Human Vision
Light, Color, Eyes, etc.

Photo of a ray of light striking a glass table top by Phil Ruthstrom

What is color?

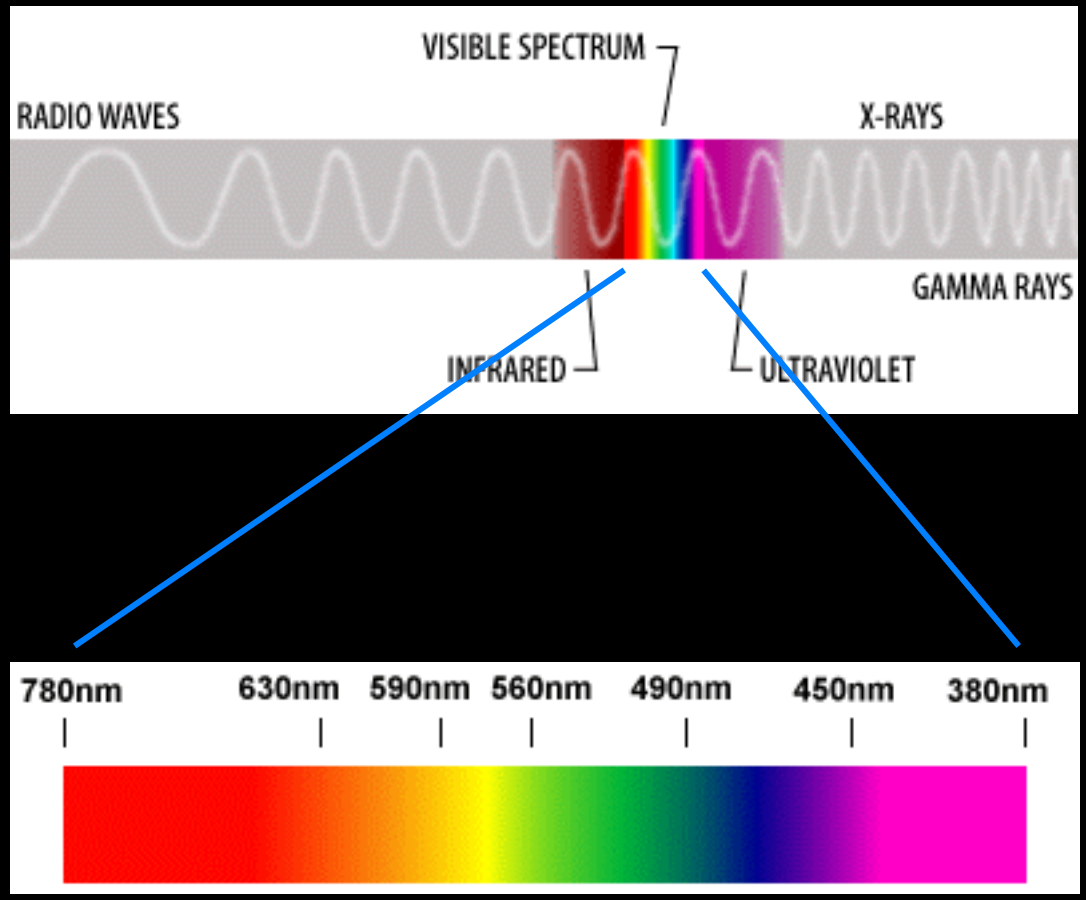
- Several definitions:
  - Color of a single frequency of light:
    - “red light” = Wavelength of 780 nanometers (nm)
  - Color of multi-frequency light:
    - Defined by the single frequency which matches it.
    - A 50/50 combination of red and green light yields _____?
  - Color of an object:
    - Defined in terms of the light it reflects (more about this later).
      - Is an apple red under green light?
      - Is an apple red in the dark?
  - *Perceived color:*
    - *A complex function of light, our visual systems, our experience, context, and our expectations.*

Goal for Today

- Understand how natural lights create responses from our light detecting cells, and how that leads to our eyes' "summary" of the incoming light.

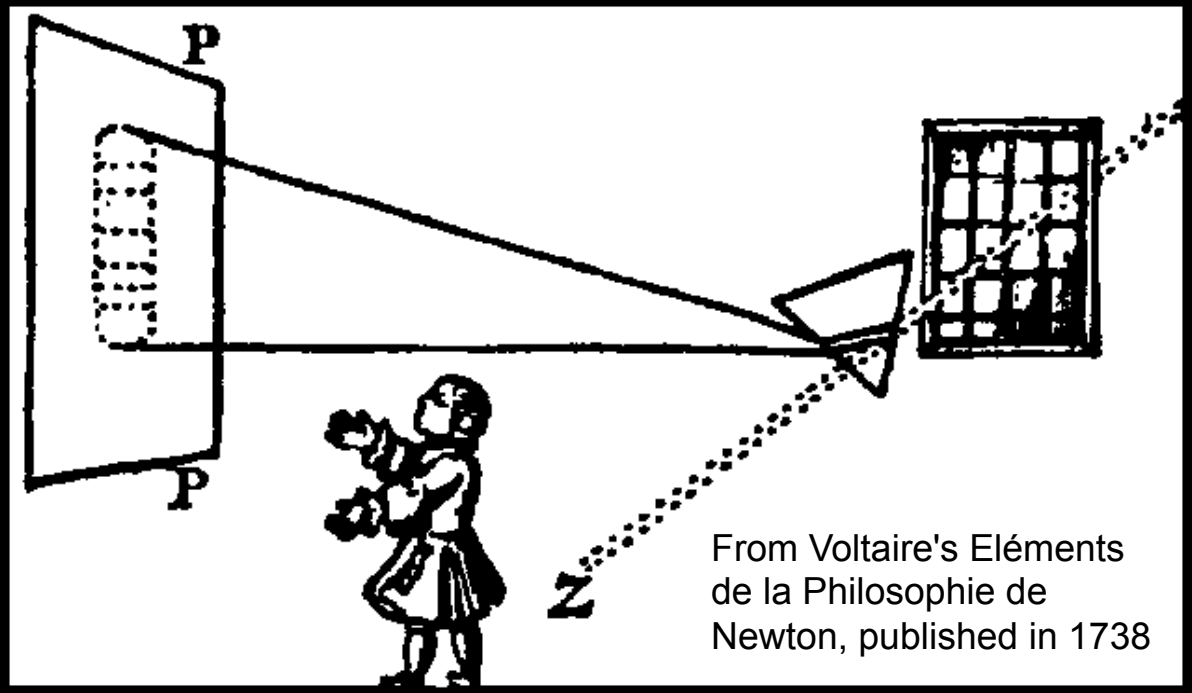
Light: EM Spectrum

Electromagnetic Spectrum



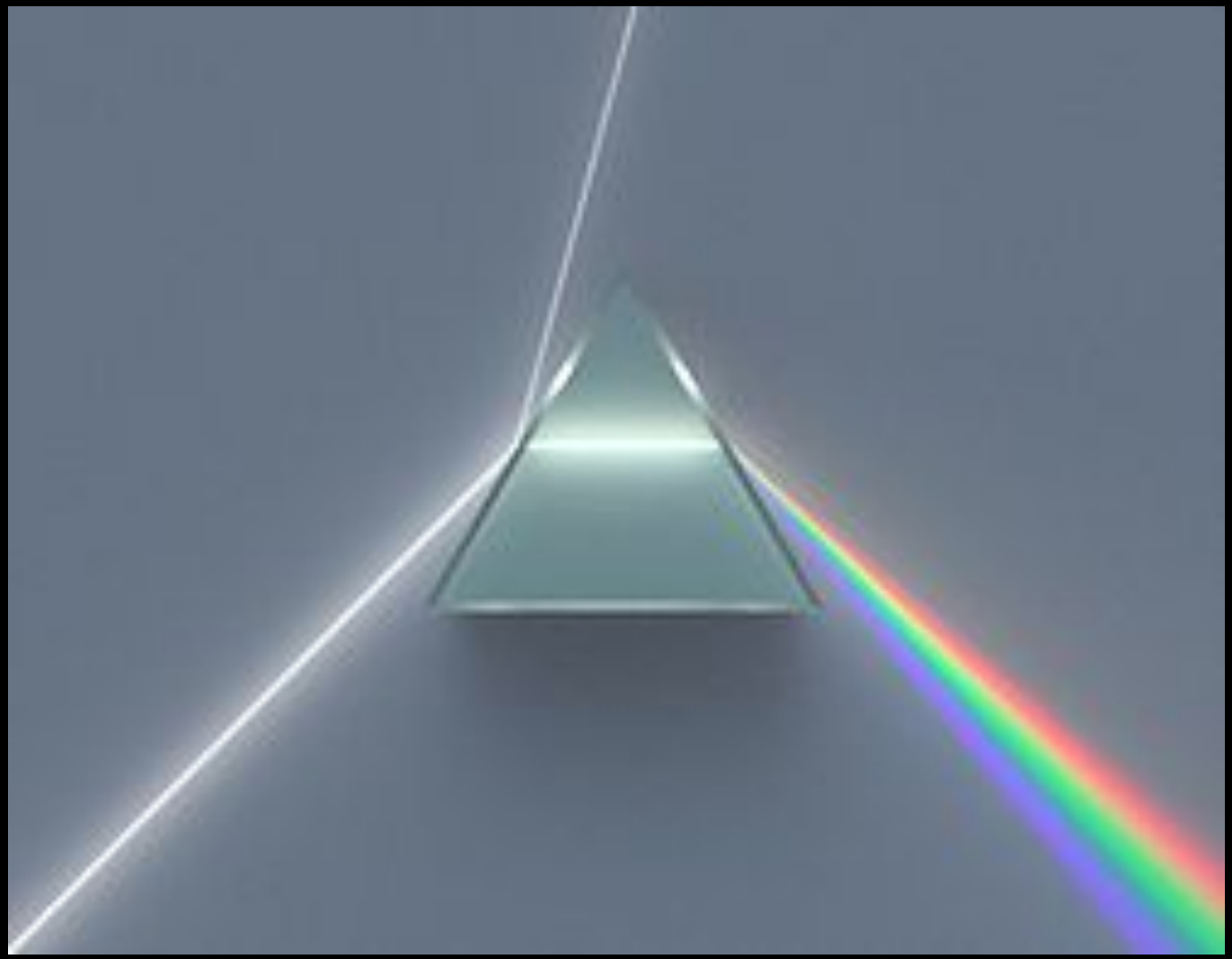
'Visible' Spectrum

Newton



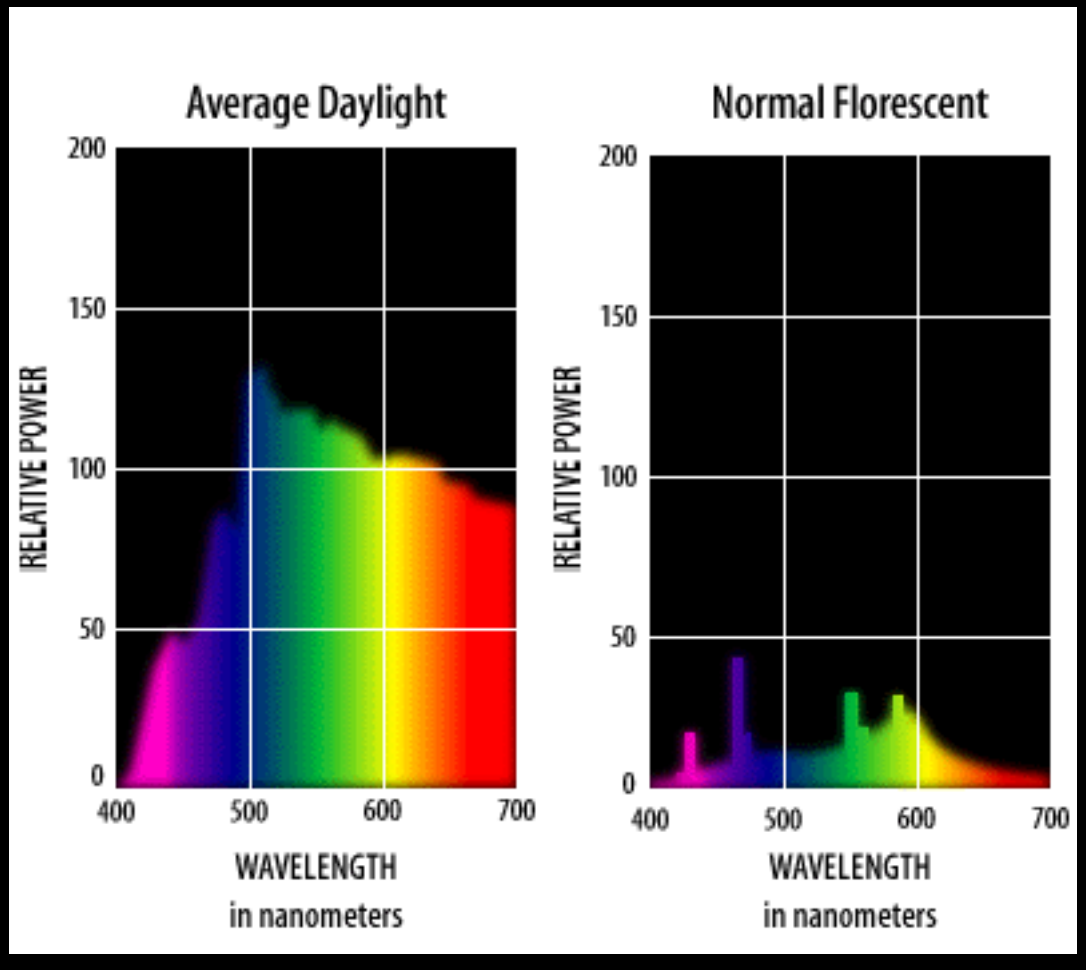
From Voltaire's Eléments de la Philosophie de Newton, published in 1738

Decomposition of White Light



Spectral Distributions

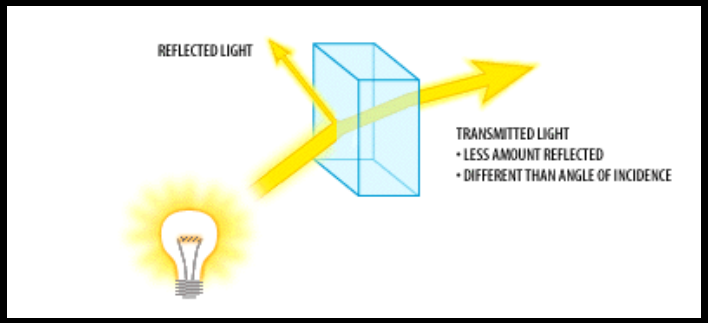
- Spectral distributions show the ‘amount’ of energy at each wavelength for a light source; e.g.

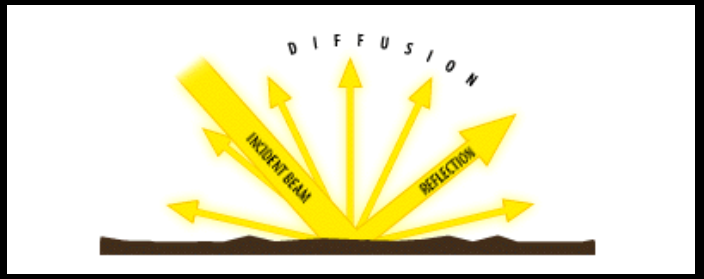


Interaction of Light and Matter

- When light strikes an object,
  - It will be wholly or partly transmitted.
  - It will be wholly or partly reflected.
  - It will be wholly or partly absorbed.
  - Physical surface properties dictate what happens

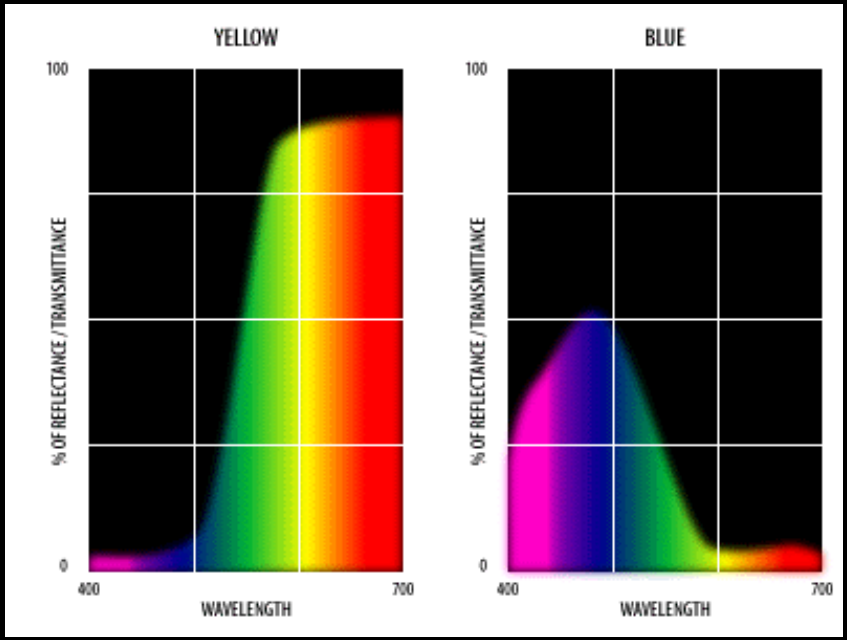
- When we see an object as blue or red or purple,
  - what we're really seeing is a partial reflection of light from that object.
  - The color we see is what's left of the spectrum after part of it is absorbed by the object.

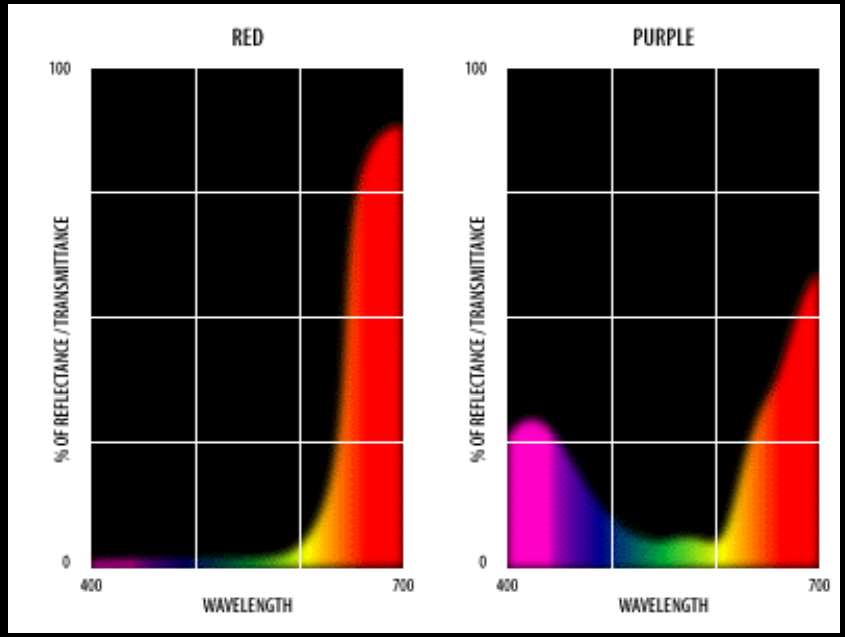




Spectral Reflectance Curves

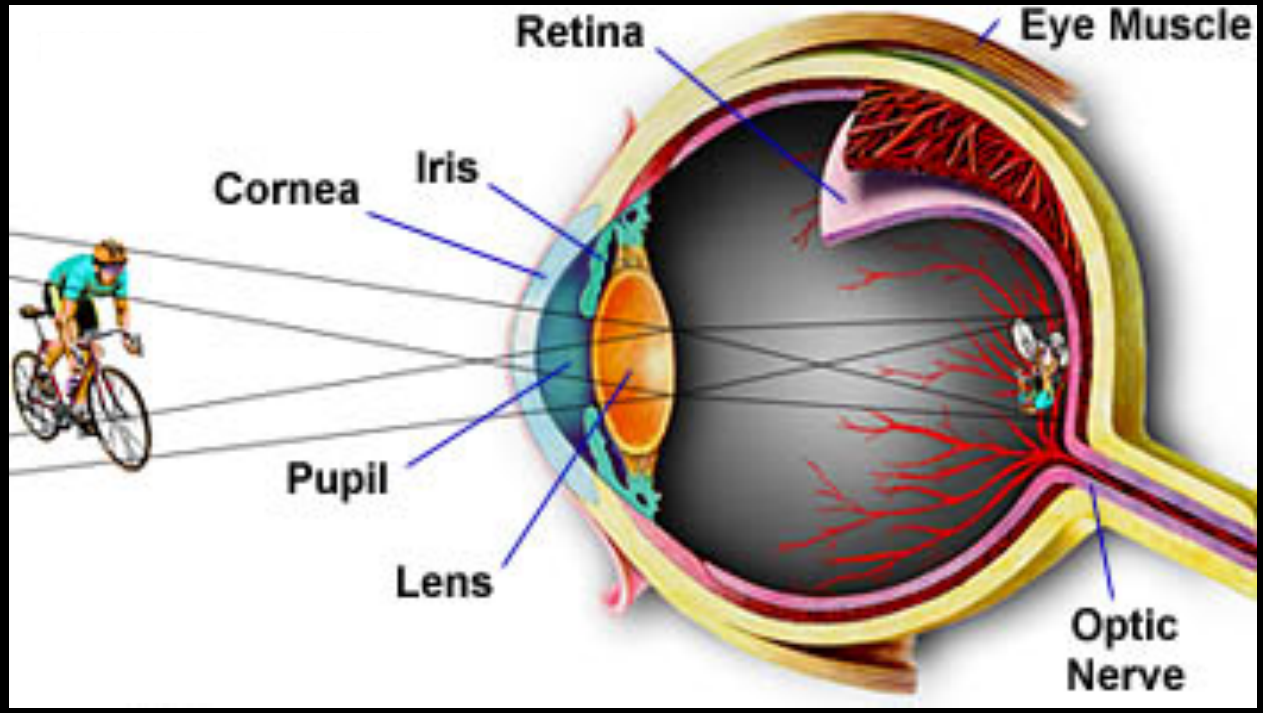
- Reflectance curves for objects that appear to be:





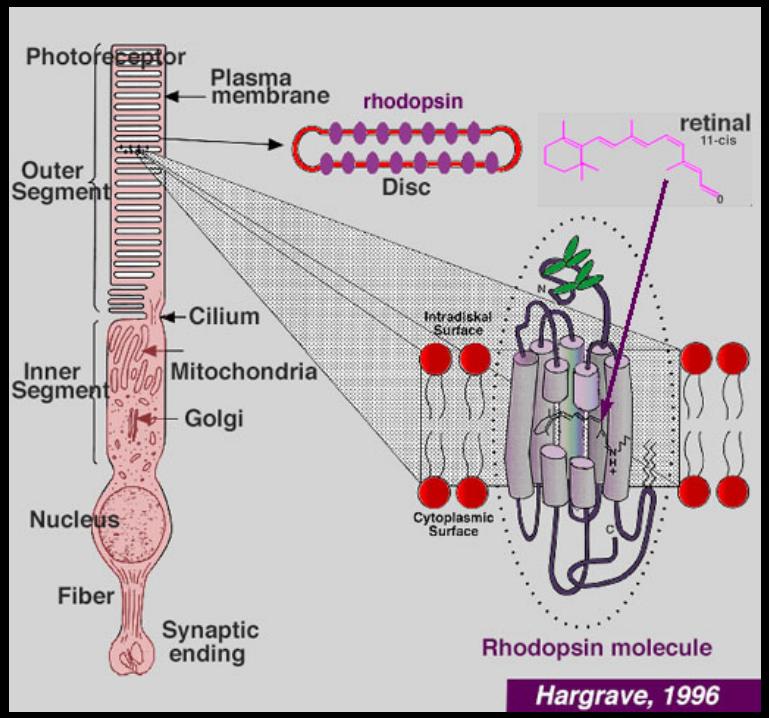
The wavelengths reflected or transmitted from or through an object determine the stimulus to the retina that provokes the optical nerve into sending responses to our brains that indicate color.

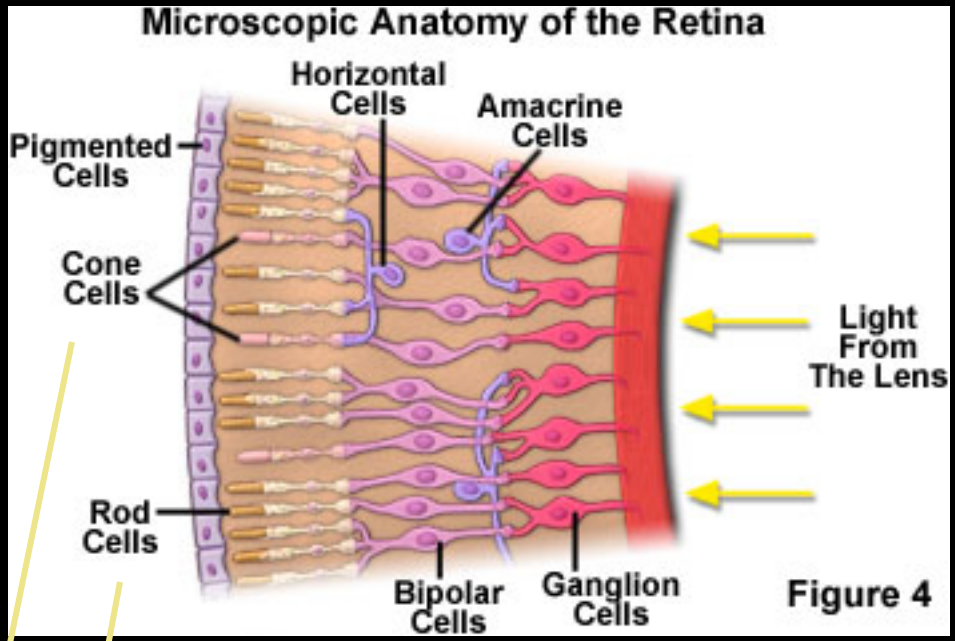
The Human Eye



Pupil - The opening through which light enters the eye - size from 2 to 8 mm in diameter
Iris - The colored area around the pupil that controls the amount of light entering the eye.
Lens - Focuses light rays on the retina.
Retina - The lining of the back of the eye containing nerves that transfer the image to the brain.
Rods - Nerve cells that are sensitive to light and dark.
Cones - Nerve cells that are sensitive to a particular primary color.

Photoreceptor

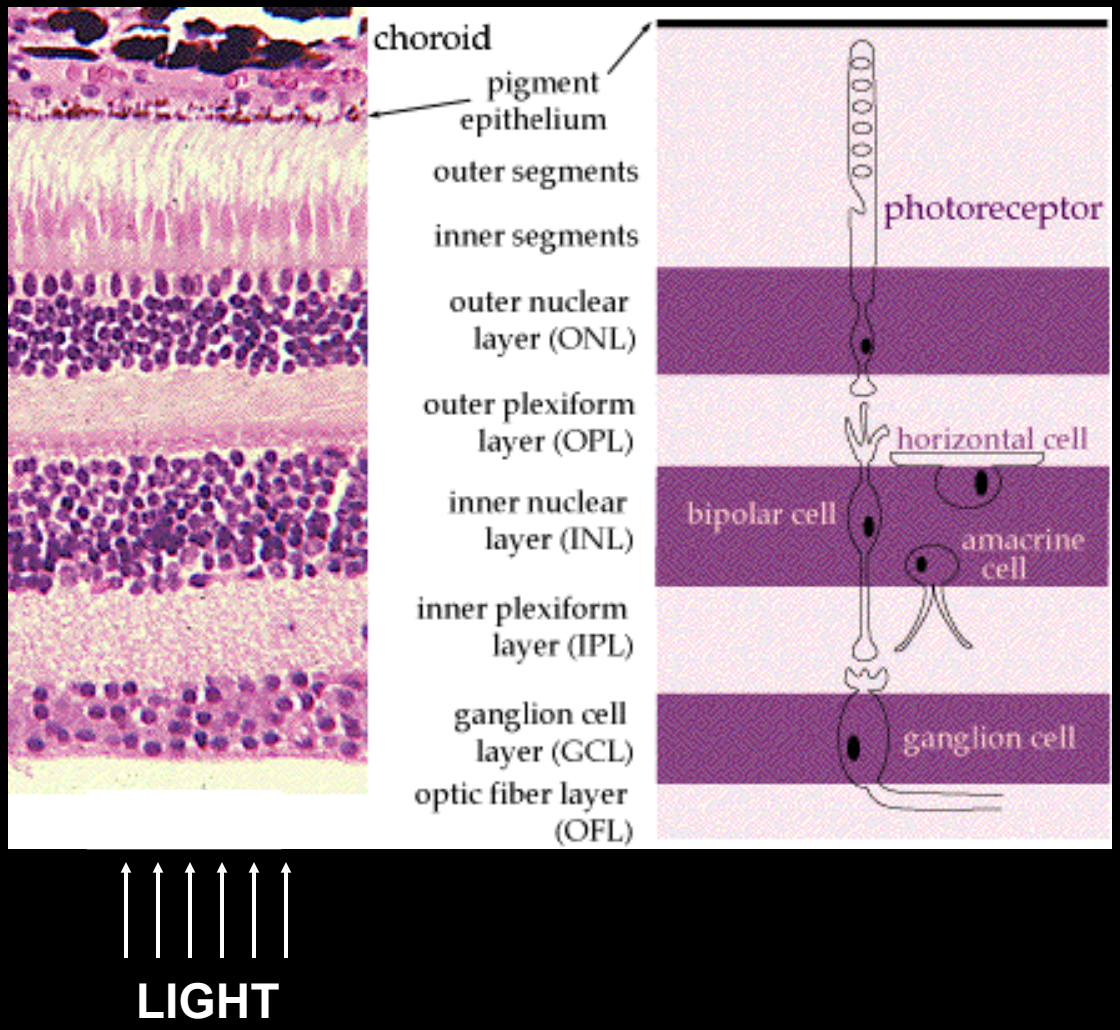




Low light receptors: ~125 million

Color receptors: 5-7 million

Retinal Tissue

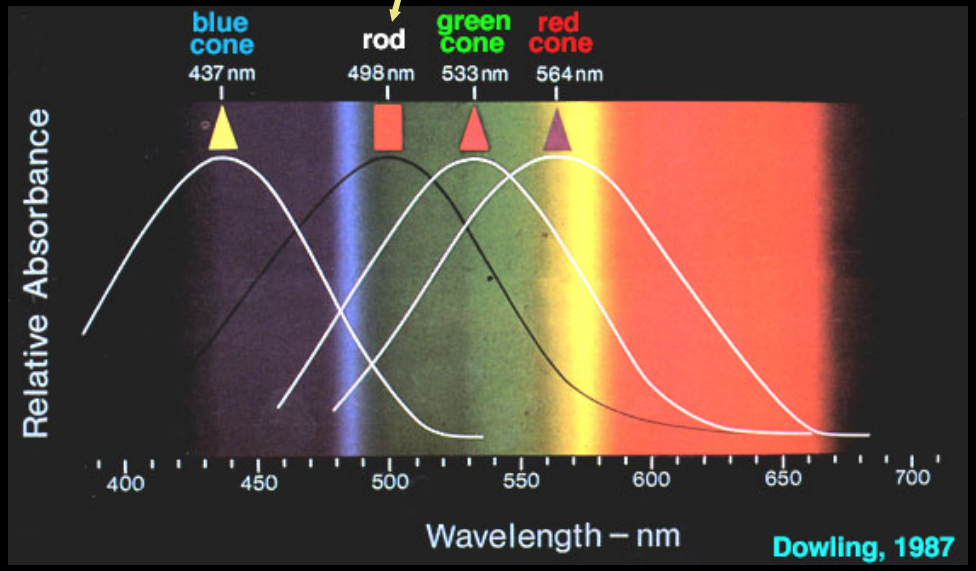


Rods and Cones

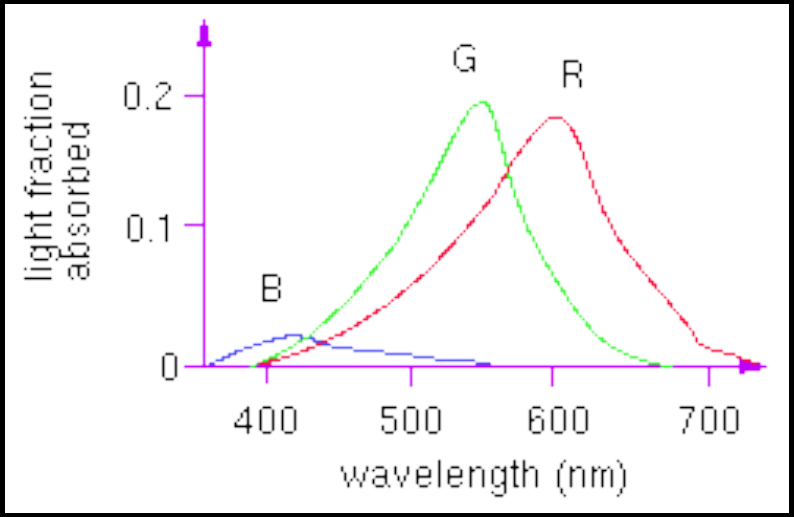
- Cones are located in the fovea and are sensitive to color.
  - Each one is connected to its own nerve end.
  - Cone vision is called photopic (or bright-light vision).
- Rods give a general, overall picture of the field of view and are not involved in color vision.
  - Several rods are connected to a single nerve and are
  - Sensitive to low levels of illumination (scotopic or dim-light vision).

Absorption Curves

Rods: achromatic vision

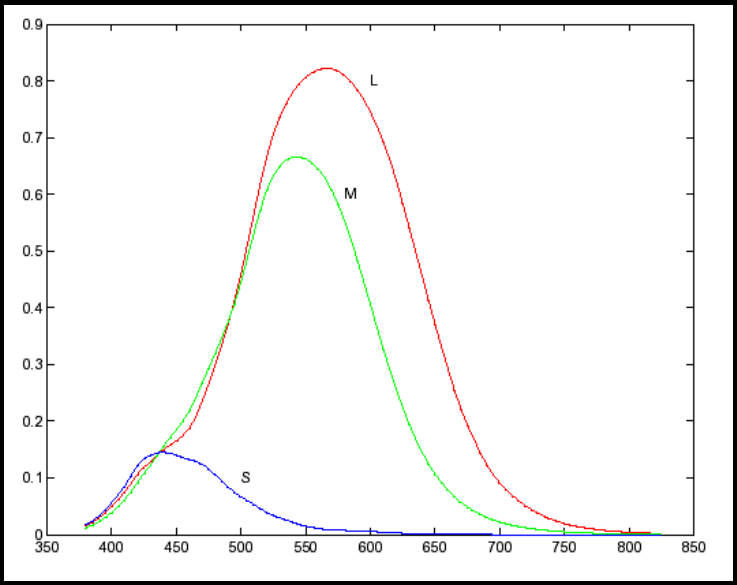


The different kinds of cells have different spectral sensitivities



Peak sensitivities are located at approximately 437nm, 533nm, and 610nm for the "average" observer.

Responses



Cone sensitivity curves

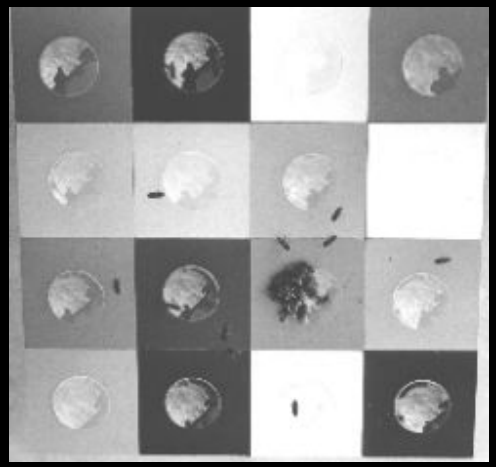
Response from i-th cone type:

$$c_i = \int s_i(\lambda) t(\lambda) d\lambda$$

$s_i(l)$ = sensitivity of i-th cone
$t(l)$ = spectral distribution of light
l = wavelength

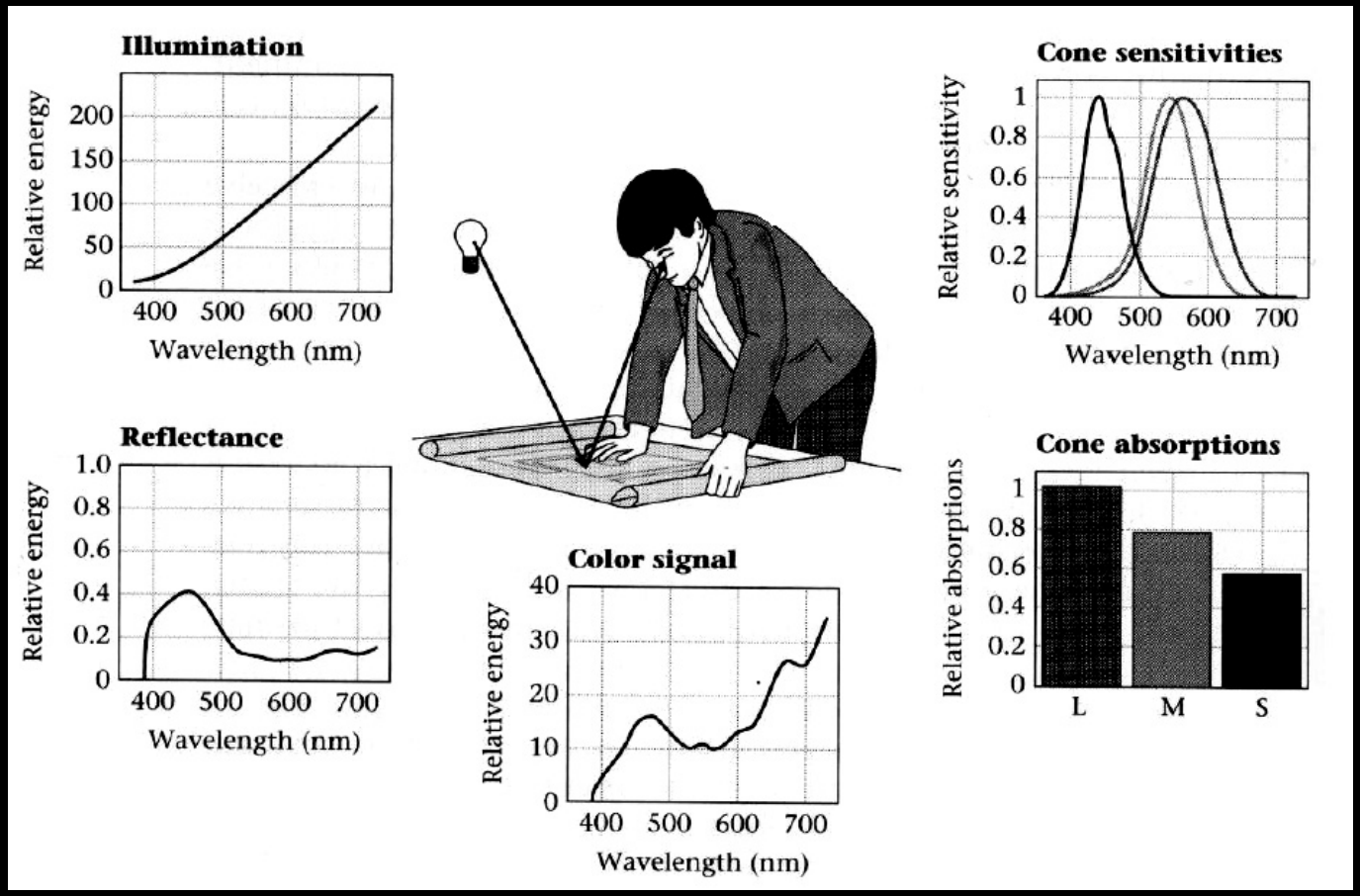
How can we find color equivalents?

The Eye of a Fly



What Do We 'See'?

Light Sources
Surface Reflectance
Eye sensitivity

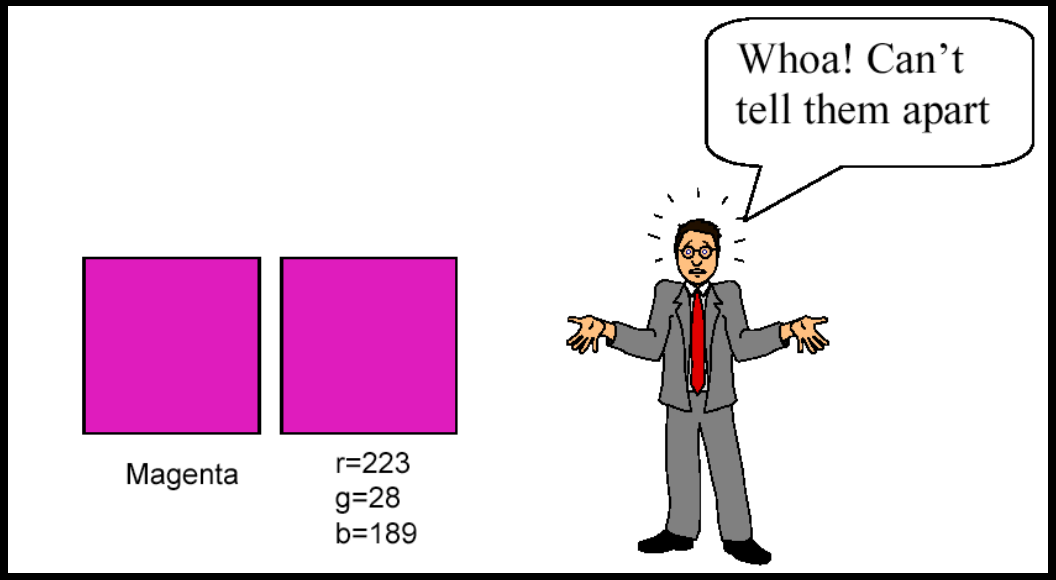


Tristimulus Theory

- Two light sources S1 and S2 may have very different spectral distribution functions and yet appear identical to the human eye.
- The human retina has three types of color receptors.
- The receptors have different responses to light of different frequencies.
- Two sources S1 and S2 will be indistinguishable if they generate the same response in each type of receptor.
  - same observer
  - same light conditions
  - called metamerism

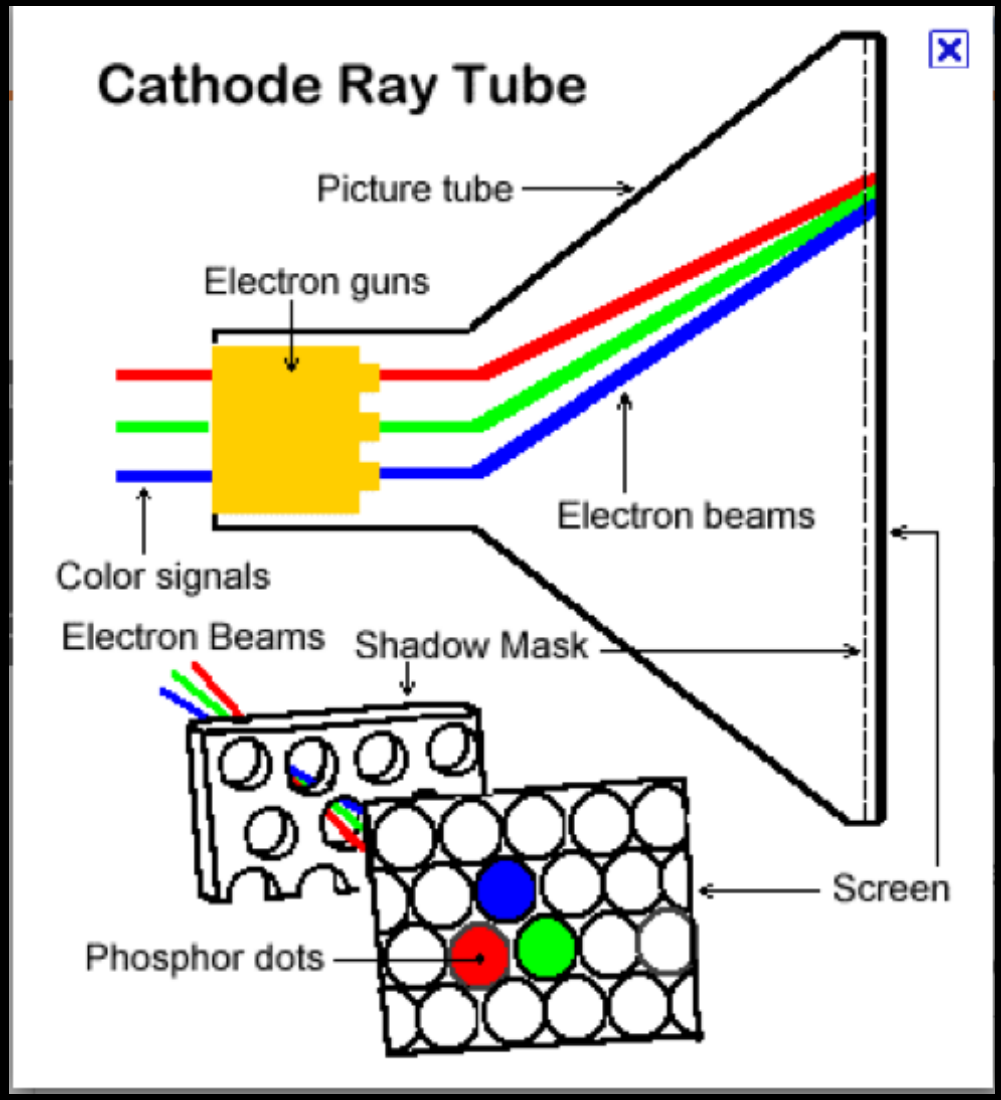
Grassman's Law (1835)

- 1st Law: Any color stimulus can be matched exactly by a combination of three primary lights.
  - The match is independent of intensity
- Basis of many color description systems



- 2nd Law: adding another light to both of these stimuli changes both in the same way.

Cathode Ray Tubes



Computations

- Response of a retinal cell to a particular light.
- Response of a retinal cell to a particular light bouncing off a particular surface.
- Computing metamers.
  - “minimal” metamers
  - general metamers

Introduction to
Computer Vision

End