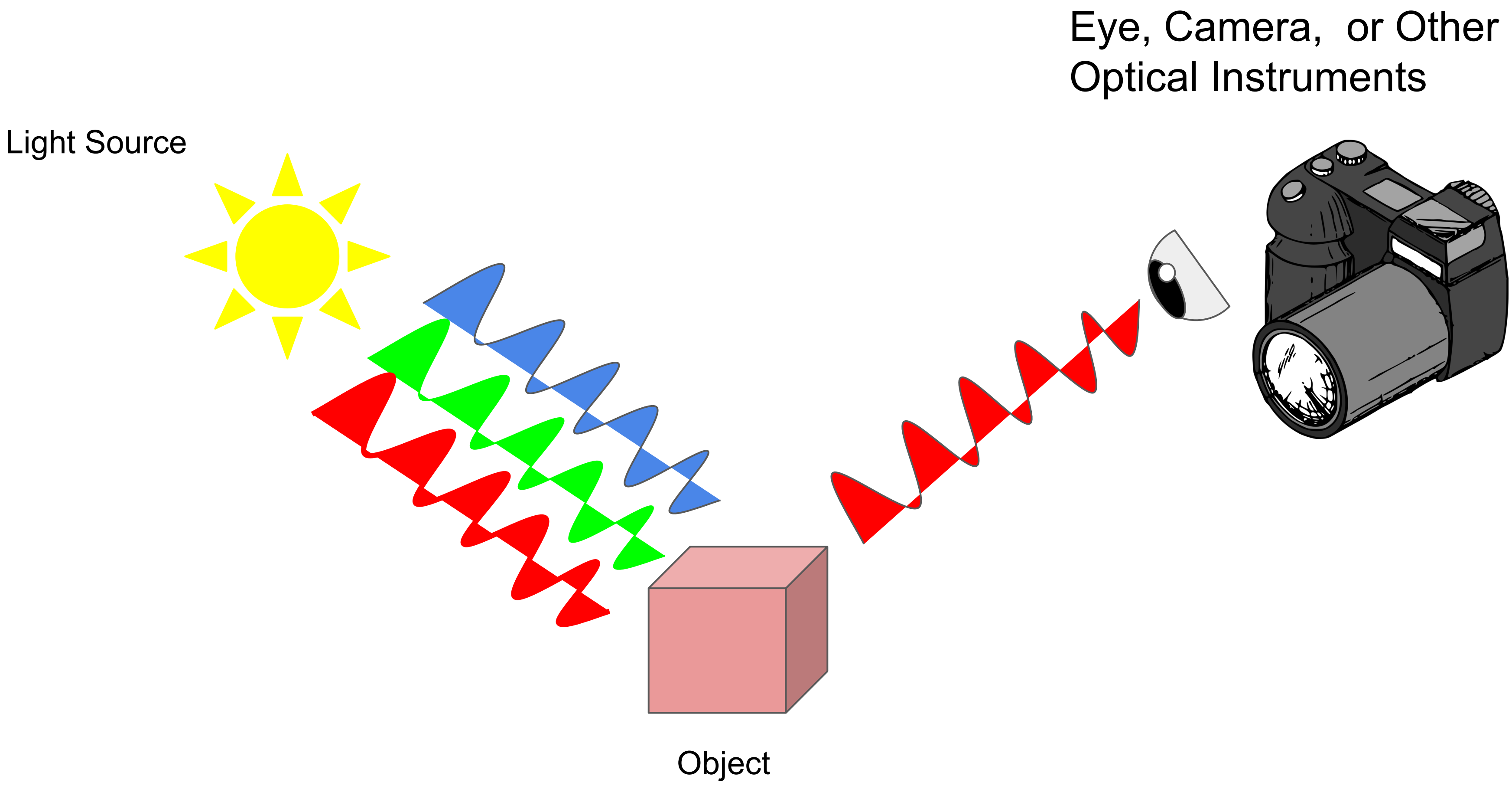
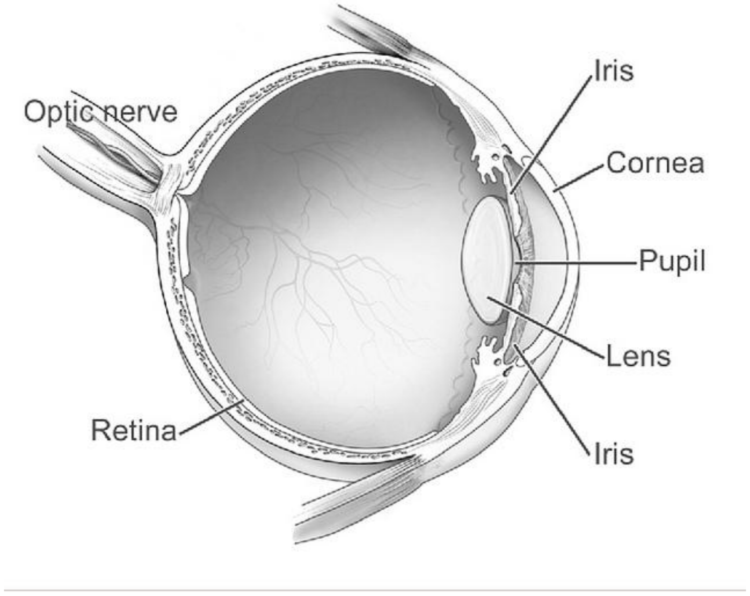
Sensors


Eye, Camera, or Other
Optical Instruments
Light Source
Object

Eye vs Camera



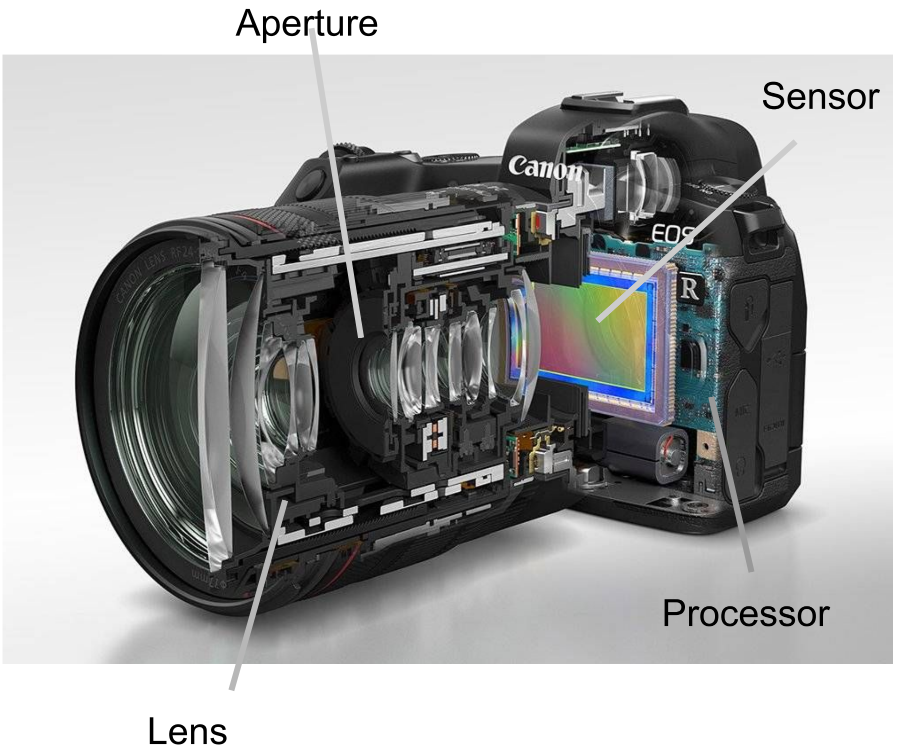
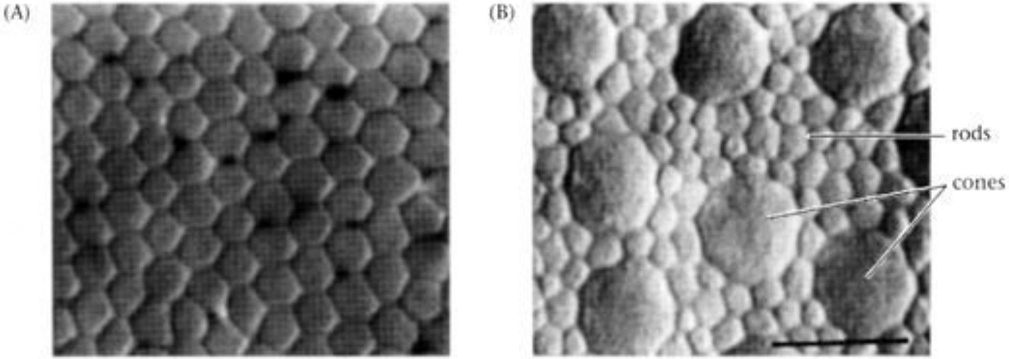
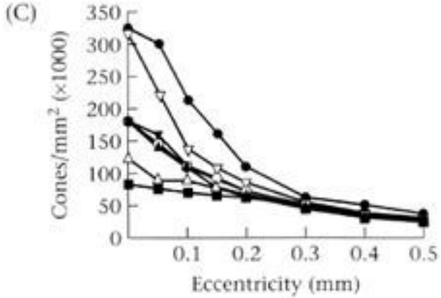


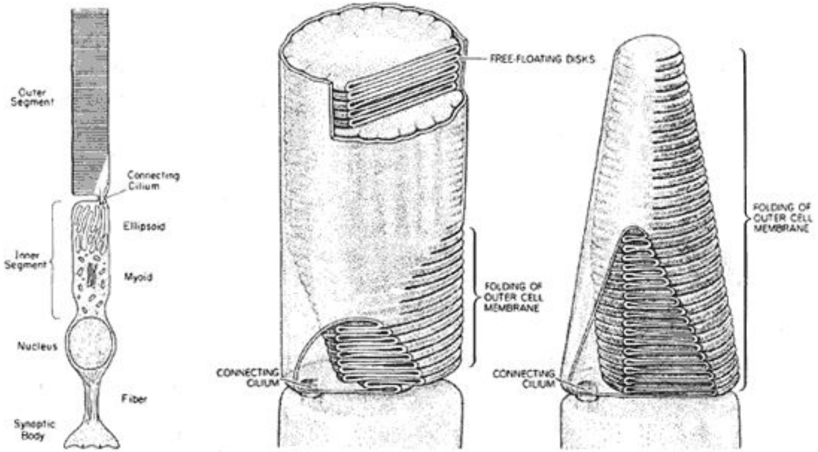
Image from:
https://www.canon.com.mt/pro/stories/eos-r-system-faqs/#

Rods and Cone in the Human Eye





3.4 THE SPATIAL MOSAIC OF THE HUMAN CONES. Cross sections of the human retina at the level of the inner segments showing (A) cones in the fovea, and (B) cones in the periphery. Note the size difference (scale bar = 10 μm), and that, as the separation between cones grows, the rod receptors fill in the spaces. (C) Cone density plotted as a function of distance from the center of the fovea for seven human retinas; cone density decreases with distance from the fovea. Source: Curcio et al., 1990.



At the left is a generalized conception of the important structural features of a vertebrate photoreceptor cell. At the right are shown the differences between the structure of rod (left) and cone (right) outer segments. These diagrams are from Young (1970) and Young (1971).

Images from:
https://www.cis.rit.edu/people/faculty/montag/vandplite/pages/chap_9/ch9p1.html

How the cones are arranged in the fovea

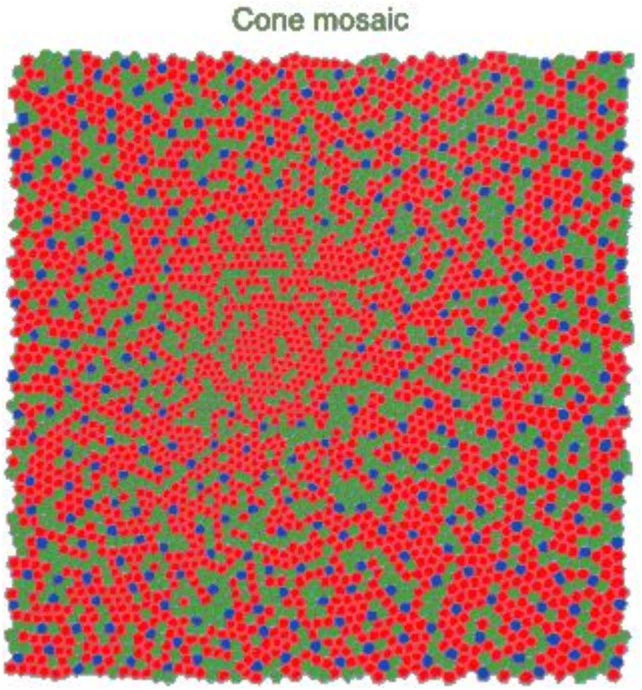
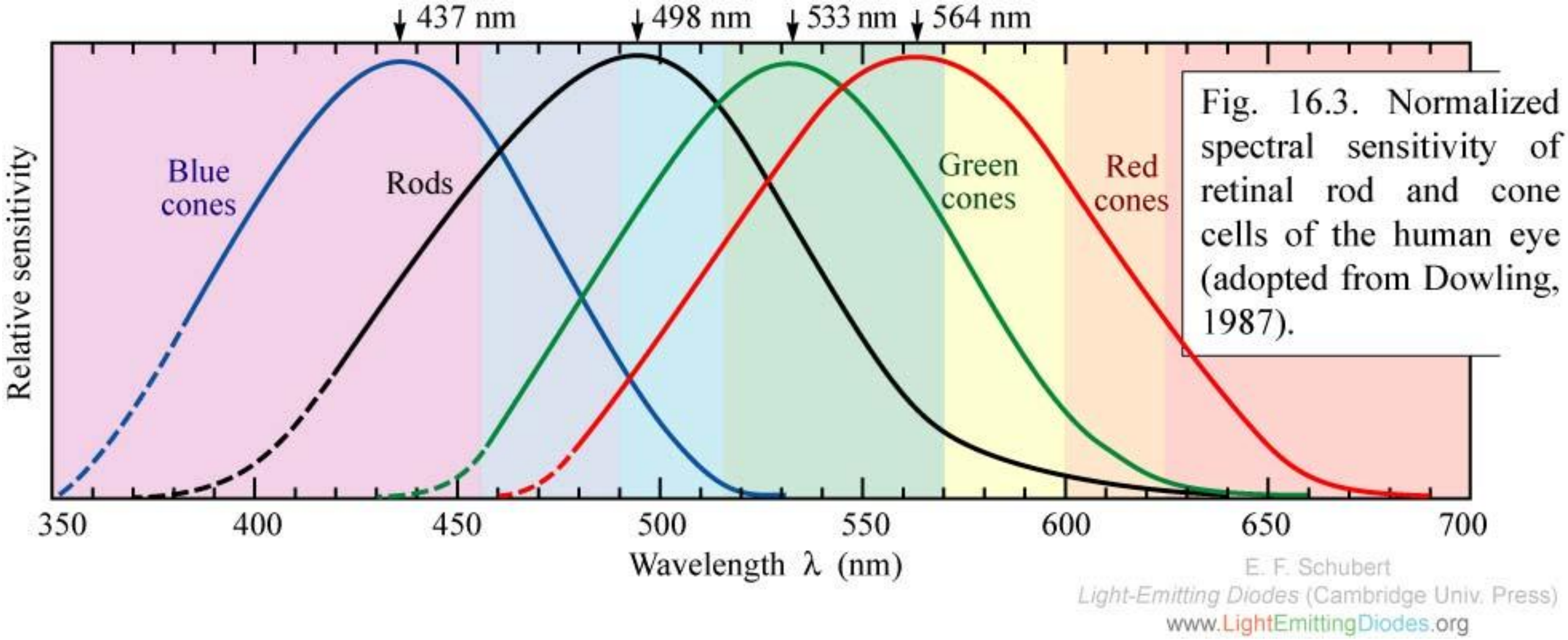


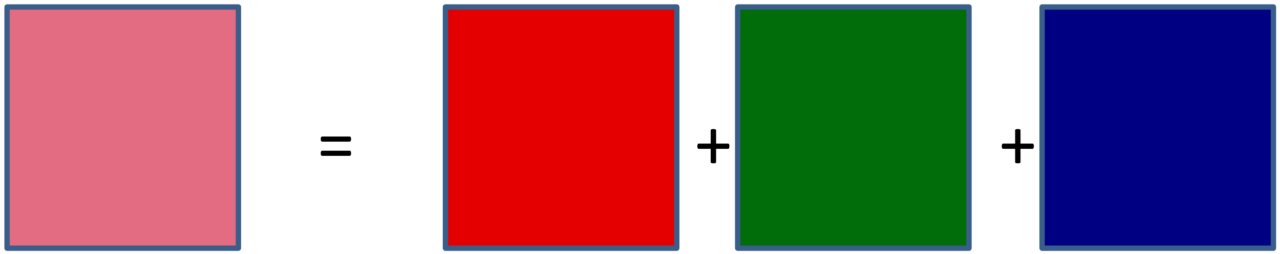
Image from: https://www.cis.rit.edu/people/faculty/montag/vandplite/pages/chap_9/ch9p1.html

Sensor Sensitivities



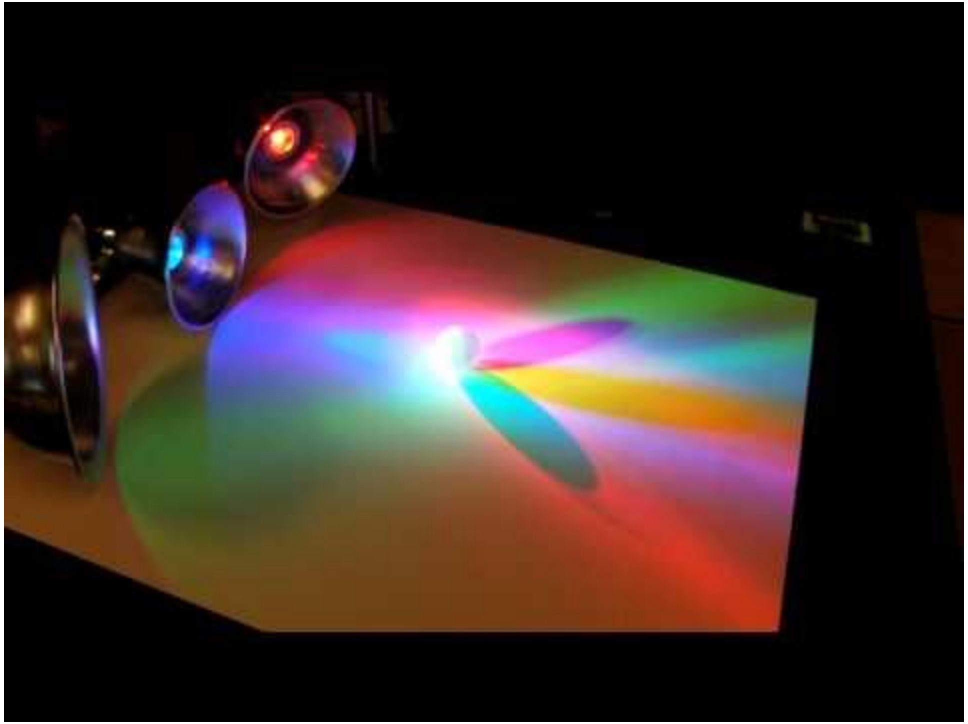
Trichromaticity

- Fundamental property of human color vision.
- Given 3 different colored lights, they can be mixed in different proportions to match any other test light.

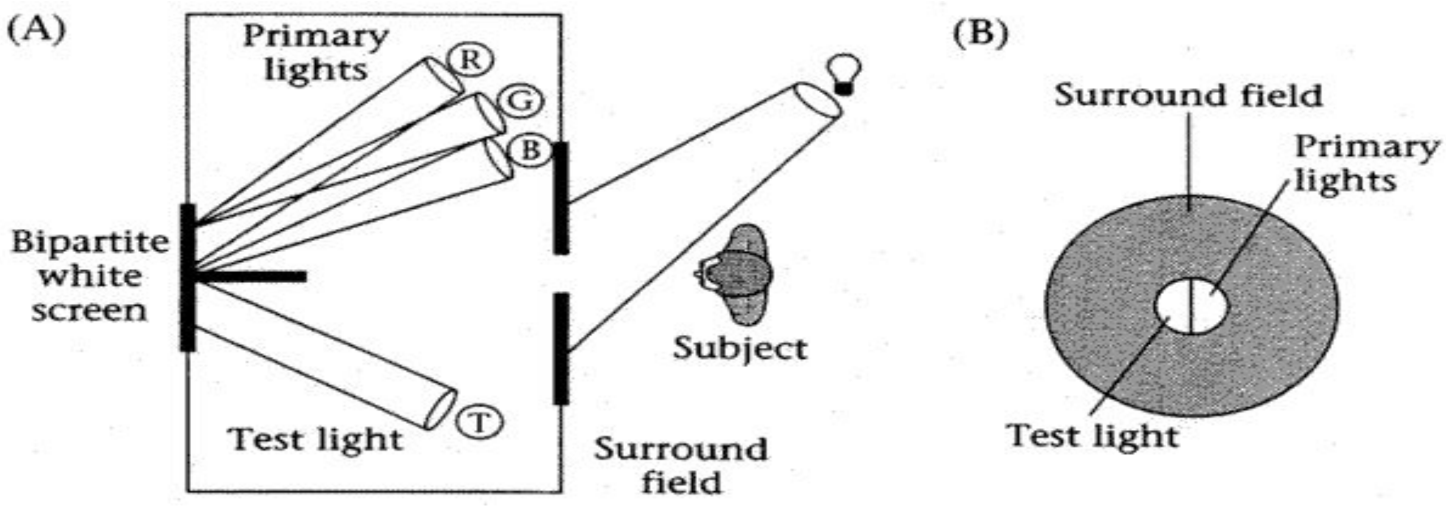


Caveat

- Mixture and test light should have the **same background**
- The choice of the 3 colored lights known as ‘primaries’ is such that **no mixture** of the **two** can produce **the third**.
- The experimenter should be able to mix one of the 3 lights to the **test light**.
- Test lights can have monochromatic spectra or broad spectra



Color Matching Experiment



http://www.ling.upenn.edu/courses/ling525/color_vision.html

Color Matching Game

- http://graphics.stanford.edu/courses/cs178-10/applets/colormatching.html

Trichromaticity allows convenient color reproduction

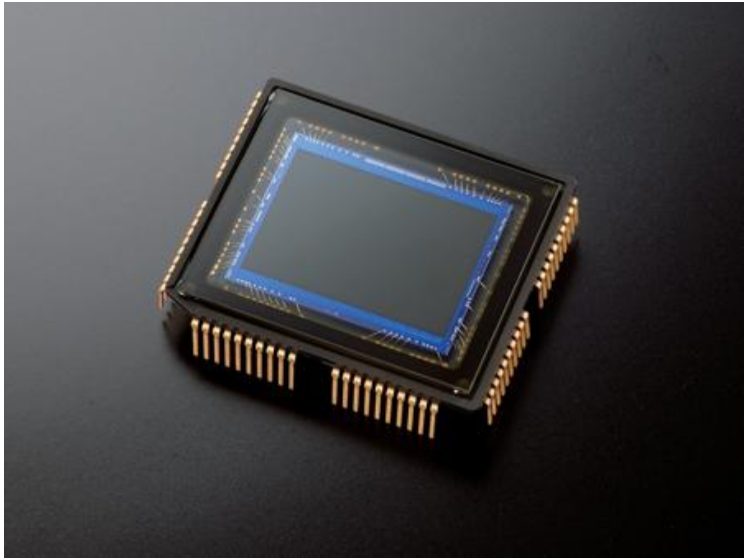
- RGB displays
- Color printing

Color Image Capture

- Apply Trichromaticity principle
- Two ways
  - Use 3 color filters
  - Use 3 monochromatic light sources

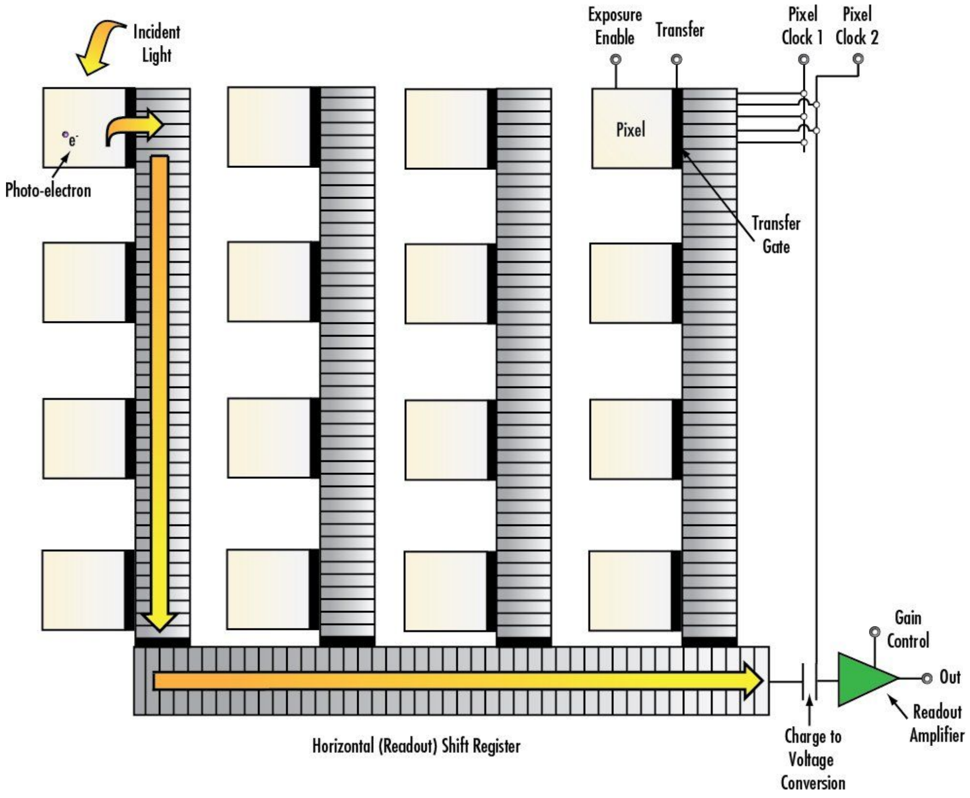
Camera Sensor

- Photosensitive Arrays
  - CCD charged couple device
  - CMOS complimentary metal oxide semiconductor

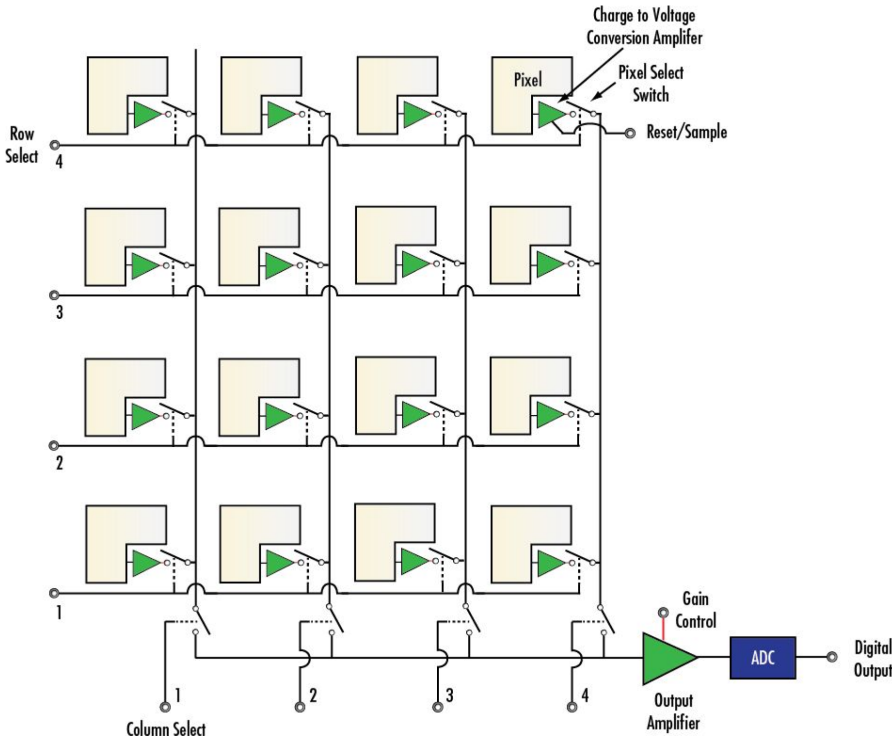


From www.edmundoptics.com

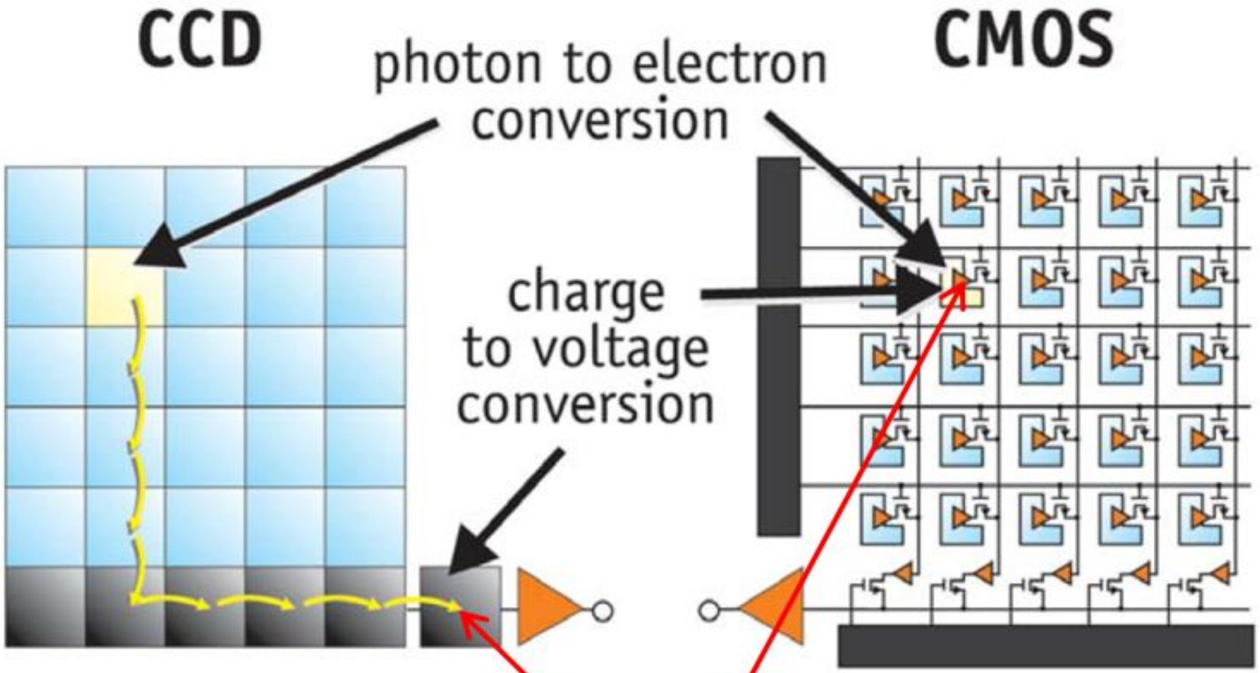
CCD



CMOS



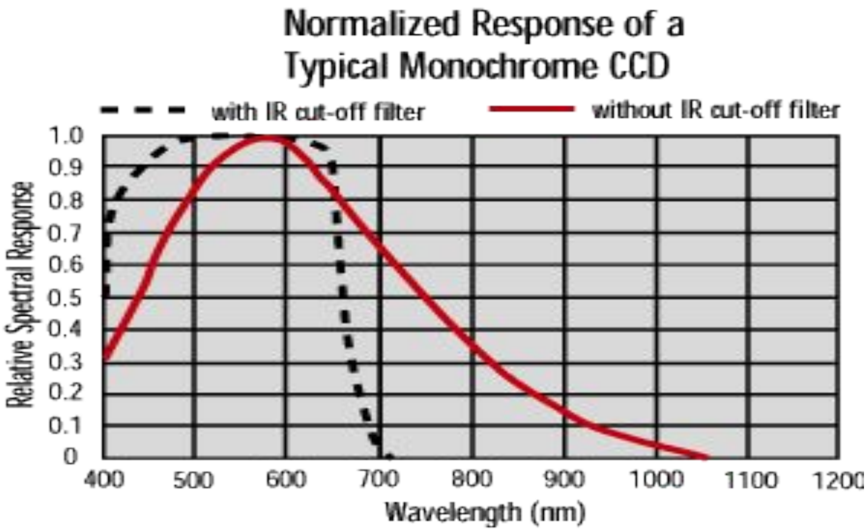
From www.edmundoptics.com

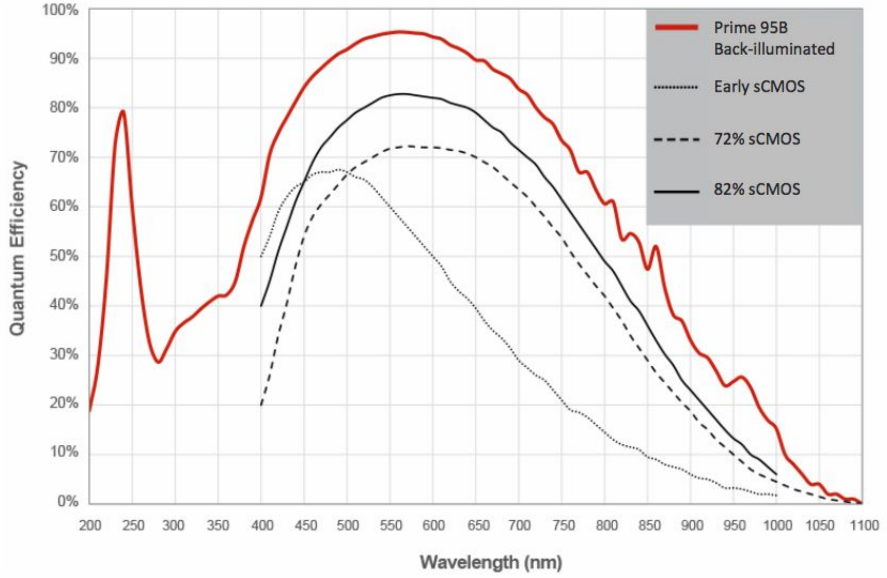


CCDs move photogenerated charge from pixel to pixel and convert it to voltage at an output node. CMOS imagers convert charge to voltage inside each pixel.

Read-out noise generated

Spectral Sensitivities of Photosensor arrays

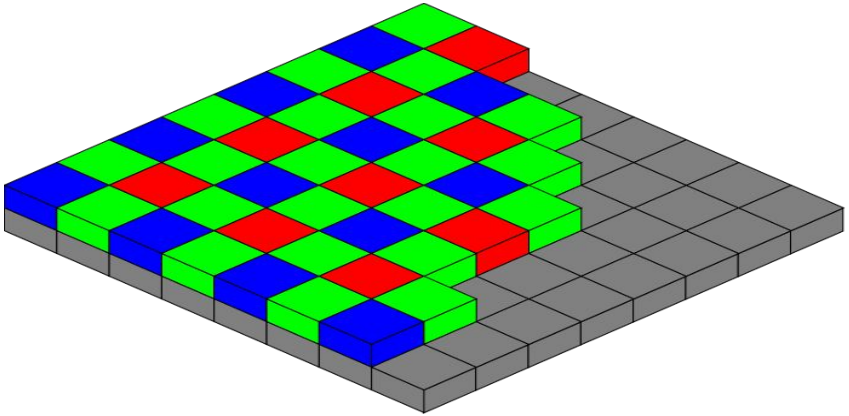




From www.edmundoptics.com

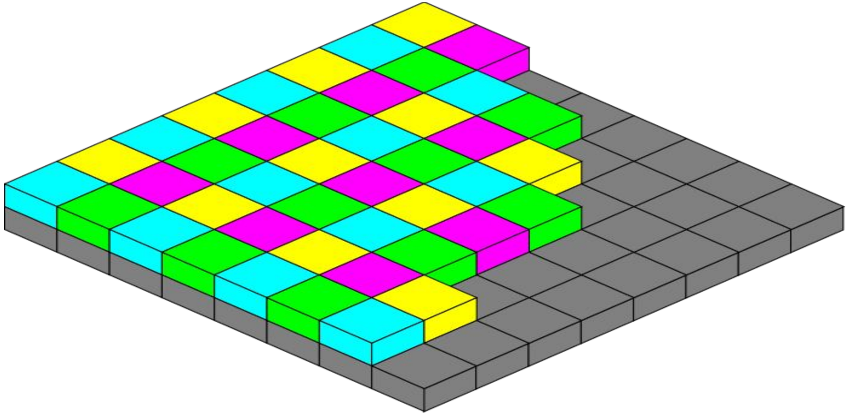
Color Filter

- From BW, color is produced by inserting a **filter mosaic** before the photoarray.
- Shown is the **Bayer Filter** Mosaic
- 4 native pixels are used to predict the color for one pixel
- Interpolation is used to find the in-between colors : **Demosaicing**

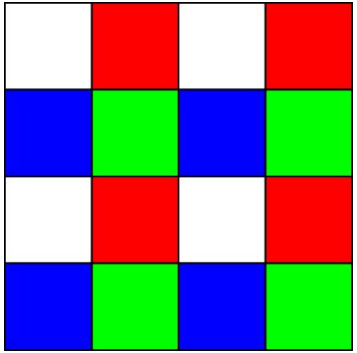


Other Color Filter Mosaics

CMYG

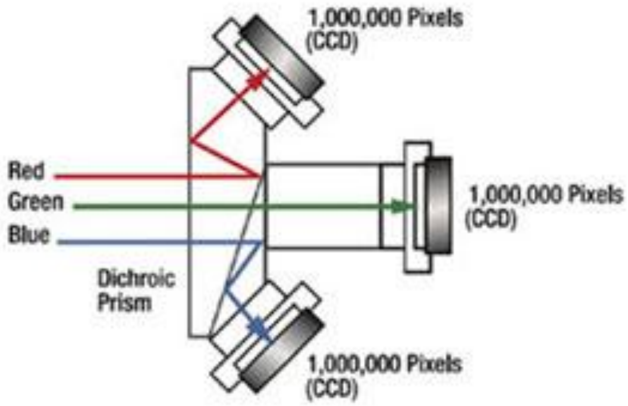


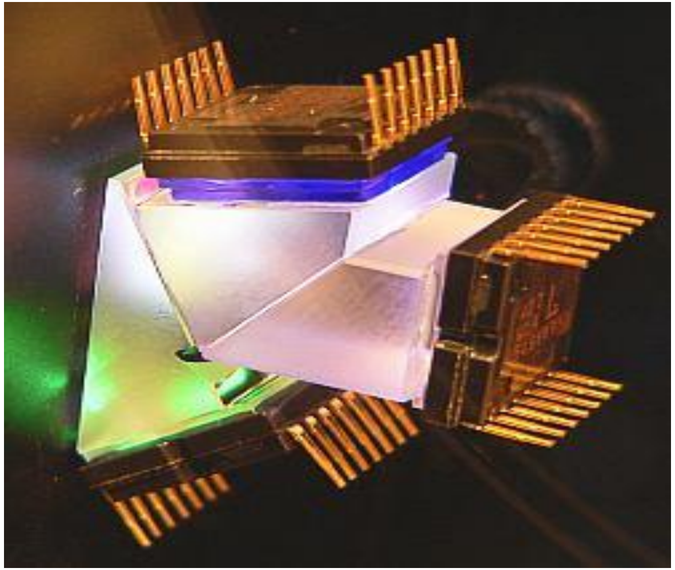
RGBW



3-Sensor Array Cameras

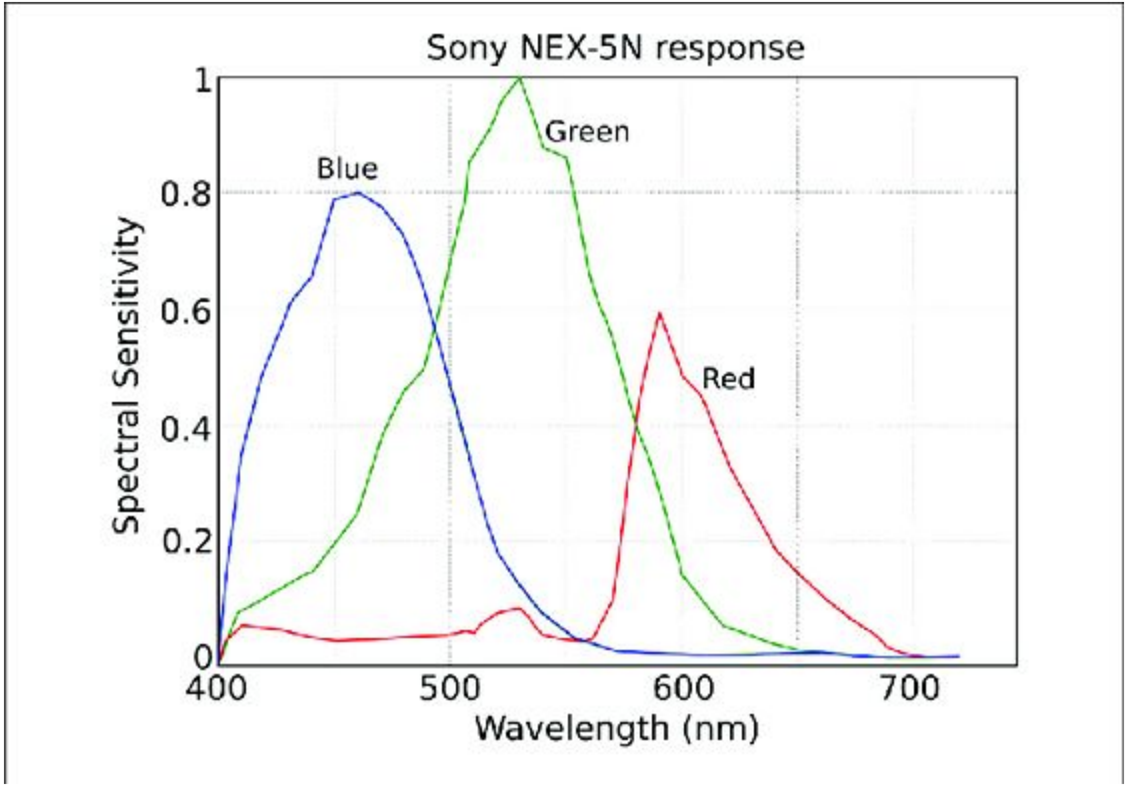
- 3-CCD
- 3-CMOS



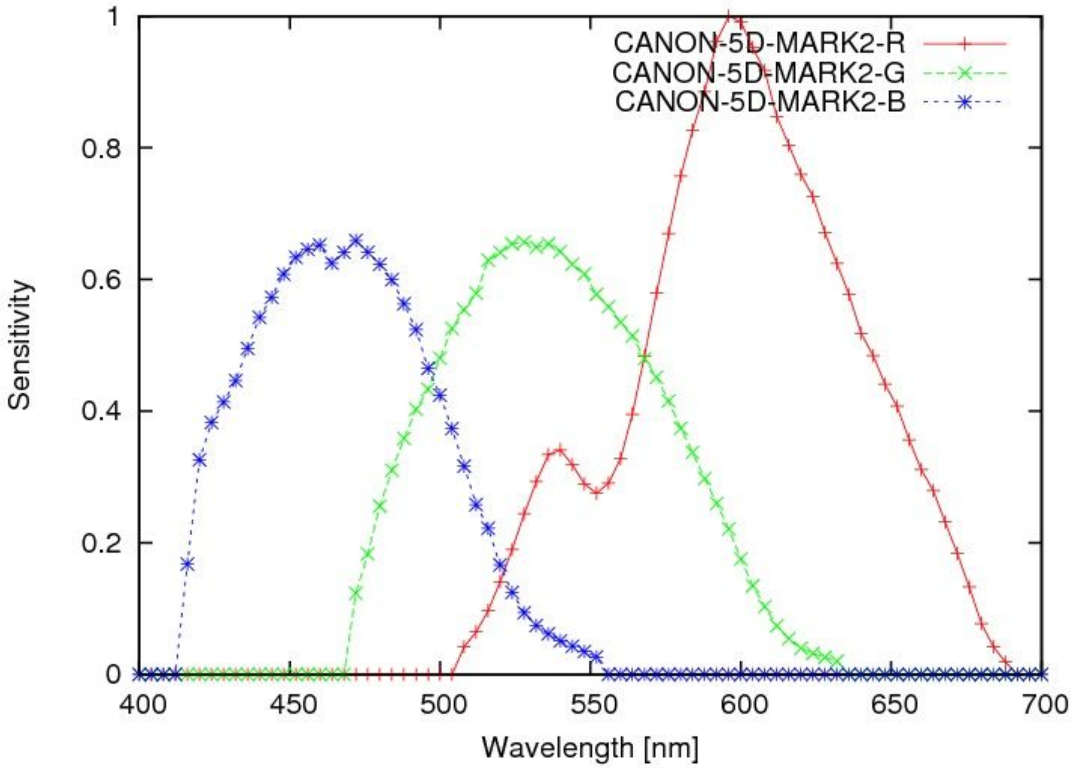


Comparison: 1 CCD vs 3CCD

Spectral Sensitivities of Color Cameras

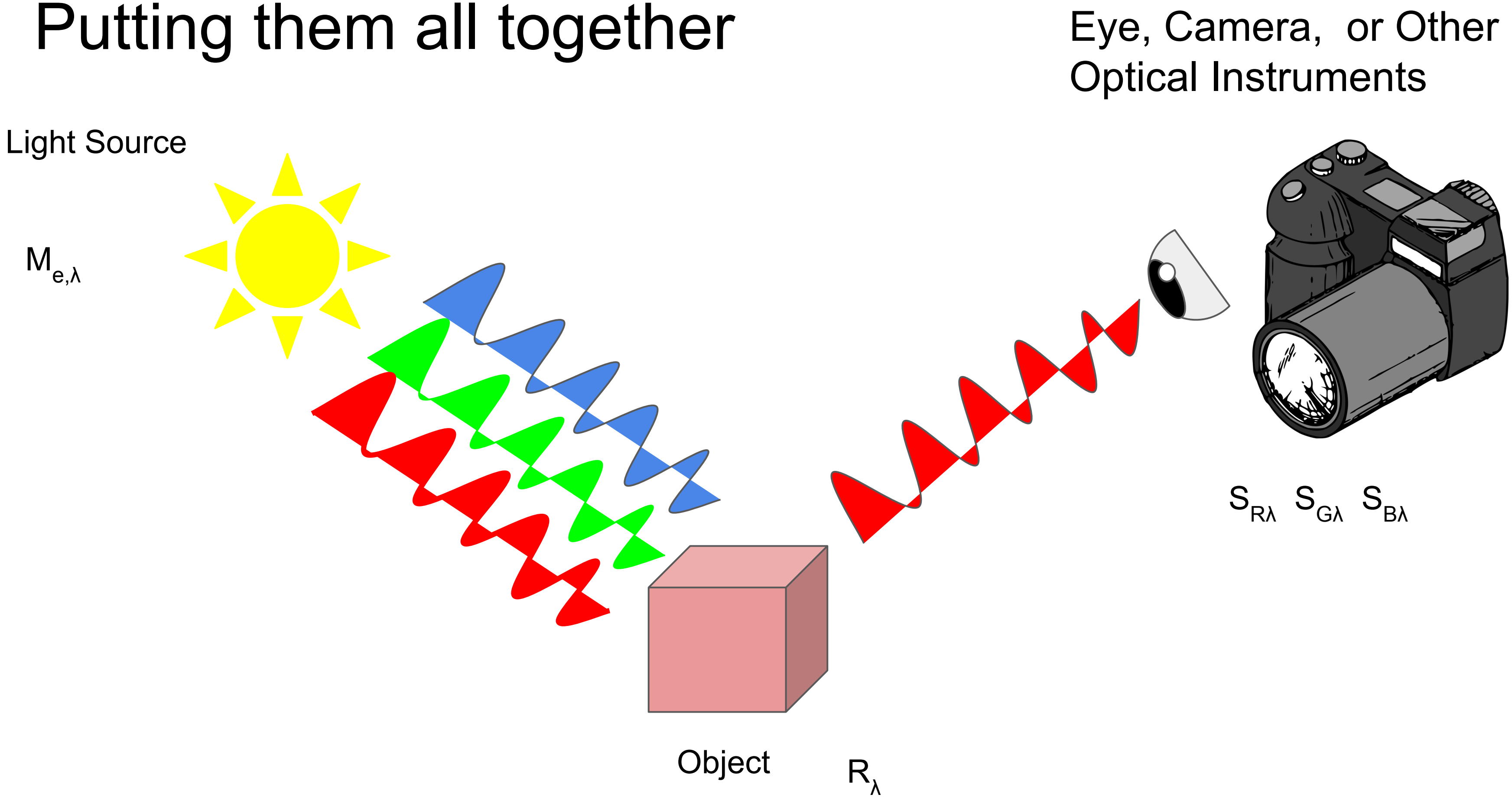


From: https://www.dpreview.com/forums/thread/4343781



From:https://nae-lab.org/~rei/research/cs/zhao/database.html

Putting them all together



Sensor Model

$$Q_i = \int_{vis} M(\lambda)R(\lambda)S_i(\lambda)d\lambda$$

Where Qi = output of sensor in the ith channel.
True for human eye or cameras

For color cameras

i = red, green, blue channel

For digital color cameras

$$DN_i = \frac{\sum M(\lambda)R(\lambda)S_i(\lambda)}{\sum M(\lambda)S_i(\lambda)}$$

Where DNi = digital number of the ith color channel, commonly known as R,G,B values.

Denominator is white balancing constant for the ith channel

Activity 4 - Rendering Color (Individual Activity)

1. Download any camera's spectral sensitivity from the web. (For example, from https://nae-lab.org/~rei/research/cs/zhao/database.html)
2. Together with data gathered in Activity 2 and 3 (spectrum of light source and reflectance of object) calculate the R,G,B digital number of the object.
3. Render the color on a square patch using powerpoint or any slide maker.
4. Comment on the similarity of the color with the captured image of your object.

Demo