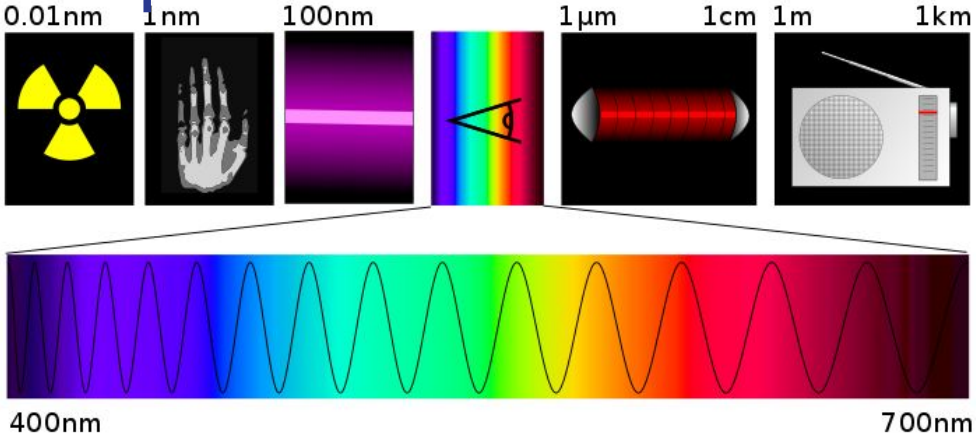
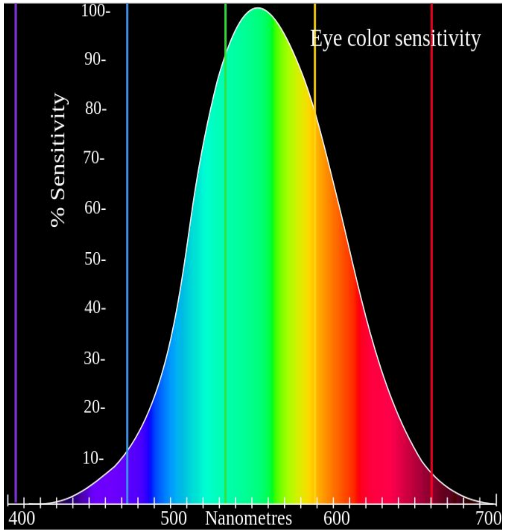
Colors vision in human eyes: optic technologies for people with color blindness.

Outline

- Color vision in human eyes
- Most frequent kind of color blindness
- Design of lenses for color blind people
- Results / other applications

Visible spectrum



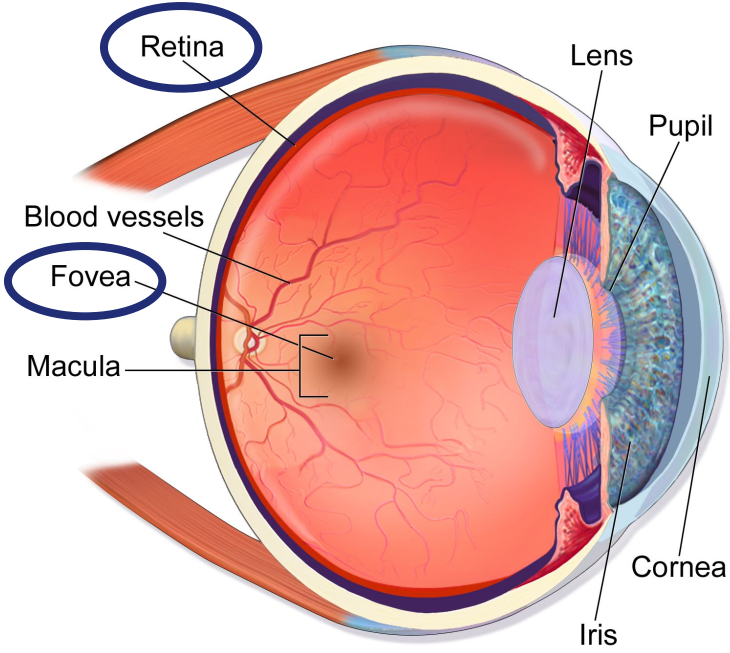


Relative brightness sensitivity of the human visual system

Flowers as seen by humans (left) and by bees (right, UV light)

Nærfoto Bjørn Rørslett http://www.naturfotograf.com/index2.html

Photoreceptors



Eye Anatomy

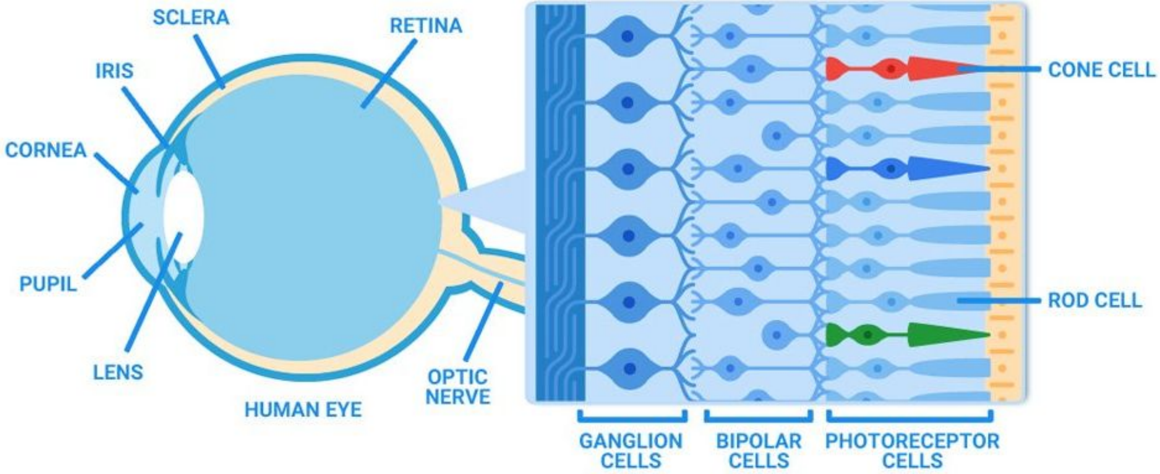
https://blausen.com/
DOI:10.15347/wjm/2014.010. ISSN 2002-4436

- **Rods → brightness detectors**
  - very sensitive to light
  - mainly responsible for our night vision
  - They can be found throughout the retina, only a few of them are in the fovea
- **Cones → color detectors**
  - cells responsible of color vision
  - they are densely packed in the fovea (the fovea is where light is primarily focused)

Color vision

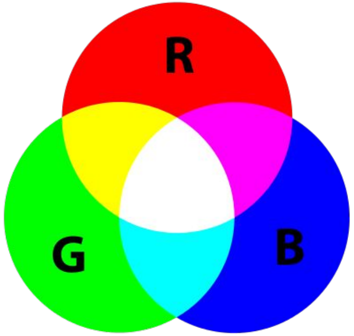
The cone cells give us detailed color vision due to specialized proteins (**opsins**).
Humans possess **three** different opsins for color vision that approximately correspond to three colors: red, green and blue.

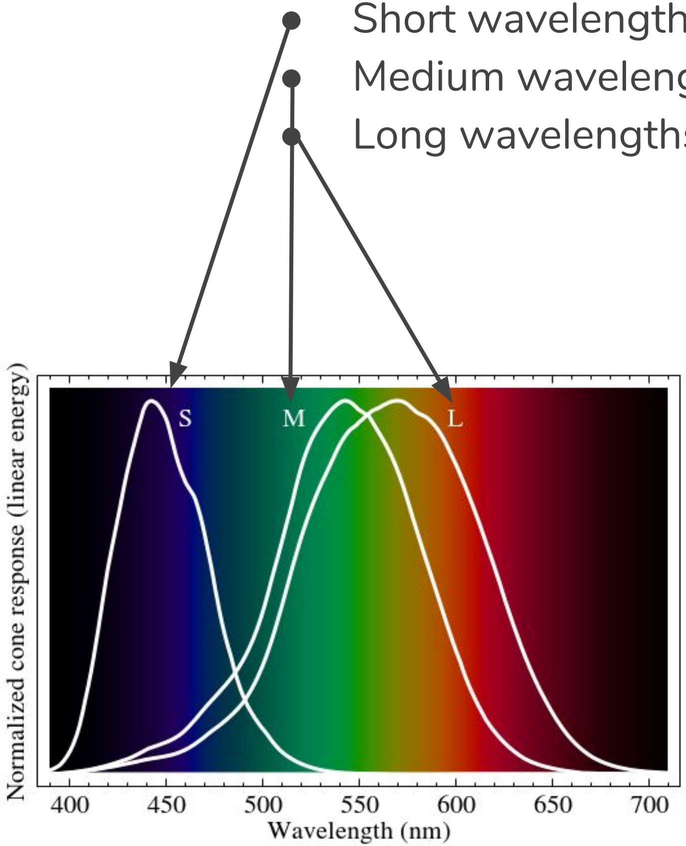
- Short wavelengths (blues) → **S-opsin**
- Medium wavelengths (green) → **M-opsin**
- Long wavelengths (red) → **L-opsin**



Trichromatic vision

- Short wavelengths (blues) are detected by the S-opsin.
- Medium wavelengths (green) are detected by the M-opsin.
- Long wavelengths (red) are detected by the L-opsin.

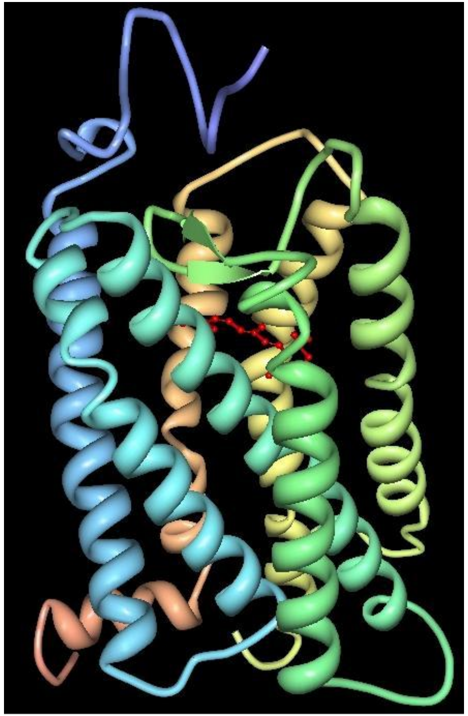




	Types of cone cells	Carriers
Monochromacy	1	Marine mammals...
Dichromacy	2	Most terrestrial non-primate mammals
Trichromacy	**3**	**Most primates, some insects (bees)**
Tetrachromacy	4	Most reptiles, amphibians, birds and insects
Pentachromacy	5	Some insects

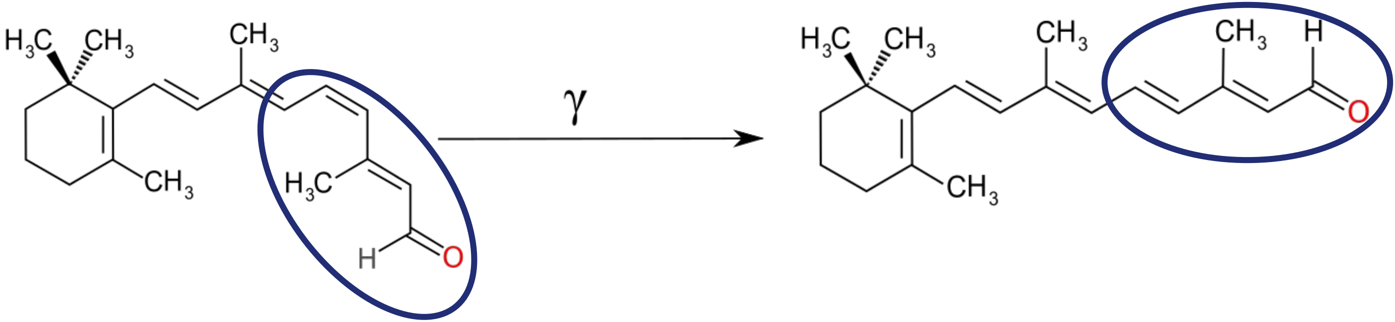
Laura Kelley “Inside the colourful world of animal vision“

Cones and opsines



3D structure of an opsin

Each cone only has one type of opsin protein. When an electromagnetic wave reaches the opsin protein, the protein changes **shape**.

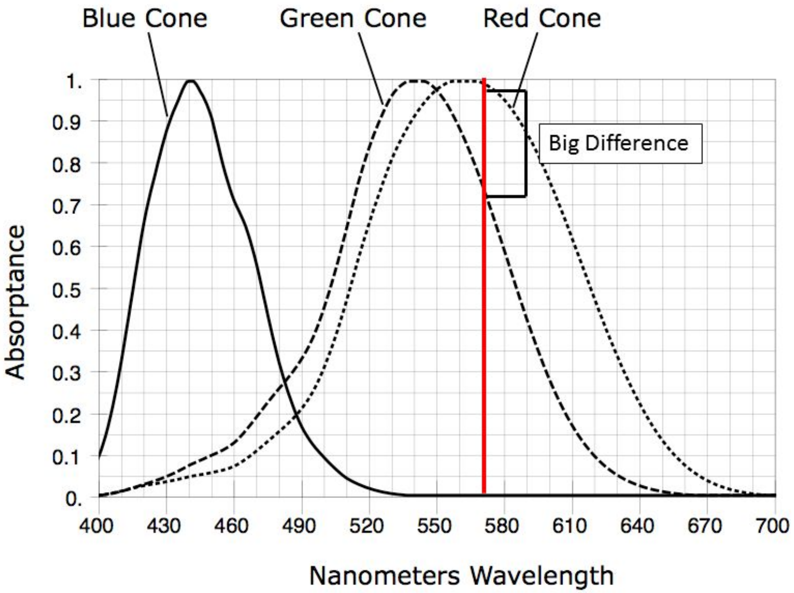


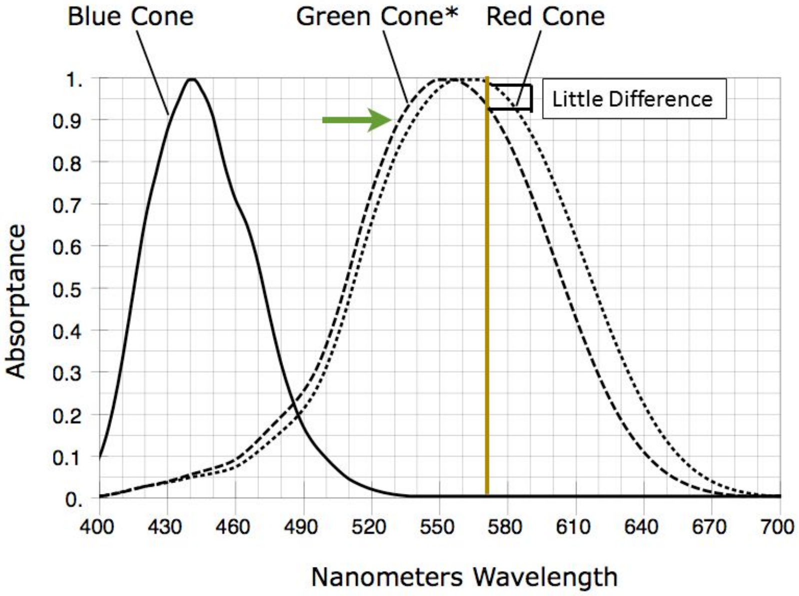
The unique shape of each type of opsin protein allows it to respond to a specific wavelength range. Opsins are constituted by long chains of amino acids. By changing just a few amino acids, the shape of an opsin protein can change as well. Such a change in shape modifies the wavelengths the cones respond to.

R.E. Stenkamp et al., *Crystal structure of rhodopsin: a template for cone visual pigments and other G protein-coupled receptors*

Color blindness

Most people with color blindness have difficulty seeing colors because the color spectrum they can perceive is constrained and lacks distinct separation of wavelength detection.
Example: their green opsin has a slightly different shape so that it responds to longer, redder wavelengths, rather than to green.

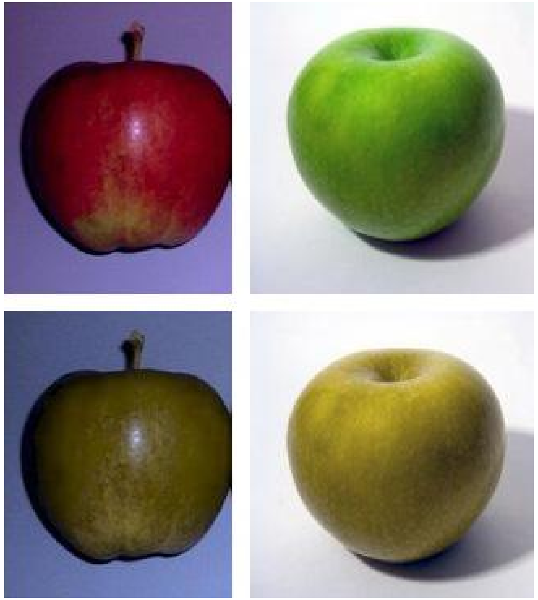




Color blind vision

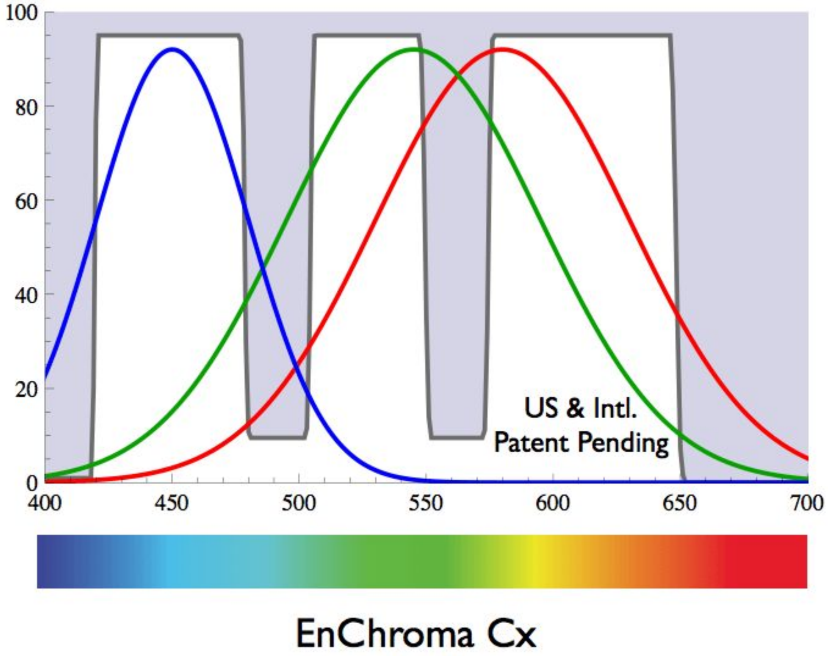
Color blindness affects 1 in 12 men and 1 in 200 women. The condition ranges from a variety of classes, red-green color blindness being the most common (about 80% of known cases of color vision deficiencies). Most people who suffer from color blindness are not blind to color, but have a reduced ability to see them.

- no red = protanopia, loss of red = protanomaly
- no green = deuteranopia, loss of green = deuteranomaly
- no blue = tritanopia, loss of blue = tritanomaly (more rare and with different genetic mechanisms than red/green)



Glasses for color blindness

Special glasses <u>filter out the wavelengths</u> that the cones do not differentially respond to.

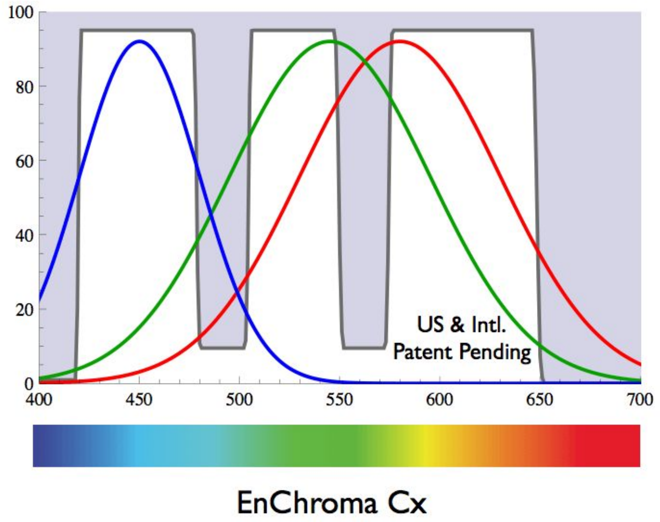


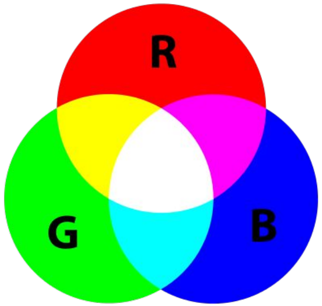
Gray area: filtered out wavelengths. Those wavelengths are those in which there would be the greatest overlap between any two cone types.

Red - green distinction

Glassed cut out wavelengths of light to enhance specific colors.
The erroneous activation overlap for distinct cone types is reduced.

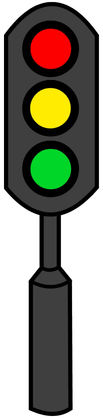
- The distinction between red and green light is more prominent because green colors are darker
- Less “wrong” cone activations → Magenta!



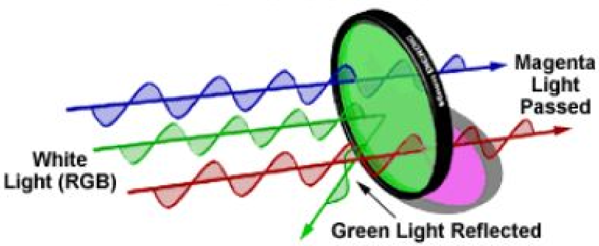


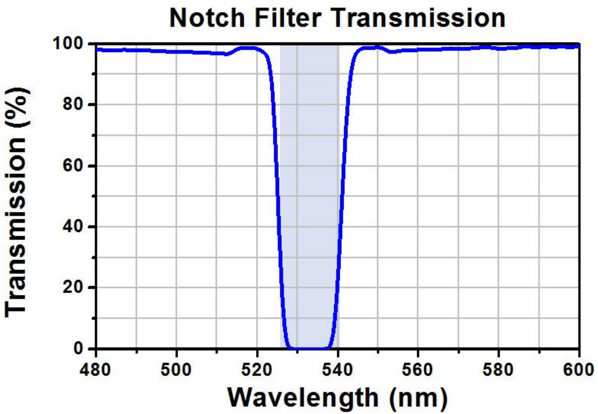
Lenses

Luminous Transmittance of Daylight	0.18
Luminous Transmittance of Red Traffic Signal	0.15
Luminous Transmittance of Yellow Traffic Signal	0.15
Luminous Transmittance of Green Traffic Signal	0.19



1. Modelisation of color perception for people with color vision deficiencies
2. Identification of a set of available elementary filters that filter the light in a specific range (notch filters).
3. Constraints on the color appearance of a few reference lights, constraint on the minimum luminous transmittance of daylight, neutral configuration of the filter white-point
4. Design of an optimal filter respecting all the criteria

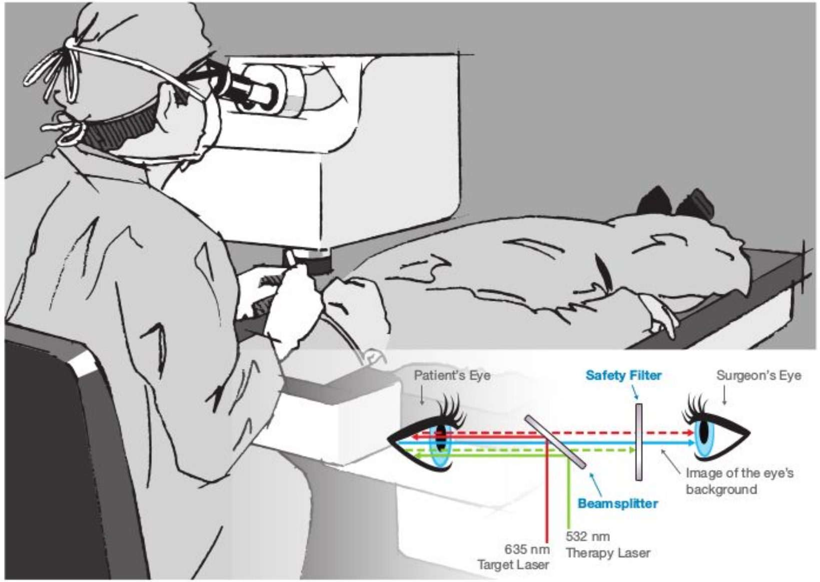




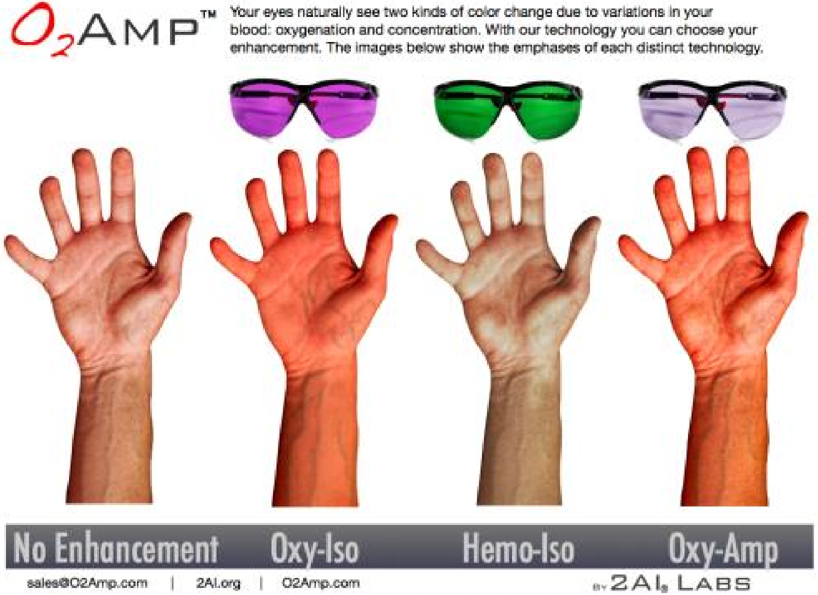
Results / effectiveness

- The lenses are designed for partial red-green color blindness
- Enchroma claims that the effectiveness rate is 80% but no scientific publication about the effectiveness of the glasses is available
- Some people with color blindness experience a big difference in their color perception, some experience a smaller difference and other do not perceive any
- The outdoor lenses (sunglasses) are more effective than indoor lenses

Similar applications



ophthalmologic surgery



Vein glasses

References

Kandel E.R., Schwartz, J.H., Jessell, T.M. (2000). *Principles of Neural Science*, 4th ed., p. 510, 576. McGraw-Hill

R.E. Stenkamp, S. Filipek, C.A.G.G. Driessen, D.C. Teller, K. Palczewski, *Crystal structure of rhodopsin: a template for cone visual pigments and other G protein-coupled receptors*, In Biochimica et Biophysica Acta (BBA) - Biomembranes, Volume 1565, Issue 2, 2002, Pages 168-182, ISSN 0005-2736, https://doi.org/10.1016/S0005-2736(02)00567-9.

Purves D, Augustine GJ, Fitzpatrick D, et al., editors. Neuroscience. 2nd edition. Sunderland (MA): Sinauer Associates; 2001. Cones and Color Vision. https://www.ncbi.nlm.nih.gov/books/NBK11059/

Michael Land “Photoreception”. Encyclopædia Britannica
https://www.britannica.com/science/photoreception/Structure-and-function-of-photoreceptors#ref531118

http://enchroma.com/

http://www.colourblindawareness.org/colour-blindness/

Laura Kelley “Inside the colourful world of animal vision“
http://theconversation.com/inside-the-colourful-world-of-animal-vision-30878

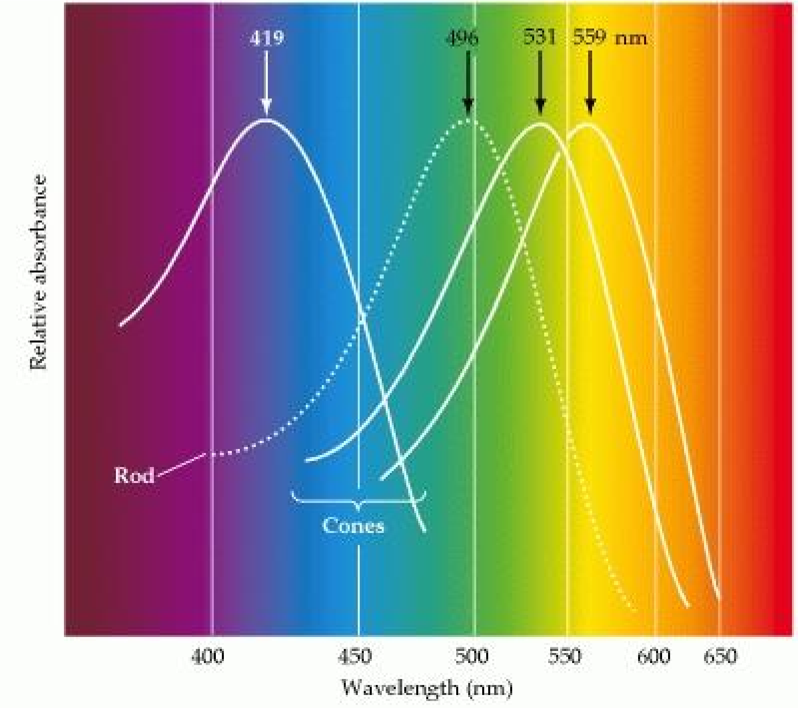
Refereces for figures

Slide 3: http://www.naturfotograf.com/index2.html https://it.wikipedia.org/wiki/Spettro_visibile https://en.wikipedia.org/wiki/Color_vision#/media/File:Eyesensitivity.svg
Slide 4: Blausen.com staff (2014). "Medical gallery of Blausen Medical 2014". *WikiJournal of Medicine* **1** (2). DOI:10.15347/wjm/2014.010. ISSN 2002-4436.
Slide 5: http://enchroma.com/
Slide 6: https://en.wikipedia.org/wiki/Color_vision#/media/File:Cone-fundamentals-with-srgb-spectrum.svg
Slide 7: https://en.wikipedia.org/wiki/Opsin https://en.wikipedia.org/wiki/Chromophore
Slide 8: http://www.blakeporterneuro.com/enchroma-neuroscience-color/
Slide 9: https://en.wikipedia.org/wiki/Color_blindness
Slide 10: http://enchroma.com/
Slide 11: http://enchroma.com/ https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=5840
Slide 14: https://www.opticsbalzers.com/en/applications/ https://www.vino.vi/

Backup

Cones

Individual cones are entirely color blind in that their response is simply a reflection of the number of photons they capture, regardless of the wavelength of the photon (or, more properly, its vibrational energy). It is impossible, therefore, to determine whether the change in the membrane potential of a particular cone has arisen from exposure to many photons at wavelengths to which the receptor is relatively insensitive, or fewer photons at wavelengths to which it is most sensitive. This ambiguity can only be resolved by *comparing* the activity in different classes of cones. Based on the responses of individual ganglion cells, and cells at higher levels in the visual pathway.

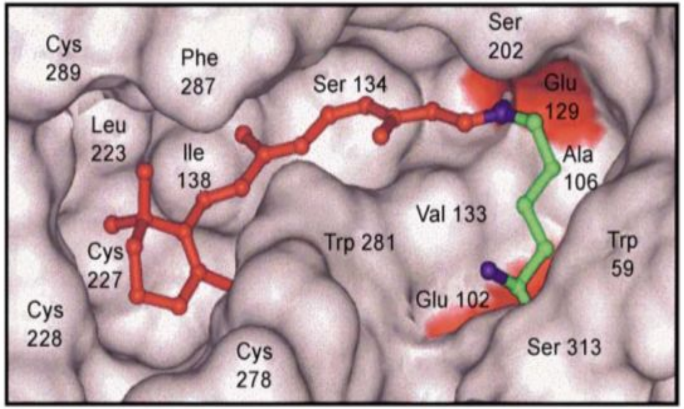


The absorption spectra of the four photopigments in the normal human retina. Absorbance is defined as the log value of the intensity of incident light divided by intensity of transmitted light.

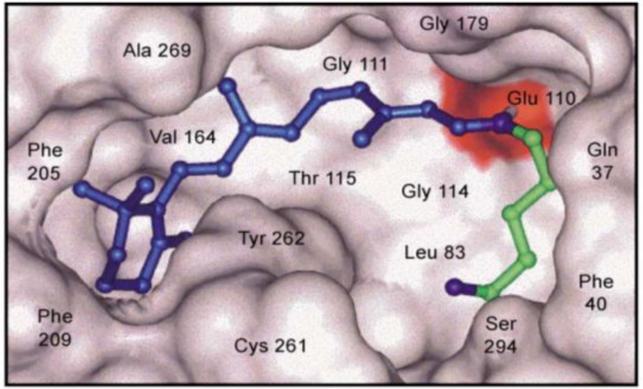
Opsin shape

Vicinity of retinal in cone pigments. **Charged amino acids are indicated in red**. The environment around the retinal in all three cone pigments is strongly hydrophobic. Red and green cone pigments share nearly the same sequence so their retinal sites are nearly identical. Contrary to other cone pigments, the central residue forming the cavity in blue cone pigments is Tyr-262. Because of the proximity of the retinal beta-ionone ring, Tyr-262 is the major factor in the blue shift of this pigment. The second glutamic acid present in red and green cone pigments is absent in this protein, and this causes an additional blue shift.

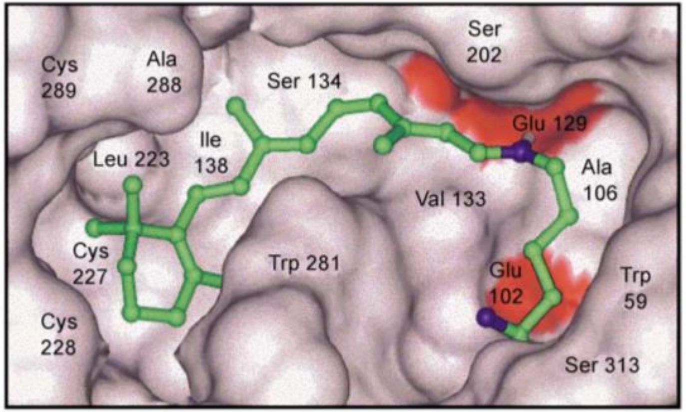
Red



Blue

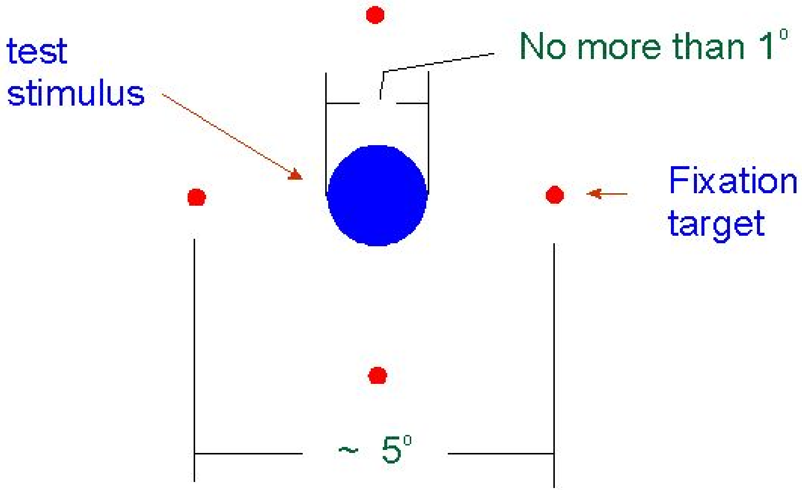


Green



Brightness measurement of colored sources

Radiometers measure the energy emitted or reflected by the source. This is a strictly physical measurement. Unfortunately the radiometric measurement of light does not represent what people see. For example, suppose that the red, yellow and green traffic signals were adjusted so that they emitted equal energies of light. All observers would report that the yellow light is much brighter than the red and green. The visual system is differentially sensitive as a function of wavelength.

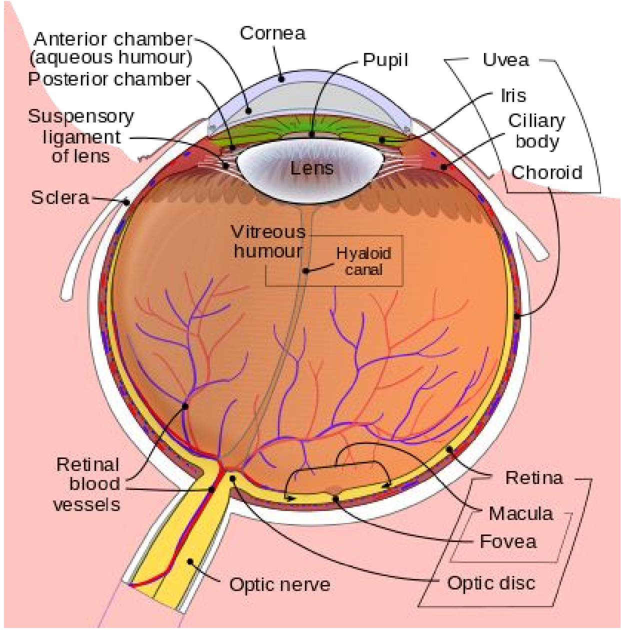


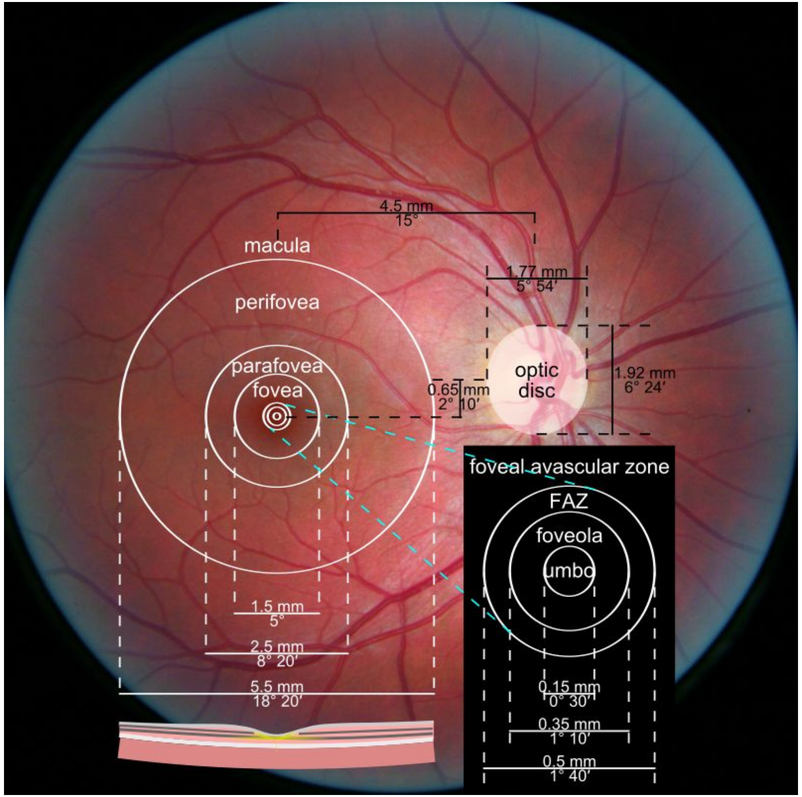
Absolute threshold method

http://www.yorku.ca/eye/absothre.htm

The question asked in the absolute threshold method of psychophysics is, how much stimulus energy is required to elicit the response, "yes I saw something."?

Fovea and retina





By Rhcastilhos - https://commons.wikimedia.org/w/index.php?curid=1597930

By Photograph: Danny Hope from Brighton & Hove, ://commons.wikimedia.org/w/index.php?curid=36685094

Filter generating method

Disclosed herein is a filter generating method for designing optical filters that, for example, provide enhancement and/or regulation to the appearance of color with respect to human color perception. The optical filter designs produced by the method may be used as the basis for manufacturing specifications used to fabricate the optical filters as, for example, **interference filters** by, for example, **physical vapor deposition of multiple layers of dielectric materials onto an optical substrate**. The interference filters may further comprise layers of metal materials that are absorptive. Such metal attenuation coatings may be fabricated by physical vapor deposition, for example.

Useful links

http://www.blakeporterneuro.com/enchroma-neuroscience-color/

https://www.rp-photonics.com/dichroic_mirrors.html

https://www.opticsbalzers.com/en/products/filters/notch-filters.html

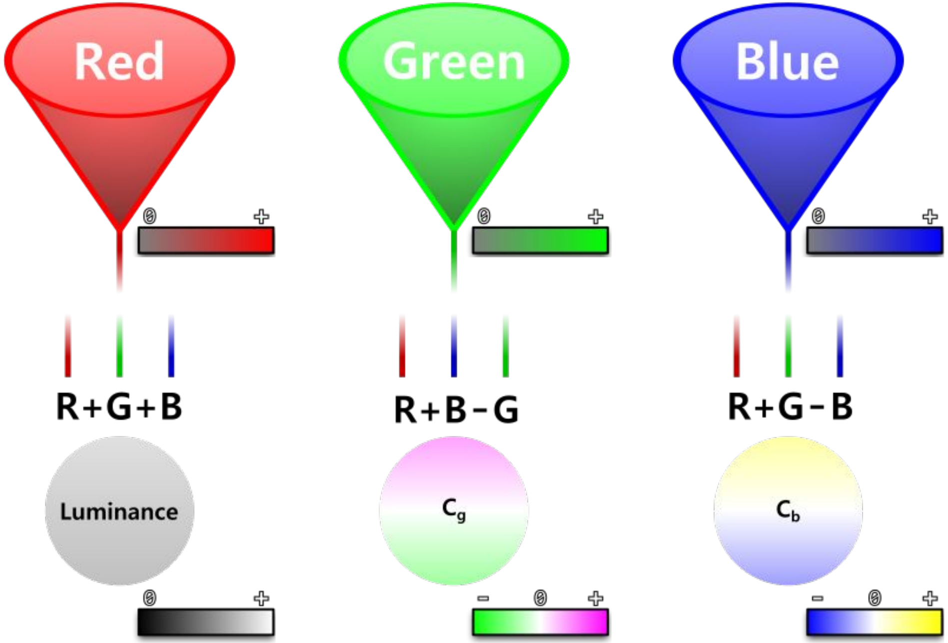
https://www.borntoengineer.com/how-do-enchroma-glasses-work

https://www.quora.com/How-do-Valspar-Color-for-the-Color-Blind-glasses-work

http://www.smithsonianmag.com/innovation/scientist-accidentally-developed-sunglasses-that-could-correct-color-blindness-180954456/

http://www.color-blindness.com/coblis-color-blindness-simulator/ simulatore

Model of human color perception



1. Trichromatic Stage

Trichromatic cone cells respond positively to one of three frequencies exhibited by photons arriving on their surface.

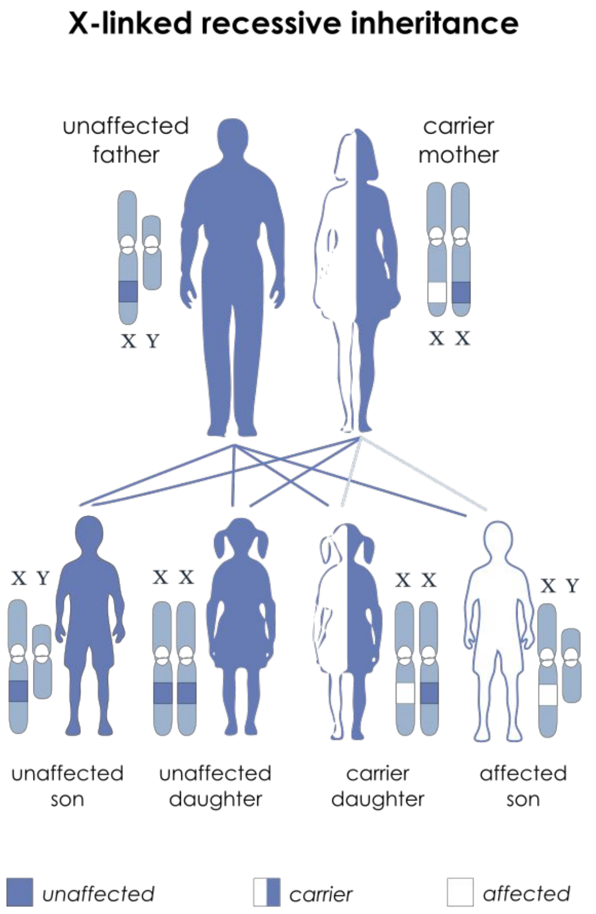
2. Opponent Process Stage

The three color channels are discovered by nearby opponent cells.

Opponent cells tuned to luminosity are excited by the red, green, and blue color signals.

Cg cells are excited by red and blue and inhibited by green. Cb cells are excited by red and green and inhibited by blue.

Mutations on the X chromosome



Population weighted cone spectral sensitivities