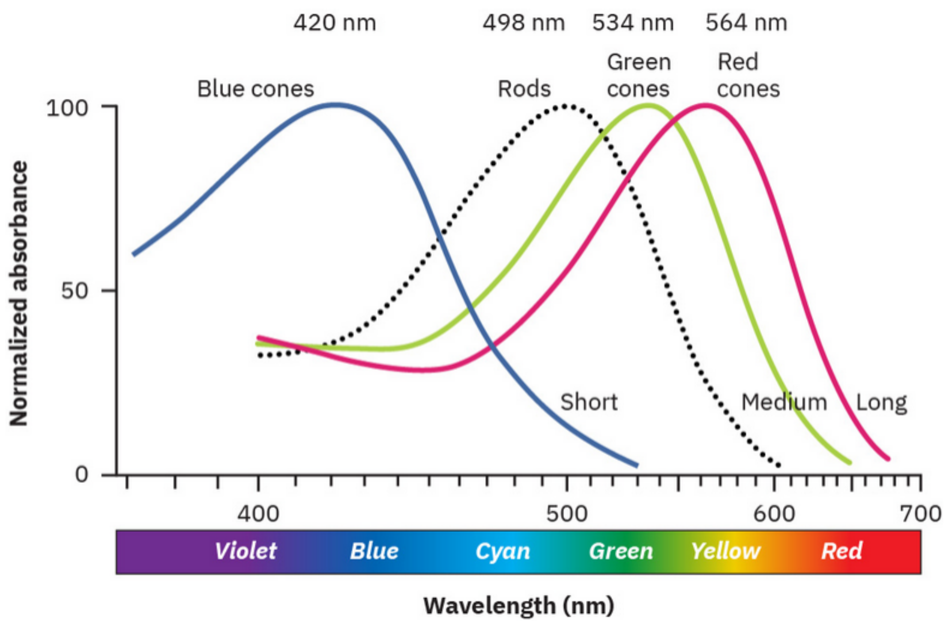
11.5: Light, Color and Perception

We've already discussed the wavelengths and frequencies of electromagnetic radiation and we've spoken of the narrow strip of frequencies that we can perceive in terms of colors. We can see the effect of a prism on beam of light as it splits into bands of color. But what does color mean? How is it that we can perceive wavelength differences as small as fifty-billionths of a meter? We've already explored sound and how it is perceived by us in different circumstances, now it is time to turn our attention to the visual.

For this portion of the textbook, we turn to human biology. When gathering data for experimental analysis it is important to understand the equipment being used, so you know how to interpret the data you've collected. Given that most of the information that we gather about the world comes to us through our eyes, understanding vision helps us better understand the data we collect about our world. As with most of this textbook, the treatment we give this topic is necessarily brief, as it encompasses biology, chemistry and psychology. What follows is a rudimentary discussion of the subject matter.

Light entering our eyes is focused on the retina. The retina is a collection of cells lining the eyeball that gather information from the light and send it to the occipital lobe of our brain via the optic nerve. There are two main types of *photoreceptors* (cells that sense light) in the retina:

- Cones: A cell concentrated near the center of the retina that work best in bright light and control high resolution vision. There are three types of cones and each type can detect a certain range of frequencies, peaking at a particular wavelength. The retina contains about six million cones.
- Rods: A cell that is far more sensitive to small energy differences than cones. They are essential for motion detection and for vision in dark environments. They do not record information about color, but provide vision in grey scale. They outnumber cones by a factor of twenty to one.



Plot of cone wavelengths taken from OpenStax *College Physics 2e* and is licensed under CC-BY

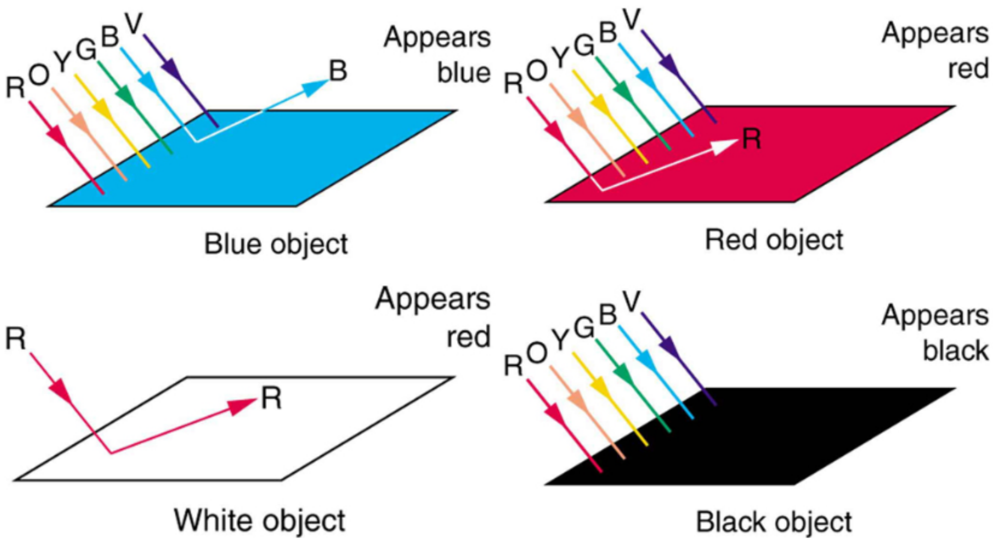
When light falls on the retina, certain cones respond to the wavelength of the incoming electromagnetic wave. The strength of the response has to do with the brightness (intensity) of the wave. In the simplest model of color vision, there are three primary colors that correspond to the red, blue and green cones. The colors we perceive depends on which cones are activated and the intensity of the cone activation.

Red and green cones can produce the perception of yellow if the intensities are properly balanced. If all three cone types are illuminated, we perceive white light. If blue and red cones are illuminated in one way, we perceive a bluish purple, another set of illuminations gives us a reddish purple. There is some evidence that our color vision is not quite as simple as this model would suggest, but the fundamental relationship between perceived color, cones and illumination levels is well established.

True Colors

In order for our eyes to see anything, light waves have to reach the object, be reflected from it and then reach our eyes where the rods and cones can then be activated. Opaque objects appear to be the colors we perceive them to be because of the light they reflect. White light is a mixture of all the visible colors of light, so if an object reflects all visible colors then it appears white to us. If an object is illuminated by white light and only reflects blue light (absorbing the rest of the colors) then the object appears blue. Similarly, if an object is illuminated by white light but only reflects red light, then it appears to be red. The *true color* of an object is defined to be the color perceived when illuminated by white light. A truly black object is one that absorbs all colors and reflects none.

However, if a white object is illuminated by red light, it will reflect that red light and appear red. If it is illuminated by red and green light, it could appear yellow. A red object illuminated by blue light will not reflect the blue light, and will appear black. Perceived colors can differ from true colors based on the color of the light that is illuminating the object.



Apparent colors taken from OpenStax(opens in new window) *College Physics 2e(opens in new window)* and is licensed under CC-BY

Light sources are assigned a color based on the frequencies (wavelengths) they emit. A neon sign appears red because it primarily emits red frequencies of light, while the Sun appears yellowish because the intensities of the yellow frequencies are greater than any of the other colors emitted.

Modified Model of Color Vision

Experiments have shown that the simple model presented above doesn't account for the full range of human color vision. It is known that there are nerve connections between rods and cones in the retina, and the optic nerve that carries information to the brain has fewer connections to the brain than there are rods and cones. This would imply that there is some sort of pre-processing that happens on the retina, before the information is sent to the occipital lobe. It is thought that the eye may make comparisons to information collected by adjacent receptors. If both receptors detect the same information, the redundant signals may be ignored. If the receptors report differences, additional processing power is allocated. This might help explain our sensitivity to detecting edges.

The founder of the Polaroid corporation, Edwin Land, proposed a model in which the three types of cones are organized into systems he called *retinexes*. Each retinex forms an image which is compared to the images formed by other retinexes. This may explain a visual ability called *color constancy*. Color constancy describes the ability of the eye to determine the color of an object under different ambient lighting conditions. It is possible to determine that a piece of paper is red whether it is illuminated by sunlight, candlelight or fluorescent light, even though the emitted color of each of these light sources is quite different. By comparing the paper to its surrounding in each case, the true color of the paper can be determined.

Our color vision is not completely understood, and it would appear that vision is far more complex than our initial model might suggest.