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Color

Unit: Light & Optics

NGSS Standards/MA Curriculum Frameworks (2016): N/A

AP® Physics 2 Learning Objectives/Essential Knowledge (2024): 14.4.A.3.ii

Mastery Objective(s): (Students will be able to…)

- Explain how colors are produced and mixed.
- Explain why we see colors the way we do.

Success Criteria:

- Descriptions & explanations account for observed behavior.

Language Objectives:

- Explain how someone who is red-green color blind might see a green object.

Tier 2 Vocabulary: color, mixing

Labs, Activities & Demonstrations:

- colored light box

Notes:

Light with frequencies/wavelengths in the part of the spectrum that the eye can detect is called visible light.

color: the perception by the human eye of how a light wave appears, based on its wavelength/frequency.

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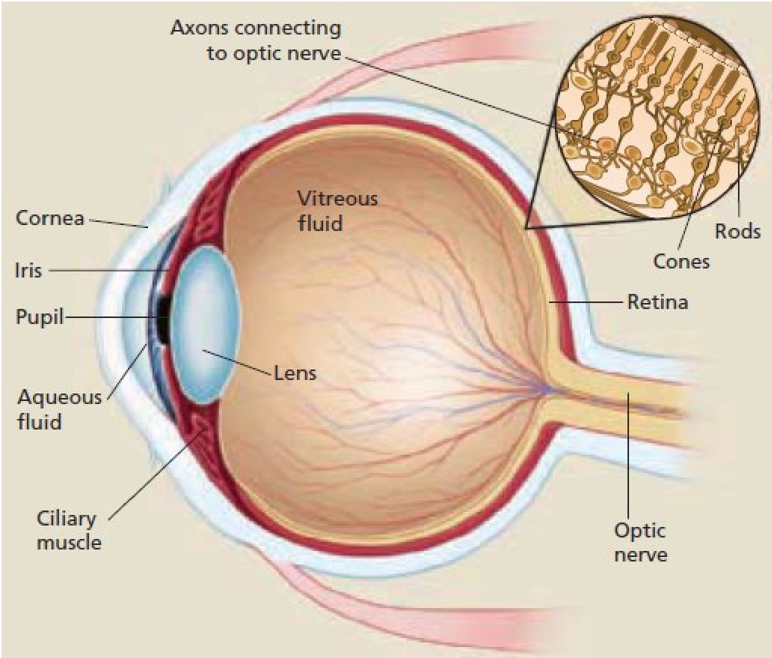
How We See Color

Humans (and other animals) have two types of cells in our retina that respond to light:



Rod cells resolve the physical details of images. Cone cells are responsible for distinguishing colors. Rod cells can operate in low light, but cone cells need much more light; this is why we cannot see colors in low light.

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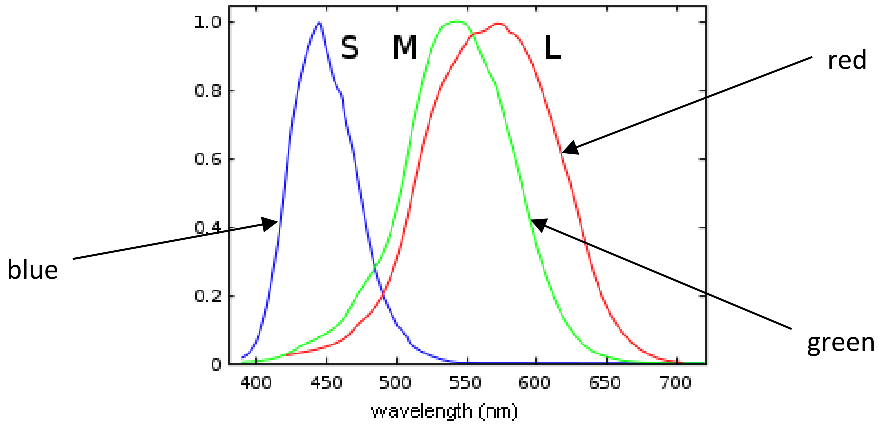
There are three different types of cone cells in our eyes, called "S", "M", and "L", which stand for "short," "medium," and "long." Each type of cone cells responds to different wavelengths of light, having a peak (maximum) absorbance in a different part of the visible spectrum:



For example, light with a wavelength of 400–450 nm appears blue to us, because most of the response to this light is from the S cells, and our brains are wired to perceive this response as blue color. Light with a wavelength of around 500 nm would stimulate mostly the M cells and would appear green. Light with a wavelength of around 570 nm would stimulate the M and L cells approximately equally. When green and red receptors both respond, our brains perceive the color as yellow.

Colorblindness occurs when a genetic mutation causes a deficiency or absence of one or more types of cone cells. Most common is a deficiency in the expression of M cone cells, which causes red-green colorblindness. This means that a person with red-green colorblindness would see both colors as red.

Because colorblindness is recessive and the relevant gene is on the X-chromosome, red-green colorblindness is much more common in men than in women.

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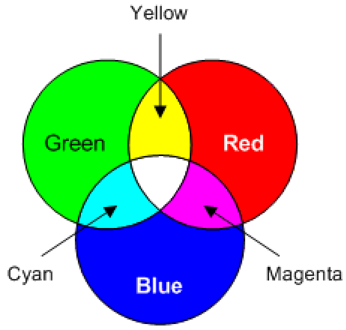
Direct Light: Additive Mixing

Because our cone cells respond to red, green, and blue light, we call these colors the primary colors of light. Other colors can be made by mixing different amounts of these colors, thereby stimulating the different types of cone cells to different degrees. When all colors are mixed, the light appears white.



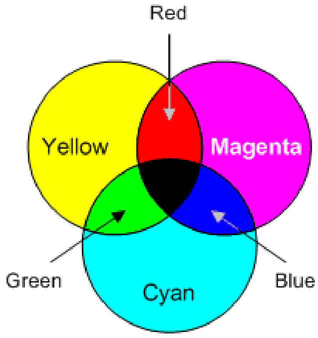
Additive (light)

<u>primary color</u>: light that excites only one type of cone cell. The primary colors of light are red, green, and blue.

<u>secondary color</u>: light that is a combination of exactly two primary colors. The secondary colors of light are cyan, magenta, and yellow.

Reflected Light: Subtractive Mixing

When light shines on an object, properties of that object cause it to absorb certain wavelengths of light and reflect others. The wavelengths that are reflected are the ones that make it to our eyes, causing the object to appear that color.



Subtractive (paint)

<u>pigment</u>: a material that changes the color of reflected light by absorbing light with specific wavelengths.

<u>primary pigment</u>: a material that absorbs light of only one primary color (and reflects the other two primary colors). The primary pigments are cyan, magenta, and yellow. Note that these are the secondary colors of light.

<u>secondary pigment</u>: a pigment that absorbs two primary colors (and reflects the other). The secondary pigments are red, green, and blue. Note that these are the primary colors of light.

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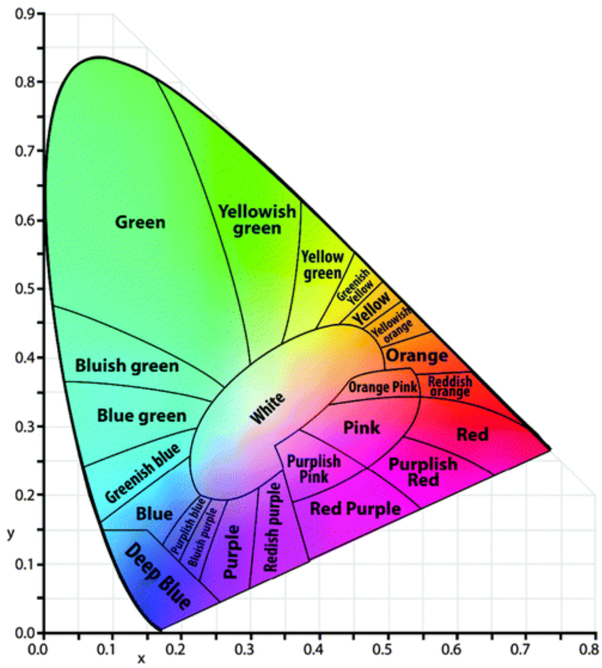
Of course, our perception of color is biological, so mixing primary colors is not a simple matter of taking a weighted average of positions on the color wheel. The relationship between the fractions of primary colors used to produce a color and the color perceived is called chromaticity. The following diagram shows the colors that would be produced by varying the intensities of red, green, and blue light.



On this graph, the *x*-axis is the fraction (from 0 – 1) of red light, the *y*-axis is the fraction of green light, and the fraction of blue is implicit [1 – (red + green)].

Notice that equal fractions (0.33) of red, green and blue light would produce white light.

To show the effects of mixing two colors, plot each color's position on the graph and connect them with a line. The linear distance along that line shows the proportional effects of mixing. (*E.g.,* the midpoint would represent the color generated by 50% of each of the source colors.) This method is how fireworks manufacturers determine the mixtures of different compounds that will produce the desired colors.