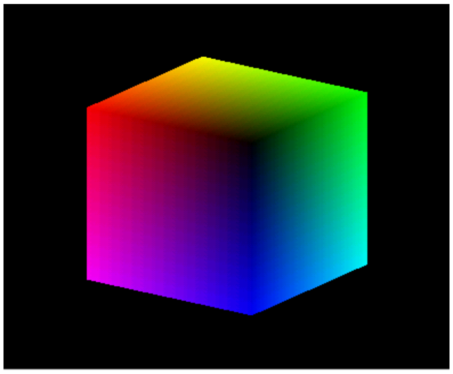
Color Representation

Foley & Van Dam, Chapter 13

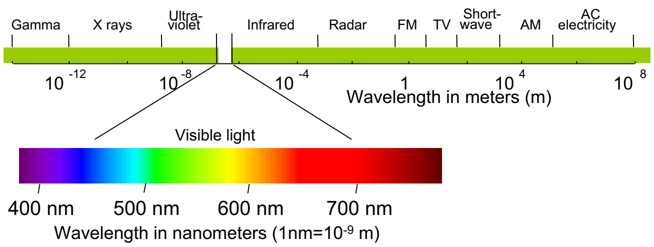


Color Representation

- Visible Light Spectrum
- Color Matching
- Trichromatic Color Theory
- Psychophysics
- CIE standard
- RGB and CMYK Color Spaces
- HLS Color Model
- YIQ Color Model

Visible Light Spectrum and Colors

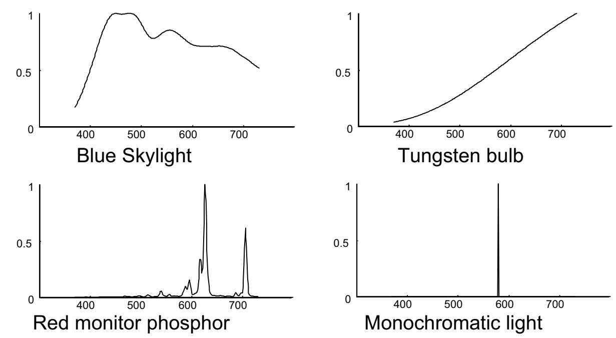
Light is an electro-magnetic radiation



- **Hue**: distinguished among colors
- **Saturation**: how far is color from a gray of equal intensity
- **Lightness**: perceived intensity of a reflective surface
- **Brightness**: perceived intensity of emitting surface

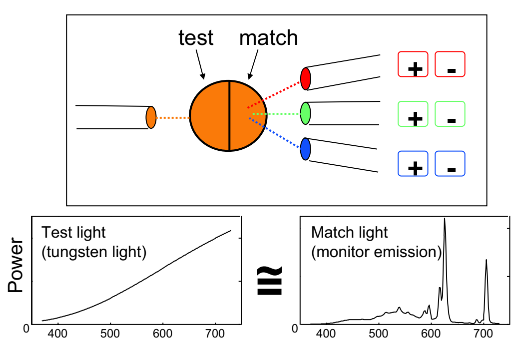
Spectral Power Distribution

- The **Spectral Power Distribution** of a light is a function f(λ) defining the energy at each wavelength



Color Matching Experiment

- Three primary lights are set to match a test light
- **Metamer**: two lights visually undistinguishable
  (they might have different spectral power distributions)

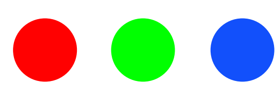


Trichromatic Color Theory

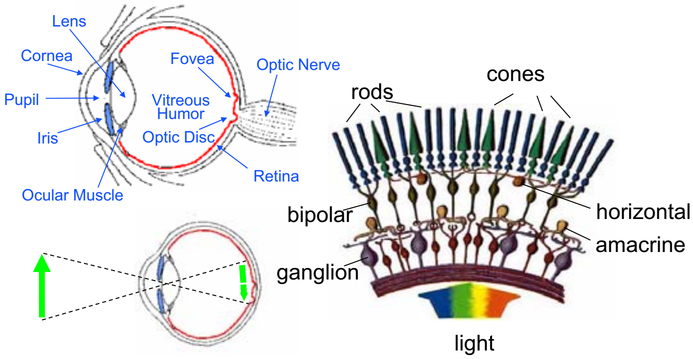
- **Trichromatic**: “tri”=three “chroma”=color also tristimulus
  color vision is based on three primaries (three dimensional)

- Thomas Young
  - A few different retinal receptors operating with different wavelength sensitivities allow humans to perceive colors
  - Suggested 3 receptors

- Helmholtz & Maxwell
  - Color matching with 3 primaries

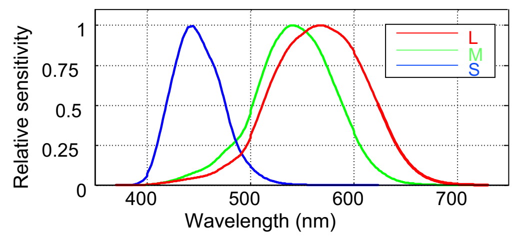


The Human Eye

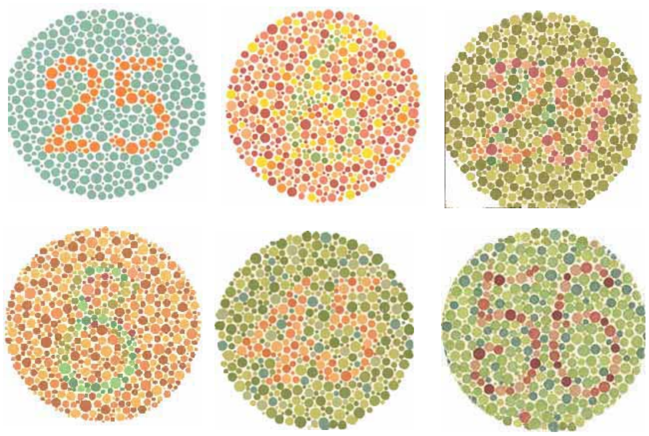


Retinal Photoreceptors

- **Cones:** Sensitive to high illumination levels (Photopic vision)
  Less sensitive than rods
  5 million cones in each eye
  Only cones in fovea (approx. 50,000)
  Density decreases with distance from fovea
  3 types differing in their spectral sensitivity: L , M, and S

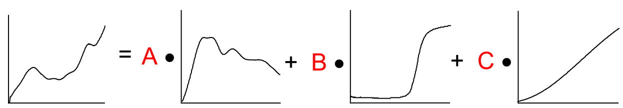


Retinal Photoreceptors

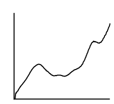


Linear Color Spaces

- Colors in 3D color space can be described as linear combinations of 3 basis colors called **primaries**



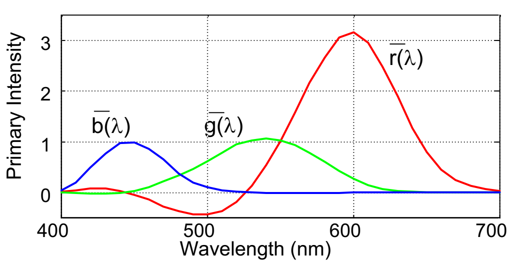
The representation of the color having spectrum:



Is given by **(A, B, C)**

Choosing The Primaries

- Stiles & Burch (1959) used 3 monochromatic primaries of wavelengths 444.4, 525.3 and 645.2

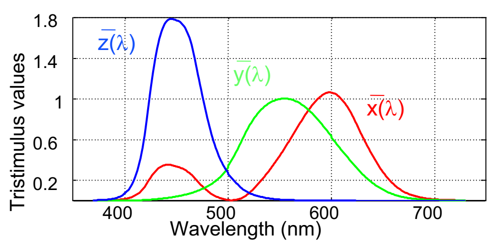


Color Matching Diagram

Problem: Subtractive components

CIE Color Standard

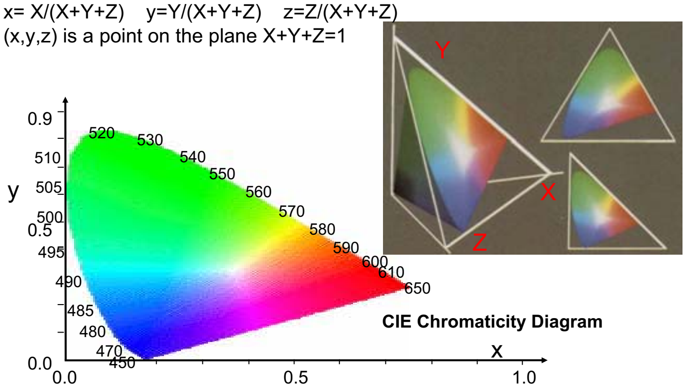
- **CIE:** Commision Internationale d'Eclairage (1931) defined a standard system (CIE- XYZ) for color representation



- Weights are non negative over the visible wavelengths
- The 3 primaries associated with x y z color matching functions cannot be easily realized in hardware
- y was chosen to equal *luminance* of monochromatic lights

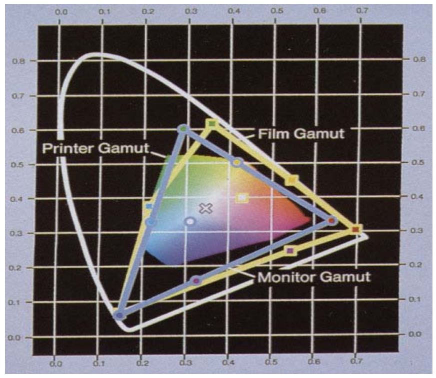
CIE Color Standard

If X, Y and Z are the weights used to define a color C, then the chromaticity values x, y, z (independent from the luminosity) are given by:
x= X/(X+Y+Z)   y=Y/(X+Y+Z)   z=Z/(X+Y+Z)
(x,y,z) is a point on the plane X+Y+Z=1

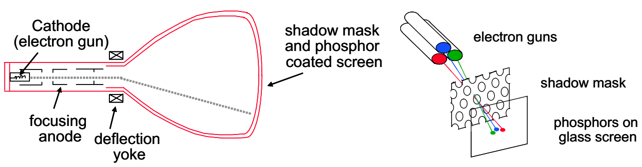


CIE Color Standard

- **Color Gamut**: A convex sum of several colors



RGB Color Representation



- In a CRT each color can be defined by the required power of each electron gun:

$$C = rR + gG + bB$$

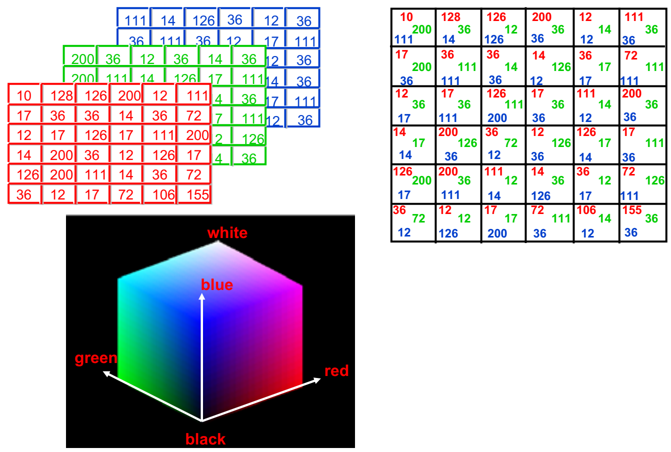
- The intensity is defined as:

$$I = r + g + b$$

- The chroma(ticy) is defined as:

$$C = \frac{rR + gG + bB}{r + g + b}$$

RGB Color Images



RGB to CIE-XYZ Conversion

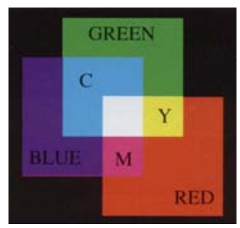
- RGB to CIE-XYZ is a linear transformation:

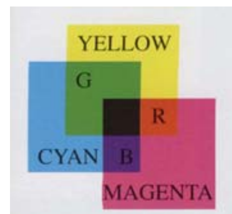
$$\begin{bmatrix} 2.365 & -0.515 & 0.005 \\ -0.897 & 1.426 & -0.014 \\ -0.468 & 0.089 & 1.009 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

- R = monochromatic primary 700nm
- G = monochromatic primary 546.1nm
- B = monochromatic primary 435.8nm

RGB vs. CMY(K) Color Scheme

- RGB and CMYK (Cyan, Magenta, Yellow and blacK) are **hardware-oriented** representations
- CMY is used in color photography and (with K) in most color printers





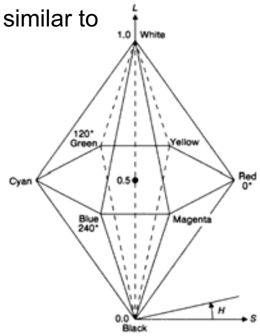
$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

RGB is Additive   CMY is Subtractive

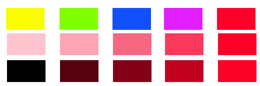
The HLS Color Model

- **HLS**: Hue Lightness, Saturation similar to **HSV**: Hue Saturation Value

Munsell Book of Colors



Hue (red, green, yellow, blue ...)
Saturation (pink, bright red, ...)
Lightness (black, grey, white ....)

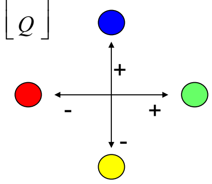


The YIQ Color Model

- Based on the concept of opponent colors
- Used in NTSC Television (National Television Systems Committee)
- Similar method (YC_bC_r) used in JPEG and MPEG

$$\begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.275 & -0.321 \\ 0.212 & -0.523 & 0.311 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} Y \\ I \\ Q \end{bmatrix}$$

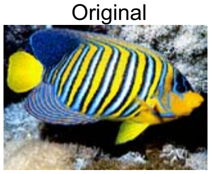
- **Y** = Luminance
- **I** = Red-Green
- **Q** = Blue-Yellow



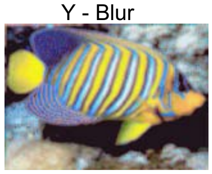
The YIQ Color Model

- The human eye is more sensitive to luminosity than to colors, so it is possible to save space by encoding colors more coarsely
- Preferred by the NTSC because of backward compatibility with B/W TV

Original



Y - Blur



I - Blur

Q - Blur

Summary

- **CIE-XYZ**
  - Tristimulus Coordinates
  - Device Independent
  - Universal standard
- **CIE-Lab**
  - Perceptual Space, used to assess image quality
- **RGB** and **CMY**
  - Hardware oriented
  - Additive spaces used for CRT, printers, photography
- **YIQ** and **YC_bC_r**
  - Opponent Space
  - Used for color television broadcast and image compression
- **HLS**
  - Perceptual Digitized Space
  - Used for Human Interactive Painting