Color

Reading

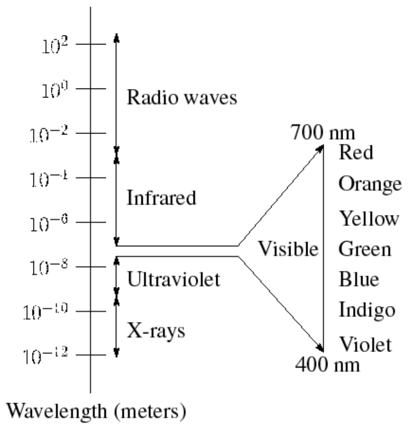
Watt , Chapter 15.

Brian Wandell. *Foundations of Vision. Chapter 4.* Sinauer Associates, Sunderland, MA, pp. 69-97, 1995.

The radiant energy spectrum

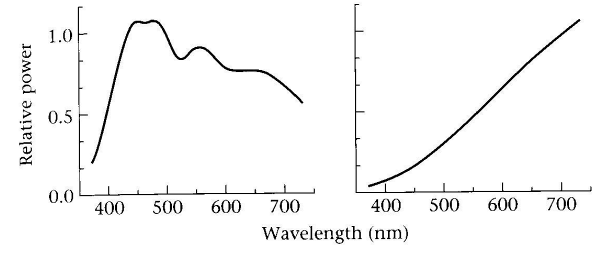
We can think of light as waves, instead of rays.

Wave theory allows a nice arrangement of electromagnetic radiation (EMR) according to wavelength:



Emission spectra

A light source can be characterized by an emission spectrum:



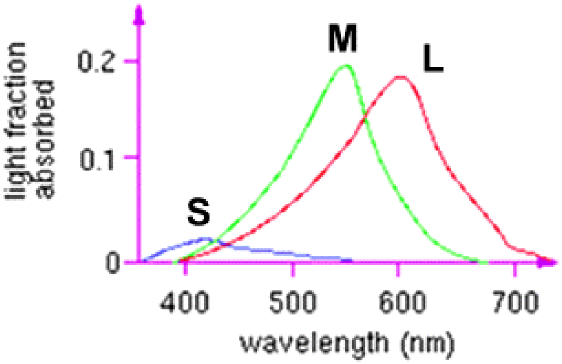
Emission spectra for daylight and a tungsten lightbulb (Wandell, 4.4)

The spectrum describes the energy at each wavelength.

How does this get converted into "color"?

Cones give color vision

Cones come in three varieties: L, M, and S.



Each cone responds to a range of the light spectrum

- it actually acts as a filter on the spectrum

Cones and color matching

Color is perceived through the responses of the cones to light.

The response of each cone can be written simply as:

$$L_t = \int t(\lambda) l(\lambda) d\lambda$$

$$M_t = \int t(\lambda) m(\lambda) d\lambda$$

$$S_t = \int t(\lambda) s(\lambda) d\lambda$$

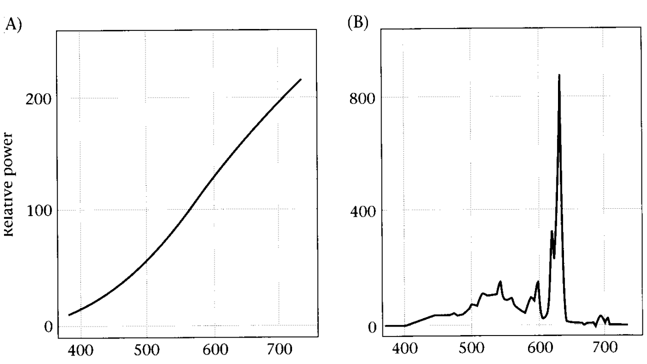
These are the only three numbers used to determine color.

Any pair of stimuli that result in the same three numbers will be indistinguishable.

Emission Spectrum is not Color

Recall how much averaging the eye does. Light is infinite dimensional!

Different light sources can evoke exactly the same colors. Such lights are called **metamers**.

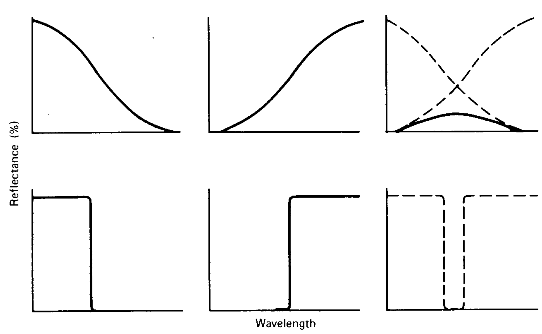


A dim tungsten bulb and an RGB monitor set up to emit a metameric spectrum (Wandell 4.11)

Colored Surfaces

So far, we've discussed the colors of lights. How do *surfaces* acquire color?

When light hits a surface, a proportion $\rho(\lambda)$ of each wavelength is reflected. This **reflectance function** determines the color of the surface.



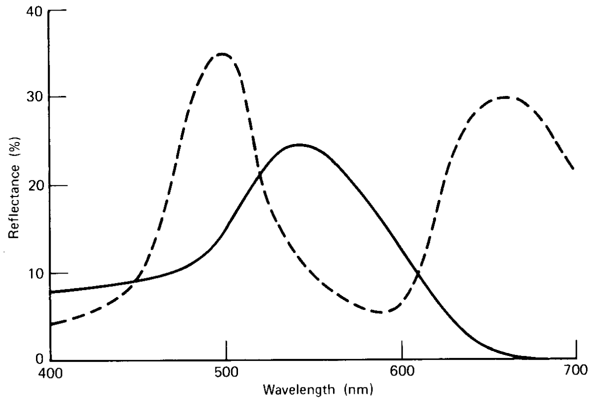
Reflectance (Wasserman 2.2)

The process is *multiplicative*:

$$I(\lambda) = \rho(\lambda) t(\lambda)$$

In general, $\rho(\lambda)$ also depends on the angle of the light source and the viewer wrt. surface normal...

Reflective Metamers

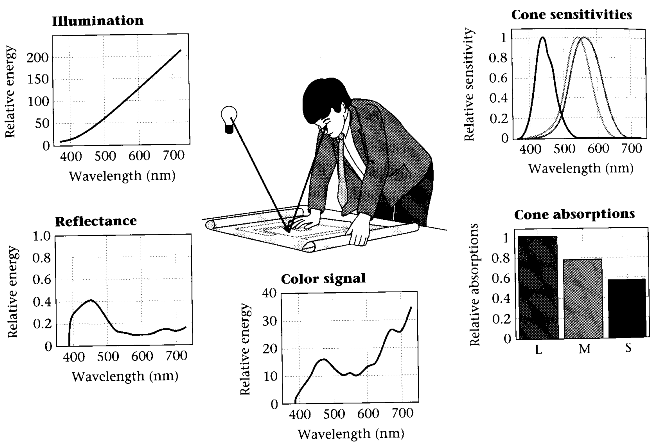


Surfaces that are metamers under only some lighting conditions (Wasserman 3.9)

Reflectance adds a whole new dimension of complexity to color perception.

The solid curve appears green indoors and out. The dashed curve looks green outdoors, but brown under incandescent light.

Color Perception



How light and reflectance become cone responses (Wandell, 9.2)

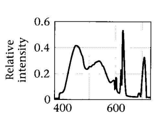
RGB Color

We often describe color in terms of RGB. How does this relate to cones and color spectra?

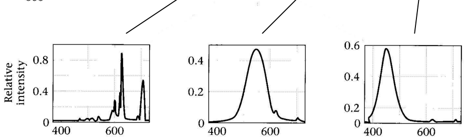
Somebody pointed at something and called it “red”. Same for “green” and “blue.” These were chosen as “primary colors.”

Note that there are many ways (spectra) to produce red—therefore red is not a spectrum but rather a particular set of cone responses. Same for green and blue.

Different display devices use different spectra to produce R, G, and B



$$e(\lambda) = Rr(\lambda) + Gg(\lambda) + Bb(\lambda)$$



Emission spectra for RGB monitor phosphors (Wandell B.3)

Other color spaces

Any perceptible color may, in principle, be specified using RGB. However, other **color spaces** are often used. Here are a few common ones:

- RGB for display
- CMYK (cyan, magenta, yellow, black) for hardcopy
- HSV (hue, saturation, value) for user selection
- YIQ for TV broadcast
- CIE, used by color scientists, related to cone response

Summary

Here's what you should take home from this lecture:

- All the **boldfaced terms**.
- How to compute cone responses
- The difference between emissive and reflective color
- Meaning of RGB