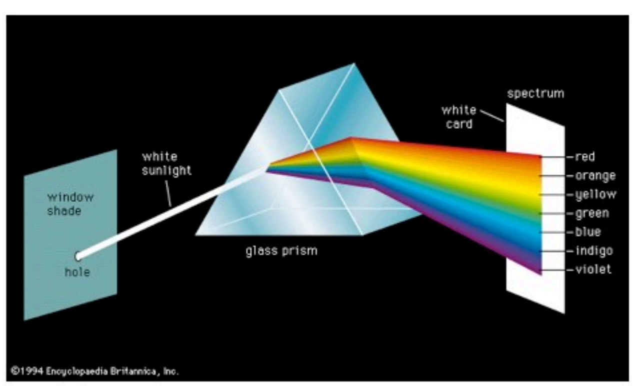
Trichromacy

- Spectral nature of light (1650+)
- Human color matching + theory (1850+)
- Physiology of photoreceptors (1980+)

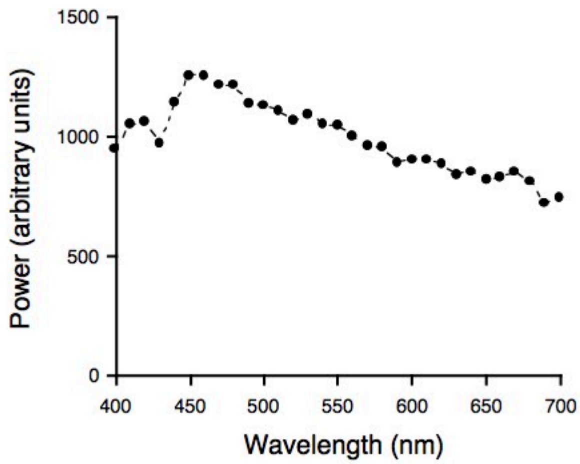
[See Wandell, Foundations of Vision]

Spectral nature of light



[Newton, 1665]

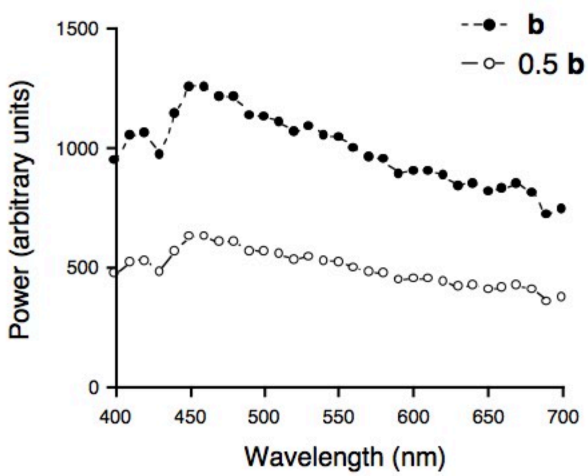
Representing spectra with vectors



$$\mathbf{b} = \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_{31} \end{bmatrix}$$

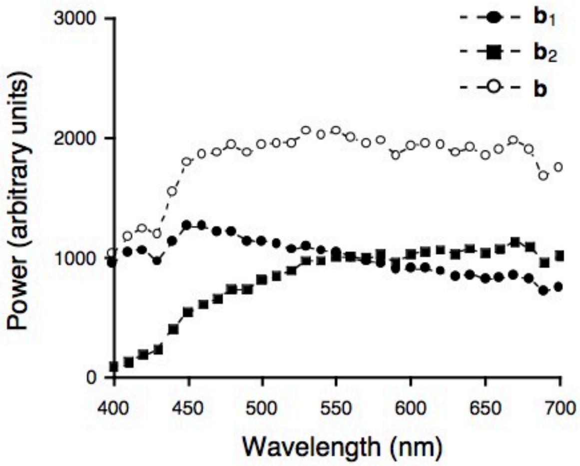
[c/o David Brainard]

Intensity Variation



[c/o David Brainard]

Additive mixtures



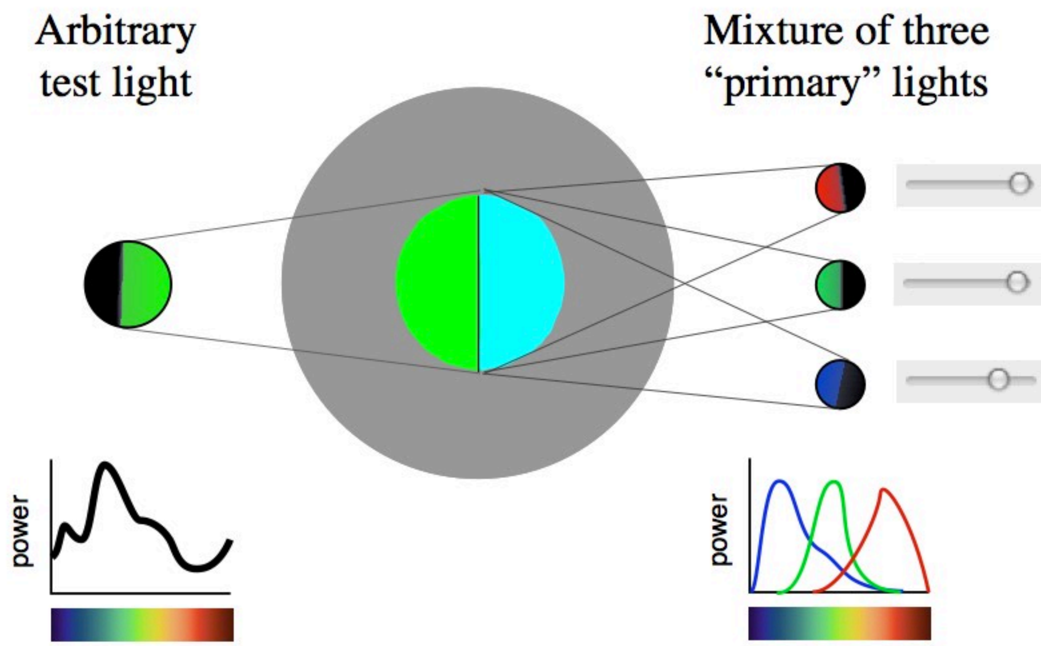
$$\begin{bmatrix} \mathbf{b} \end{bmatrix} = \begin{bmatrix} \mathbf{b}_1 \end{bmatrix} + \begin{bmatrix} \mathbf{b}_2 \end{bmatrix}$$

[c/o David Brainard]

Color perception: what's it for?

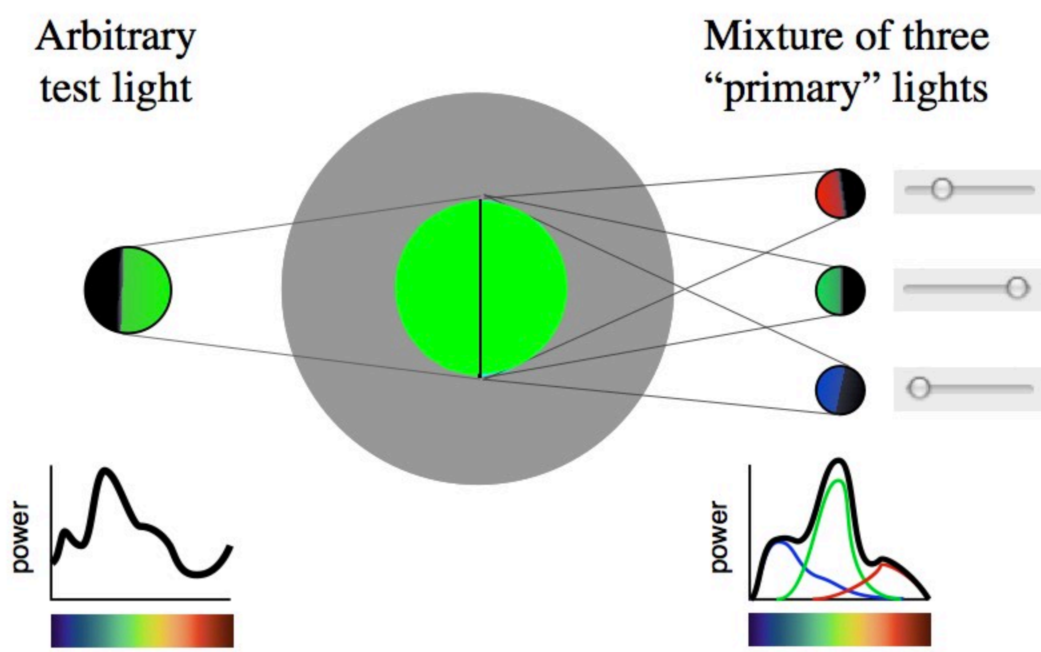
[c/o David Brainard]

Perceptual color matching experiment

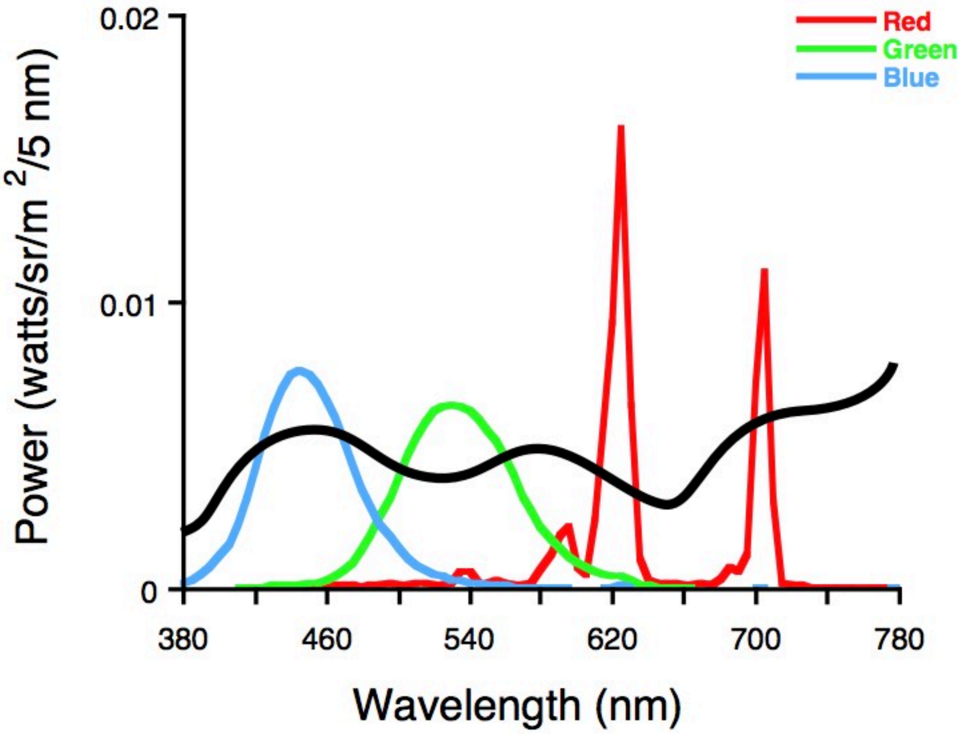


[Young, Helmholtz, Grassman, etc, 1800's]

Perceptual color matching experiment



[Young, Helmholtz, Grassman, etc, 1800's]



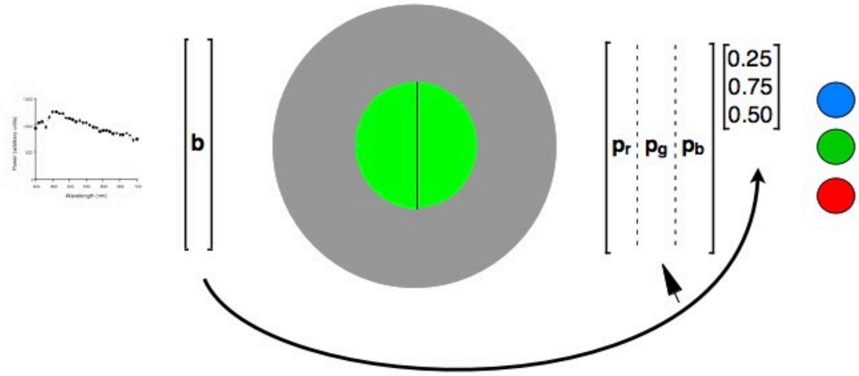
Grassmann's Laws (1853)

1) Any light can be matched with a mixture of 3 primaries
2) Adding two lights results in a sum of their mixtures
3) Rescaling the light results in a rescaled mixture

➡ Color matching can be described by an Nx3 linear system!

* Fine print: i) Normal human observer; ii) photopic intensity levels, not too bright; iii) independent primaries; iv) negative primary amplitude = add to test light.

Experimental measurement:



Linear model: $\begin{bmatrix}0.25\\0.75\\0.50\end{bmatrix} = \begin{bmatrix} & \mathbf{H} & \end{bmatrix}\begin{bmatrix}\mathbf{b}\end{bmatrix}$

[c/o David Brainard]

Implications

- If *P* is an *Nx3* matrix containing the primary spectra, and *H* is an *3xN* "matching matrix" that captures human color matching responses (mapping a spectrum to 3 "knob settings"), then for any light (spectrum) vector $\vec{l}$:

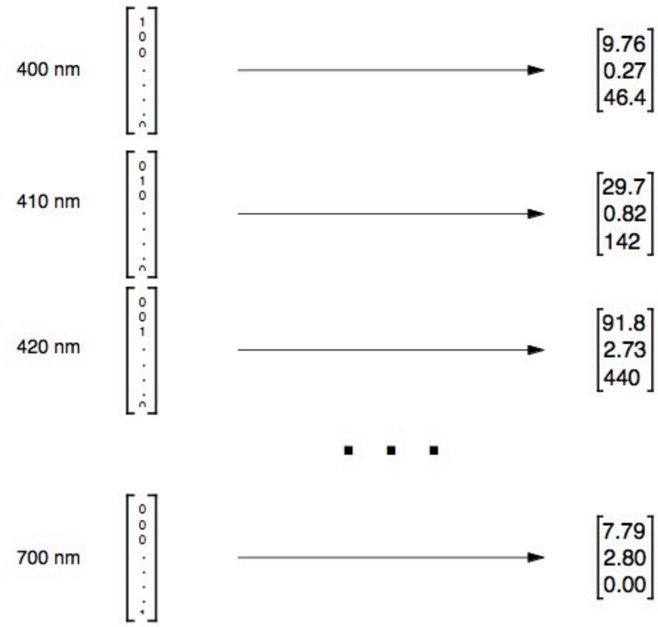
$$\vec{l} \sim PH\vec{l}$$

  where $\sim$ means "looks the same as"

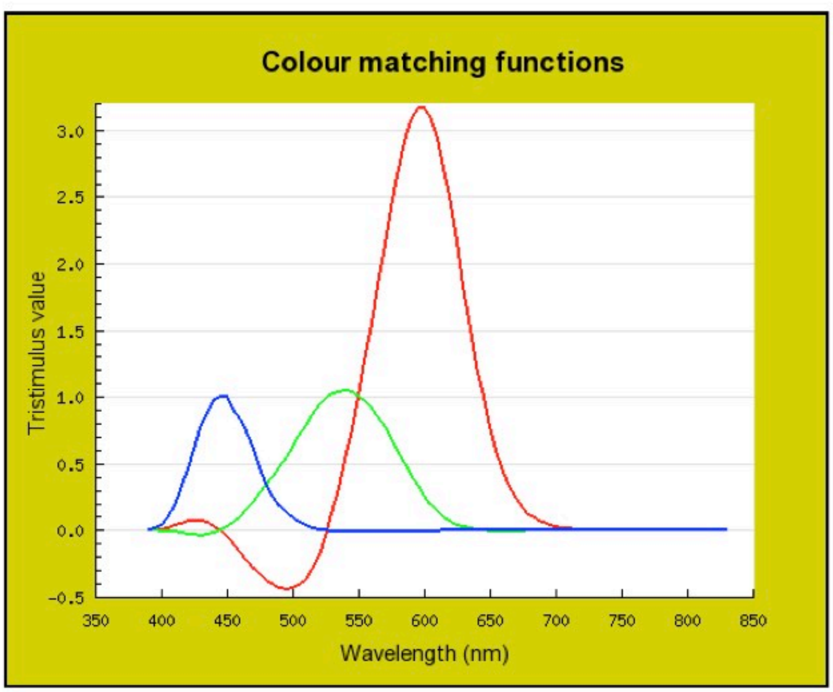
- Two lights look the same if (and only if) they produce the same match settings:

$$\vec{l}_1 \sim \vec{l}_2 \quad \Leftrightarrow \quad H\vec{l}_1 = H\vec{l}_2$$

Characterization



[c/o David Brainard]



Stiles-Burch Data, Monochromatic RGB Primaries of 645, 526, and 444 nm.

[Stiles & Burch, 1959]

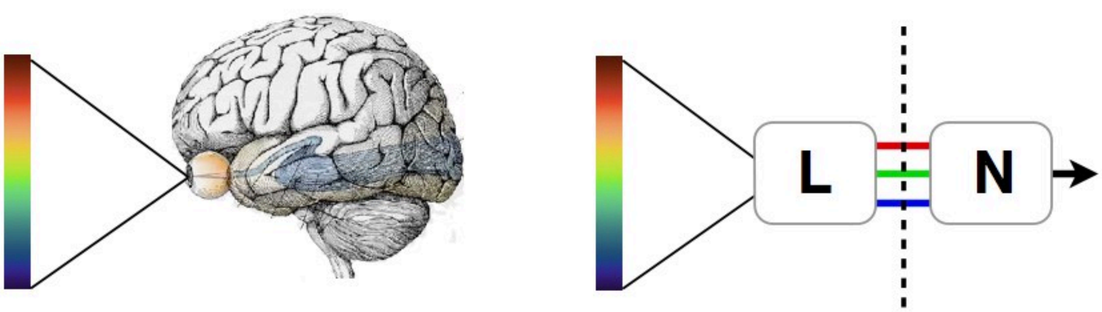
Useful calculations

- Scientific: given results of one matching experiment, predict the results of another one with different primaries.
- Practical: calibrate a display device, so as to generate mixtures of three colors that match the appearance of any desired real-world spectrum.

[derive on board]

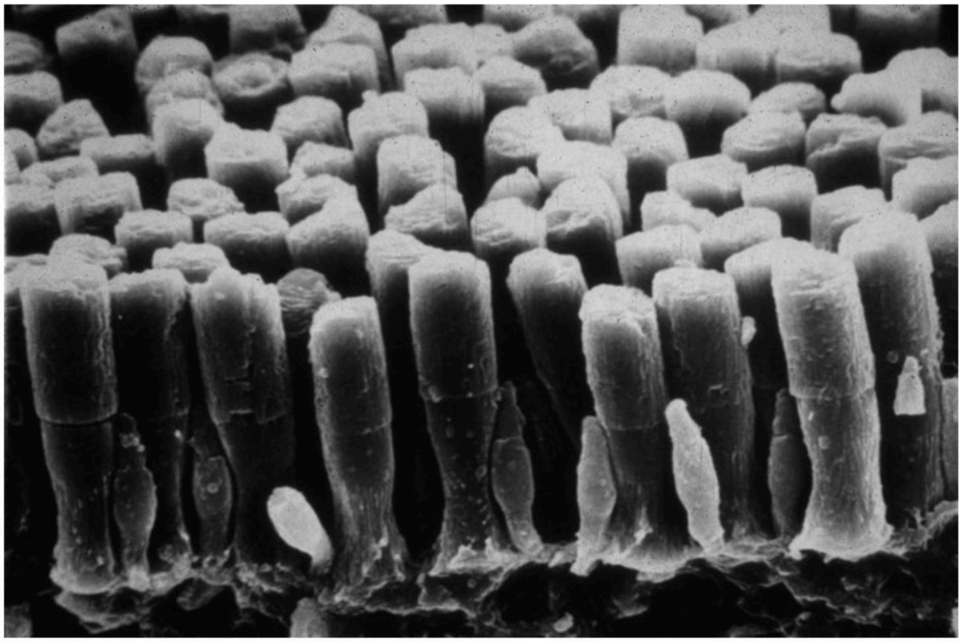
In summary:

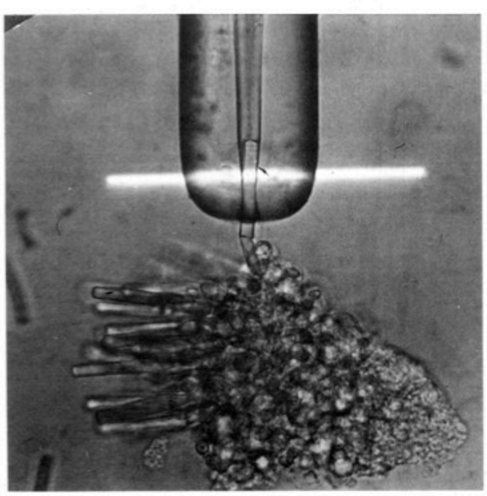
Theory: the visual system projects the wavelength spectra of light onto a 3-dimensional subspace

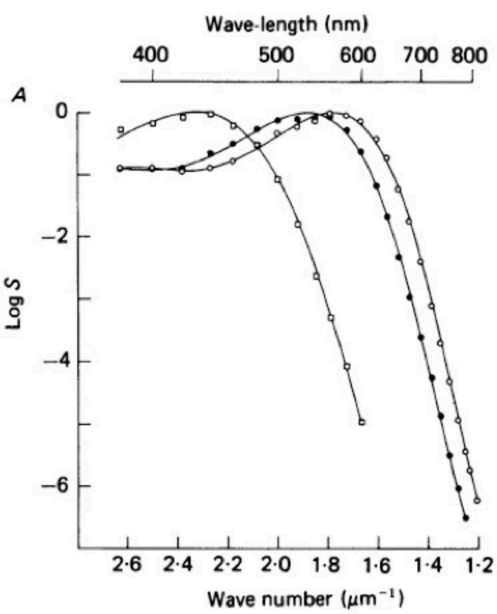


- Predicts/explains perceptual "metamers" - lights that appear identical, but have physically distinct wavelength spectra (1800's).
- Codified in CIE standards for color representation in 1931
- Underlying mechanism (cones) verified in 1987!

The underlying mechanism...

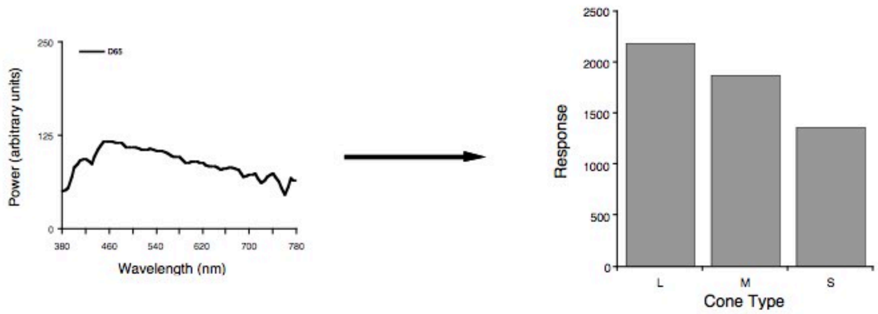


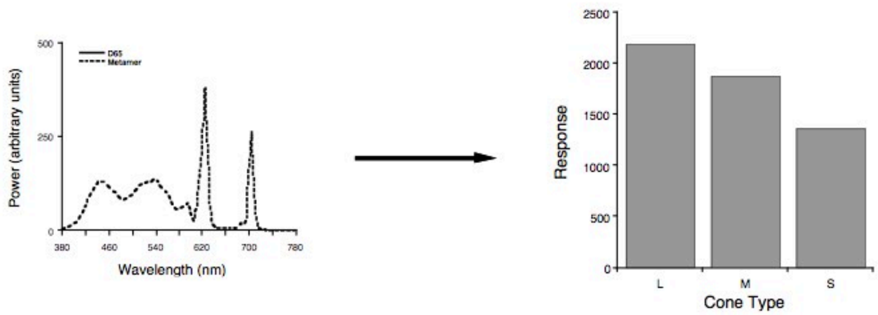




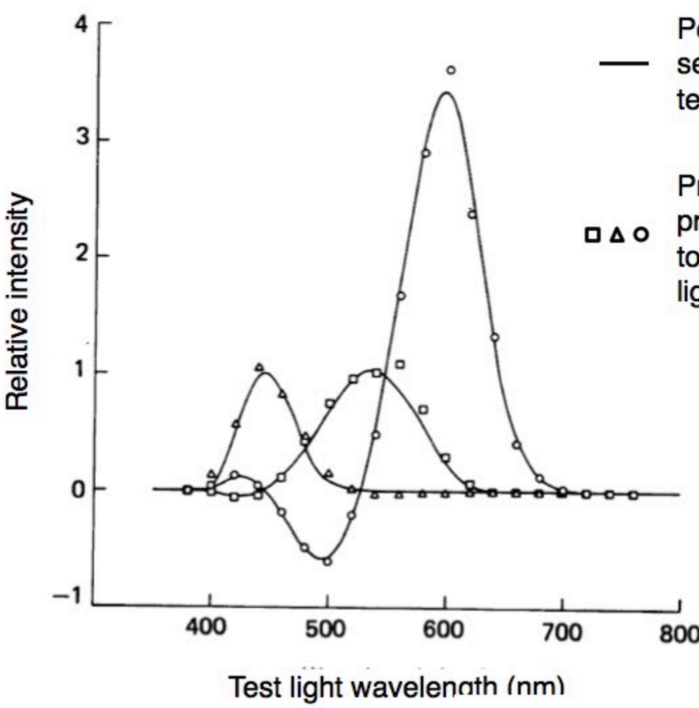
[Baylor, Nunn & Schnapf, 1987]

Physiological basis for color "metamers"





Confirmation of prediction (100+ years later):



— Perceptual trichromatic "knob settings" for monochromatic test lights

□ △ ○ Primary intensities that produce cone responses equal to those of monochromatic test lights

[Baylor, Nunn & Schnapf, '87]

Some dimensionality caveats

- Normal human vision, at high (“photopic”) light levels is tri-chromatic
- At low (“scotopic”) light levels, we are all monochromats
- At intermediate (“mesopic”) light levels, we are quadrachromats!
- Common genetic forms of color blindness are due to lack of one or more cone types