Color

Light and color

Trichromatic color matching

- **Grassman's laws**
- **Color coordinates**
- **Human color vision**

Intuitive color systems

Computer representations of color

- **RGB**
- **HSV, HSB, HSL**
- **CMYK**

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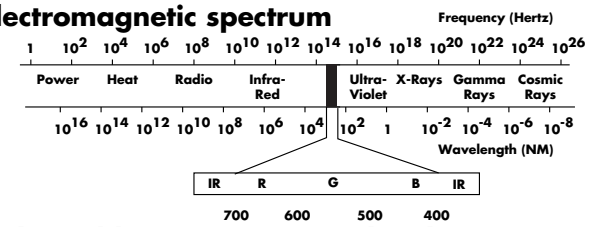
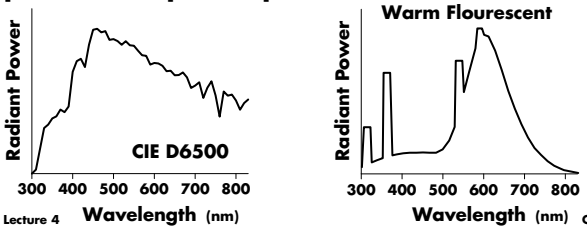
Spectrum

The electromagnetic spectrum



Example visible spectra power distribution



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Measuring Light and Color

Physics: Radiometry

- **The amount of *power* per wavelength interval**

  Termed *radiance*, we will often use *intensity*

Psychophysics

Photometry

- **The relative brightness of a light source (color or black/white) when compared to a standard candle**

  Termed *luminance*

- **Uniform perceptual scale**

  Termed *lightness*

Colorimetry

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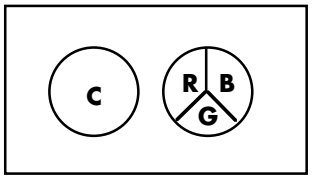
Color Matching

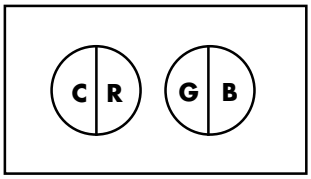
Adjust brightness of 3 primaries to "match" color

C - color to be matched

RGB - laser sources (R=700 nm, G=546 nm, B=435 nm)



C = R + G + B



C + R = G + B

Therefore: *humans have trichromatic color vision*

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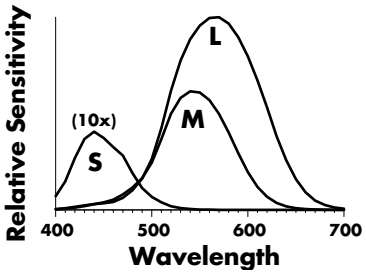
Human Color Vision

- **There are 3 light sensitive pigments in your cones (L,M,S), each with a different *spectral response curve***

$$L = \int L(\lambda)E(\lambda)d\lambda$$
$$M = \int M(\lambda)E(\lambda)d\lambda$$
$$S = \int S(\lambda)E(\lambda)d\lambda$$



- **Metamerism**
- **Biological basis of color blindness - genetic disease**

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Color Matching is Linear!

Grassman's Laws

1. Scaling the color and the primaries by the same factor preserves the match

$$2C=2R+2G+2B$$

2. To match a color formed by adding two colors, add the primaries for each color

$$C_1+C_2=(R_1+R_2)+(G_1+G_2)+(B_1+B_2)$$

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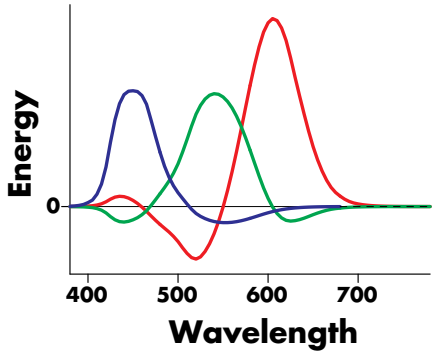
Spectral Matching Functions

Spectral matching curves

Match each pure color in the visible spectrum (rainbow), and record the color coordinates as a function of wavelength



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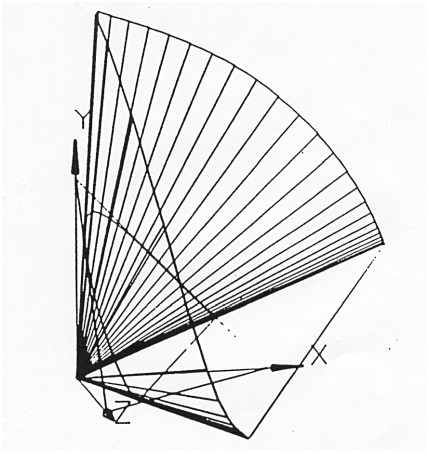
Spectral Locus



Human Percpetual Gamut

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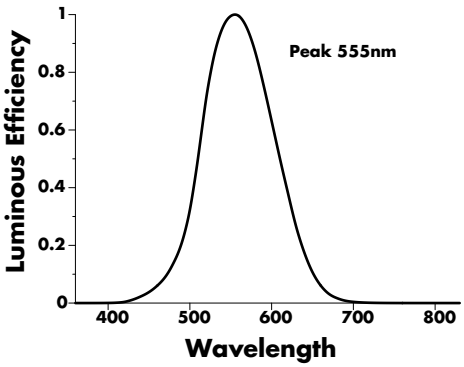
Luminance



Compare color source to a grey source

$$Y = \int V(\lambda)E(\lambda)d\lambda$$

- **Luminance**

  Y = .30R + .59G + .11B

  Color signal on a BW tv (Except for gamma)

- **Lightness**

  $L^* = Y^{1/3}$

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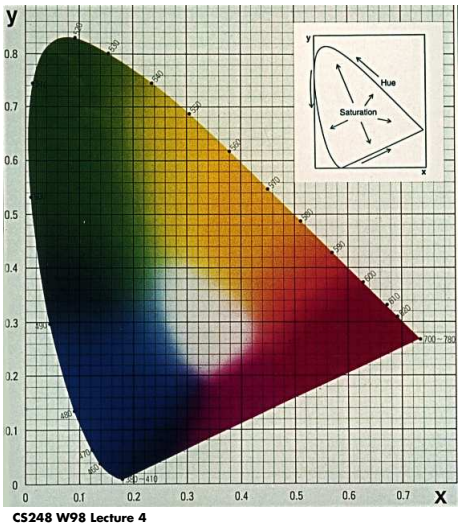
Chromaticity Diagram



CIE Color Coordinates

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 2.77 & 1.75 & 1.13 \\ 1.00 & 4.59 & 0.06 \\ 0.00 & 0.57 & 5.59 \end{bmatrix} \begin{bmatrix} R_\lambda \\ G_\lambda \\ B_\lambda \end{bmatrix}$$

$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z}$$

1931 CIE Chromaticity Diagram From Minolta

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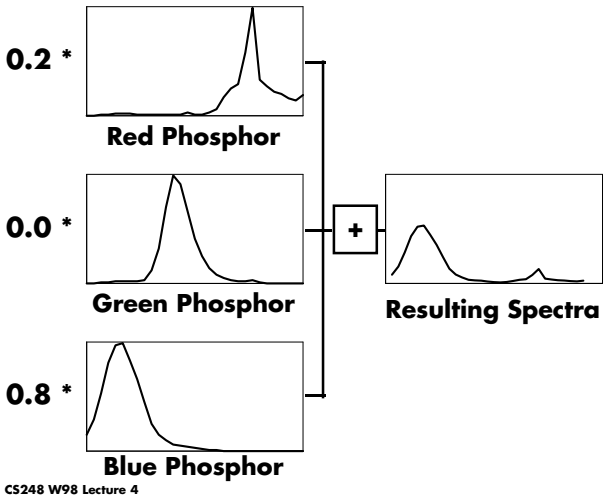
Monitor



Monitor Phosphors

x	y
.635	.340
.305	.595
.155	.070

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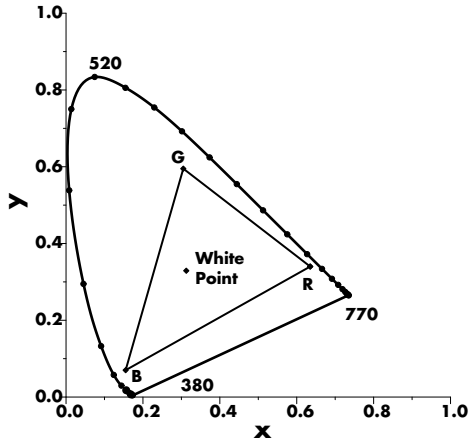
Gamut



Monitor Phosphors

x	y
.635	.340
.305	.595
.155	.070
.313	.329

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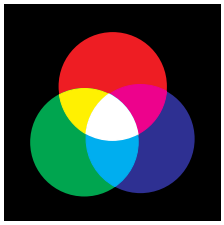
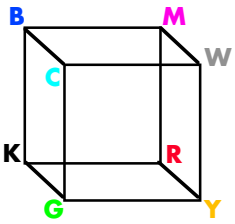
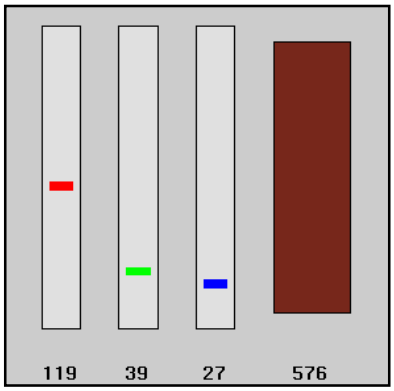
Color Cube







cedit

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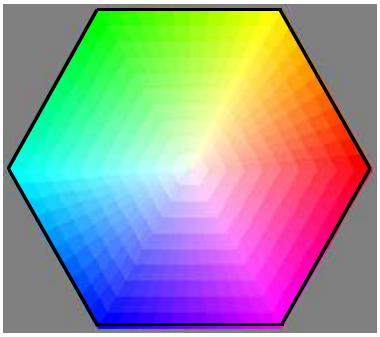
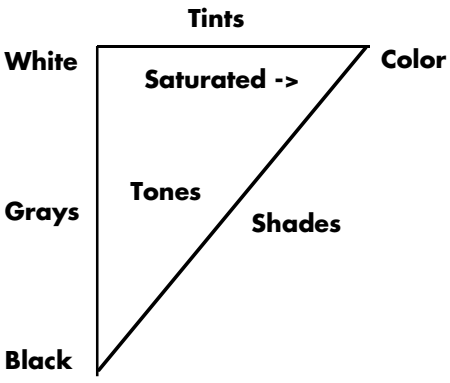
Intuitive Color Spaces





Hexagon is a diagonal Cross-Section of the Color Cube

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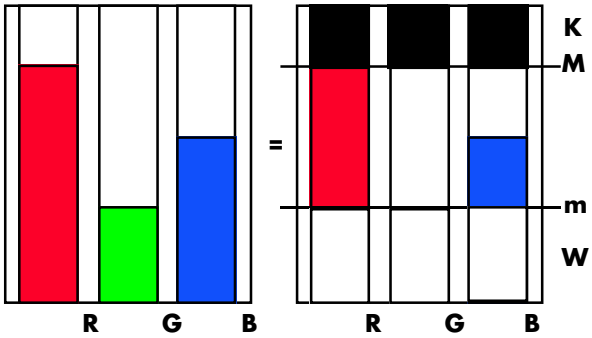
HSV and HSL



M=max(R,G,B),
m=min(R,G,B)
r=(M-R)/(M-m)
g=(M-G)/(M-m)
b=(M-B)/(M-m)
if(M==R) H=(6+b-g)/6
....

HSL
L=(M+m)/2
S=(M-m)/(M+m)

HSV
V=M
S=(M-m)/M

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Filtering

Reflection

Blue Towel

D6500 Light Source

Swiss Army Knife

Comments

- Transmission similar
- Things look different under different illuminations
- Multiplying color components is an approximation!

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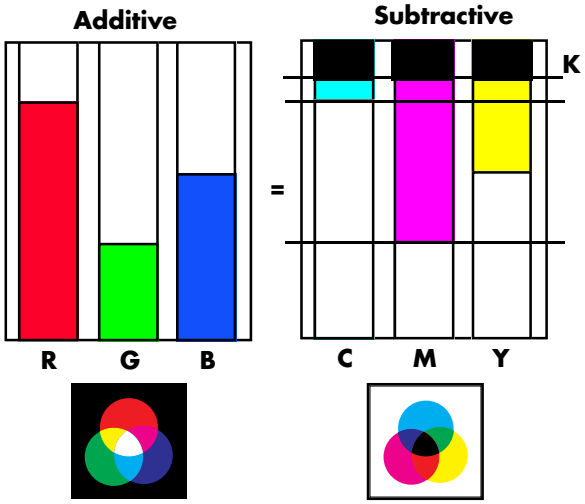
CMYK



R = (1-C) (1-K) W
G = (1-M) (1-K) W
B = (1-Y) (1-K) W

K = G(1-max(R,G,B))
C = 1 - R/(1-K)
M = 1 - G/(1-K)
Y = 1 - B/(1-K)

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