is based on the additive mixing of these three monochromatic lights. Adding or overlapping red and blue light will give magenta light while adding blue and green light will give cyan light.

Absorption of light by materials follows different rules from perception of light by the eye. Thus, the behaviour of pigment mixtures used by artists and photographers is said to be subtractive and is based on the CMYK (cyan-magenta-yellow-black) model. So a red surface absorbs (subtracts) green and blue light and reflects red light to look red. Cyan absorbs red light and reflects blue and green light which add together to give cyan. Colors (green, orange, purple) created by mixing two primary colors are called secondary colors. Tertiary colors are obtained by mixing primary and secondary colors.



Additive color model



Subtractive filters

Colored filters (optical filters) made of glass or plastic containing dissolved dye(s) absorb a range of light wavelengths and appear the color that they transmit. Optical filters can pass long wavelengths only (longpass), short wavelengths only (shortpass) or a band of wavelengths, blocking longer and shorter wavelengths (bandpass). However, note that filters are subtractive and can be used either alone or in pairs to transmit different wavelengths.

Bees and other insects, birds and goldfish can detect ultraviolet light. Tropical fish and birds have more complex color vision systems than humans. So the subtle colors they display are actually signals for other fish and birds. While reptiles and amphibians have four cone types and can probably see the same number of colors that humans can, mammals like dogs and some farm animals have two-receptor color vision systems and cannot distinguish between oranges and reds.

Color wheel

The color wheel is a very basic tool for combining colors and it consists of 12 colors based on the RYB (subtractive) color model. Color chords or color harmonies are color combinations that are made up of 2 or more colors with a fixed relation in the color wheel. Let us look at the following color chords:

- Complementary colors (opposite on the color wheel)
- Analogous colors (next to each other on the color wheel)
- Triadic colors (at three vertices of an equilateral triangle on the color wheel)
- Split-complementary colors (a base color on the color wheel and the other two adjacent to the complement of the base color)
- Rectangle or tetradic colors (a rectangle with opposite vertices on complementary colors)
- Square colors (a square with opposite vertices on complementary colors)

Image credits:

1) Color Vision adapted from http://clipground.com/nerves-from-eye-to-brain-clipart.html

   and http://sitn.hms.harvard.edu/flash/2015/from-kansas-to-oz-how-new-glasses-could-change-the-way-the-colorblind-see-the-world/
2) Additive color model adapted from http://hyperphysics.phy-astr.gsu.edu/hbase/vision/addcol.html#c1
3) Subtractive filter adapted from http://hyperphysics.phy-astr.gsu.edu/hbase/vision/filter.html#c1
4) Color wheel: https://commons.wikimedia.org/wiki/File:BYR_color_wheel.svg uploaded by Sakurambo at English Wikipedia; GFDL-WITH-DISCLAIMERS; Released under the GNU Free Documentation License.