Digital Image Processing

COSC 6380/4393

Lecture – 26

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Pranav Mantini

Color Image Processing

What is color?

- Color is a psychological property of our visual experiences when we look at objects and lights,
  not a physical property of those objects or lights
  (S. Palmer, *Vision Science: Photons to Phenomenology*)
- Color is the result of interaction between physical light in the environment and our visual system

Wassily Kandinsky (1866-1944), Murnau Street with Women, 1908

Motivation

- Visual Descriptor (descriptions of the visual features of the contents)

Principal Descriptor

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  - **SHAPE**

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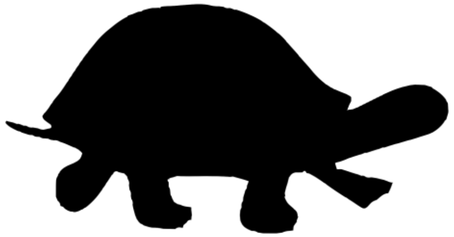
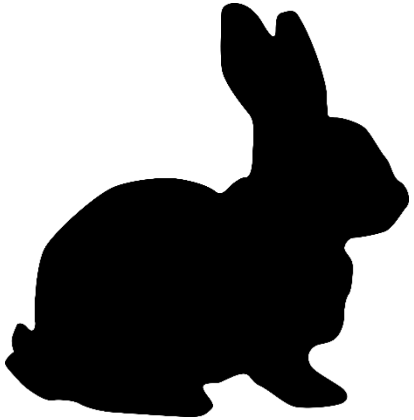




Principal Descriptor

- Visual Descriptor (descriptions of the visual features of the contents)
  - **SHAPE**
  - **COLOR**

Principal Descriptor

Principal Descriptor

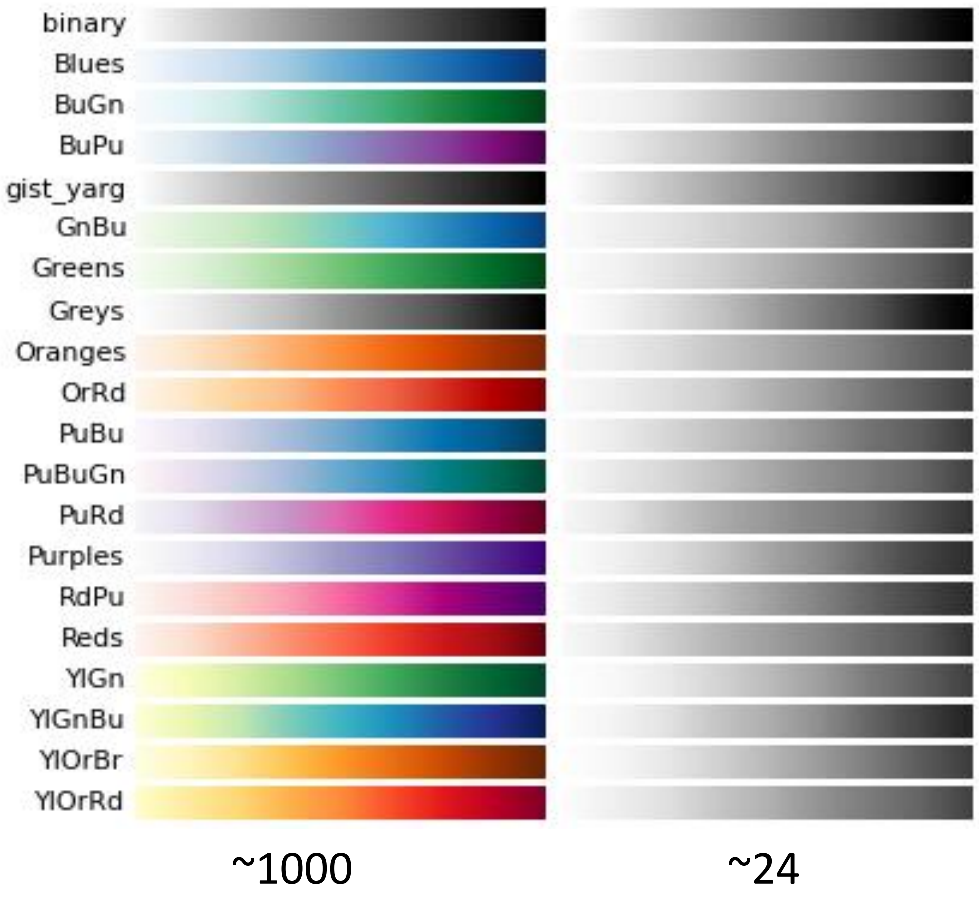
Principal Descriptor

- Visual Descriptor (descriptions of the visual features of the contents)
  - **SHAPE**
  - **COLOR**
    - Color is a powerful descriptor that often simplifies object identification and extraction from a scene.

Principal Descriptor

- Visual Descriptor
  - **SHAPE**
  - **COLOR**
  - **TEXTURE**
  - **MOTION**

Discerning Color



Motivation

- Color is principal descriptor
- Ability to discern thousands of colors

Color Image Processing

- Two majors areas
  - Full color processing
  - Pseudocolor processing

Color Image Processing

- Two majors areas
  - Full color processing

Color image

Color Image Processing

- Two majors areas
  - Full color processing
  - Psuedocolor processing

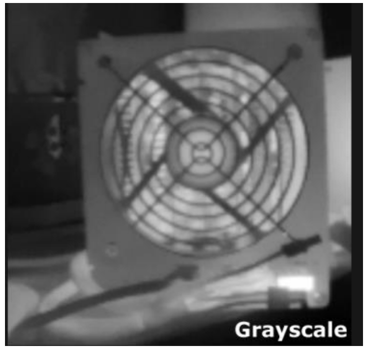
Intensity values

Thermal Camera

Color Image Processing

- Two majors areas
  - Full color processing
  - Psuedocolor processing

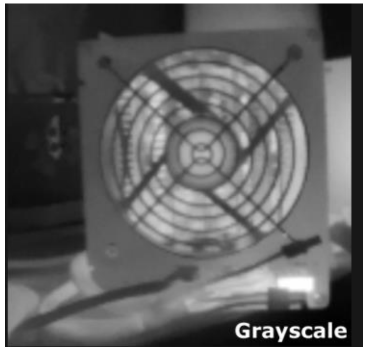
Thermal Camera



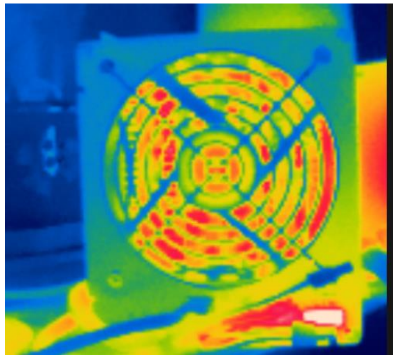
Color Image Processing

- Two majors areas
  - Full color processing
  - Psuedocolor processing

Thermal Camera



Assign values



Color image

Color fundamentals

- Physio-psychological phenomenon
  - How human brain perceive and interpret color?
- Physical phenomenon
  - Physical nature of color can be expressed on formal basis (using experiments and theoretical results)

Characterization of Light

- Acromatic light has only intensity (or amount) (void of color)

- Black and white television
- Gray level: scalar measure of intensity

Physical quantities to describe a chromatic light source

- Radiance: total amount of energy that flow from the light source, measured in watts (W)
- Luminance: amount of energy an observer *perceives* from a light source, measured in lumens (lm)
  - Far infrared light: high radiance, but 0 luminance
- Brightness: subjective descriptor that is hard to measure, similar to the achromatic notion of intensity

Color Fundamentals

- Six broad regions, each blends into the next smoothly.

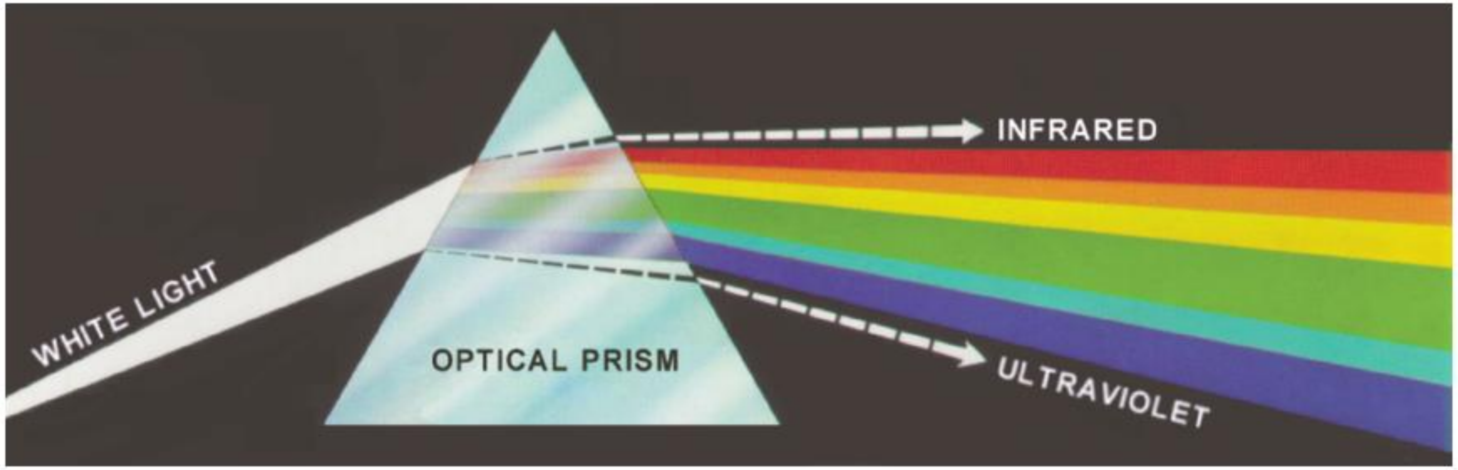


FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

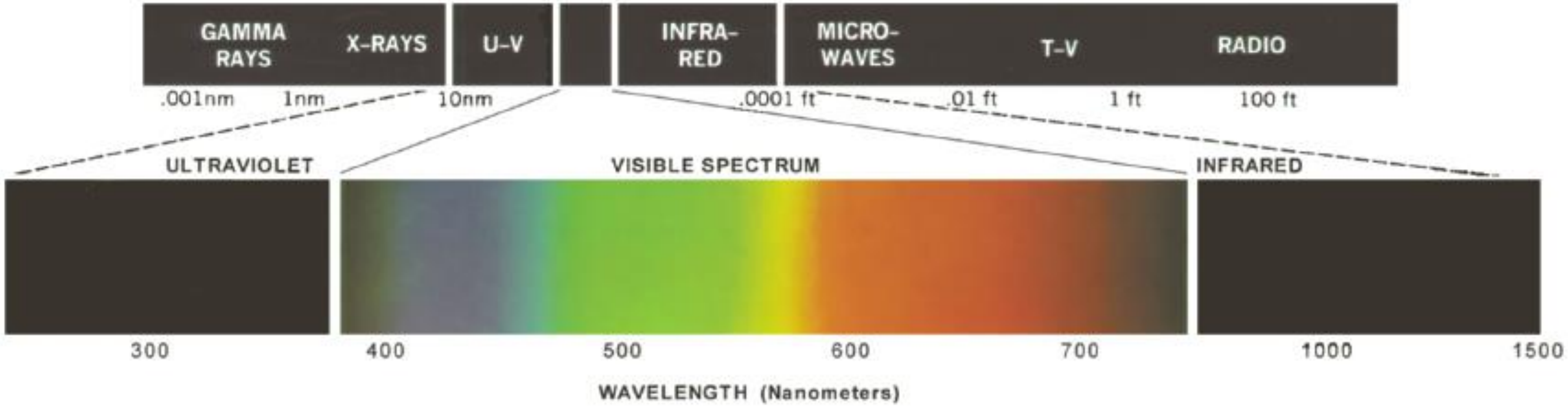
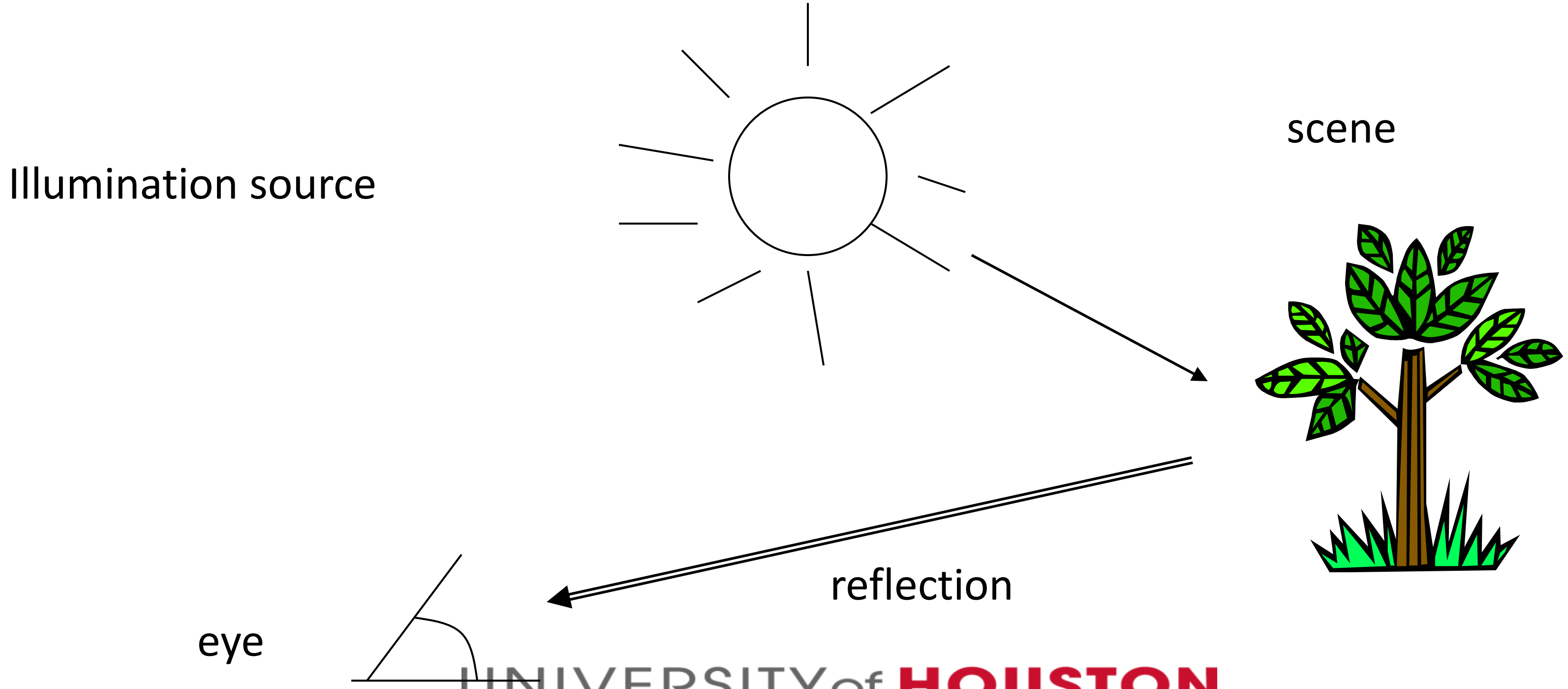


FIGURE 6.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

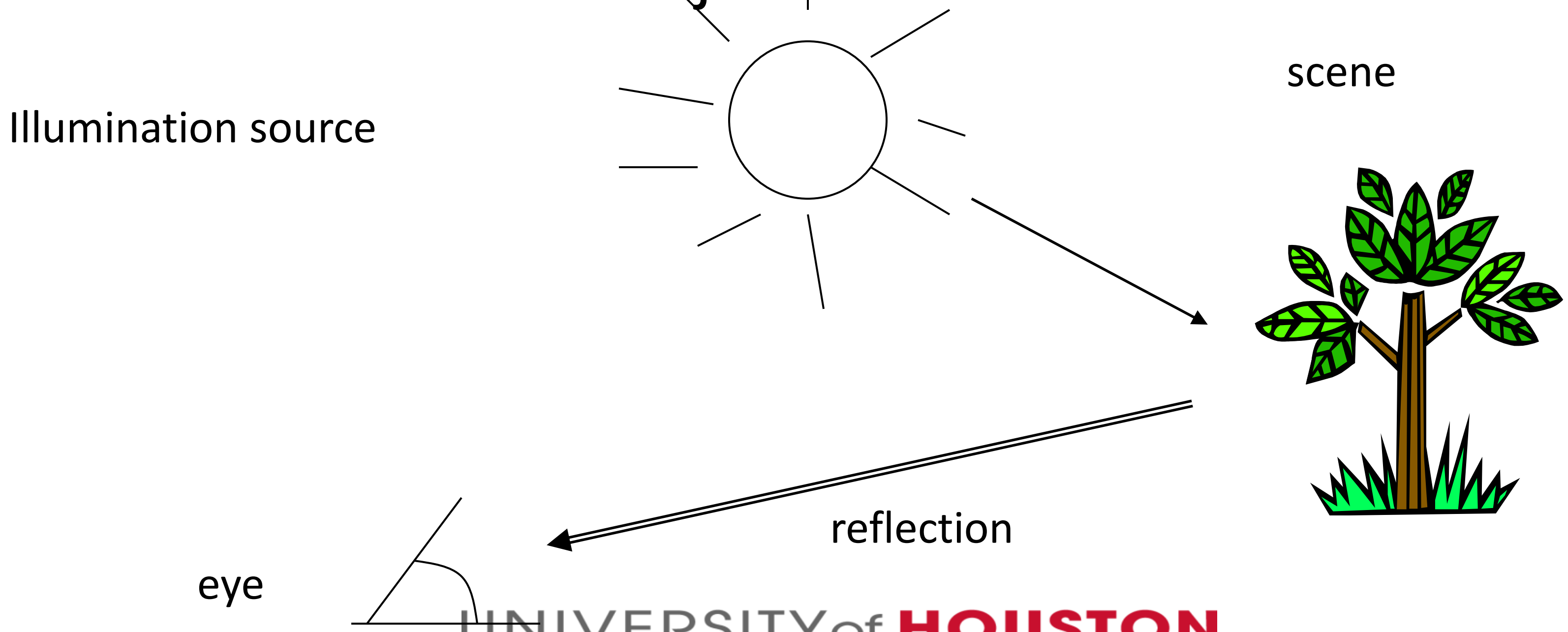
Color fundamentals (cont.)

- The color that human perceive in an object = the light reflected from the object



Color fundamentals (cont.)

- Balanced in all visible wavelengths → white
- Absorbs all light → black
- Limited range of visible spectrum → color shade
- 500 to 570 nm → Green object



Color Fundamentals

- Cones are the sensors in the eye that are responsible for color vision
- 6 to 7 million cones in the human eye
- Can be divided into three principal sensing categories, corresponding roughly to red, green, and blue.

65%: red 33%: green 2%: blue (blue cones are the most sensitive)

Color Fundamentals

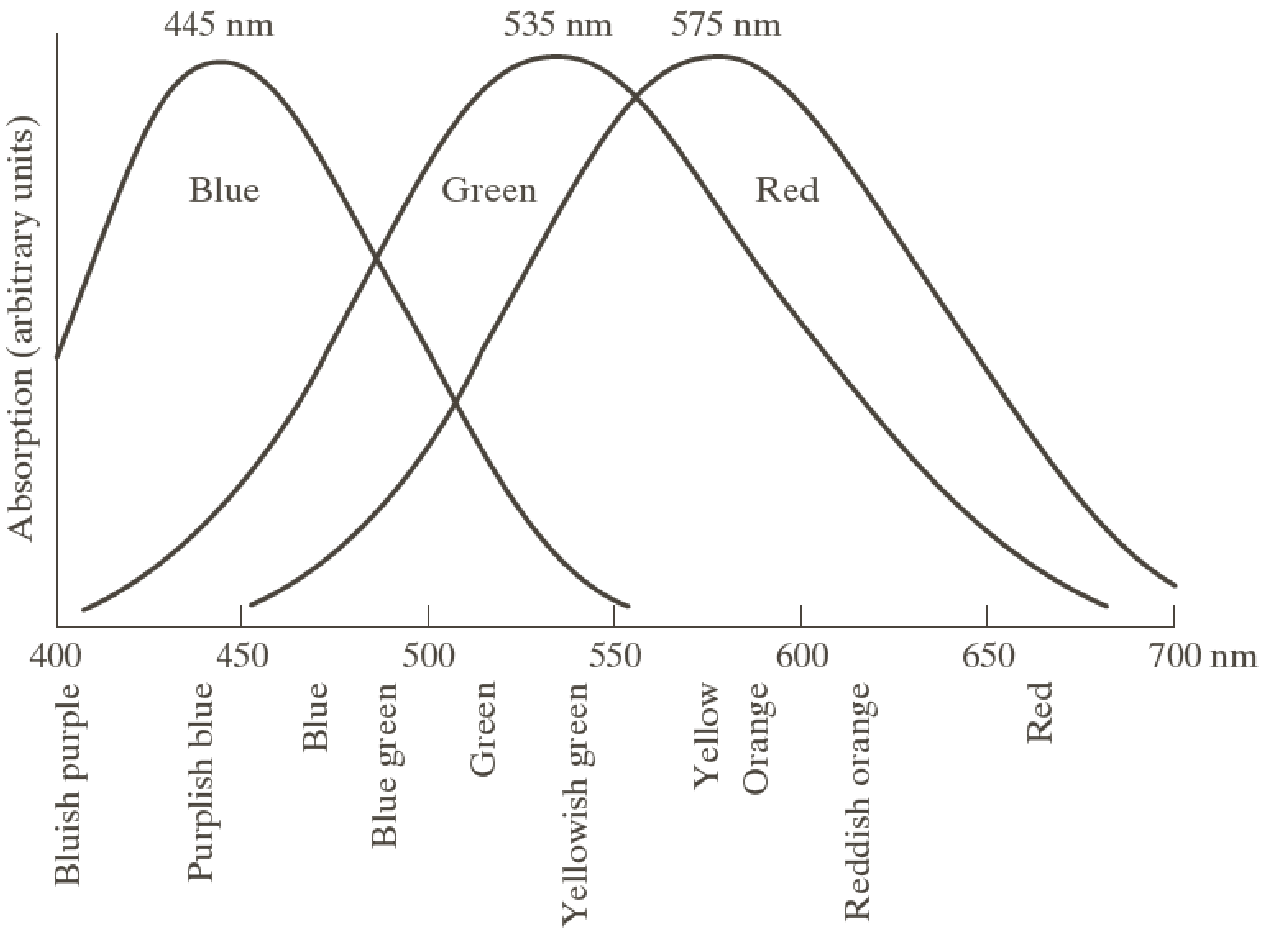
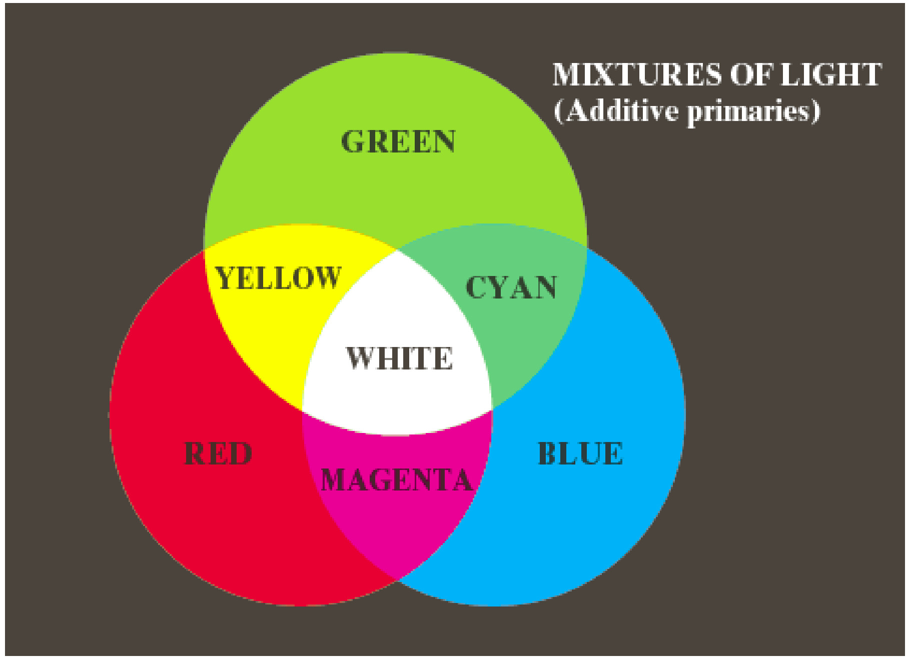


FIGURE 6.3 Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.

Primary colors

- Due to the absorption characteristics of human eye,
- Primary colors:
  - Red
  - Green
  - Blue
- Color: described as a variable combination of the primary colors
- In 1931, CIE(International Commission on Illumination) defines specific wavelength values to the primary colors
  - B = 435.8 nm, G = 546.1 nm, R = 700 nm
  - However, we know that <u>no single color</u> may be called red, green, or blue



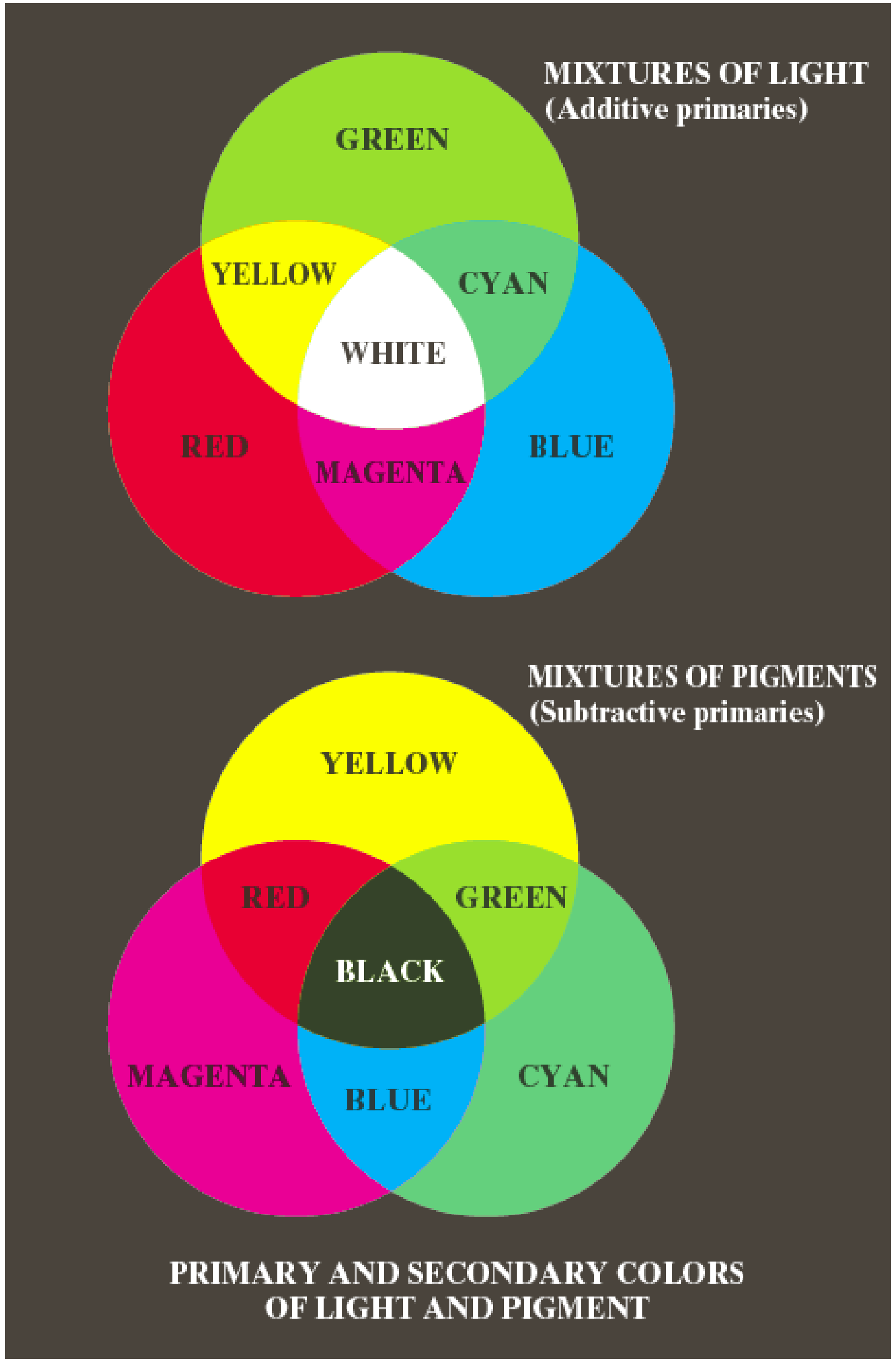
a

FIGURE 6.4
Primary and secondary colors of light and pigments. (Courtesy of the General Electric Co., Lamp Business Division.)

Primary colors of light v.s. primary colors of pigments

- Primary color of pigments
  - Color that subtracts or absorbs a primary color of light and reflects or transmits the other two

Color of light:	R	G	B
	↓	↓	↓
Color of pigments:	absorb R Cyan	absorb G Magenta	absorb B Yellow

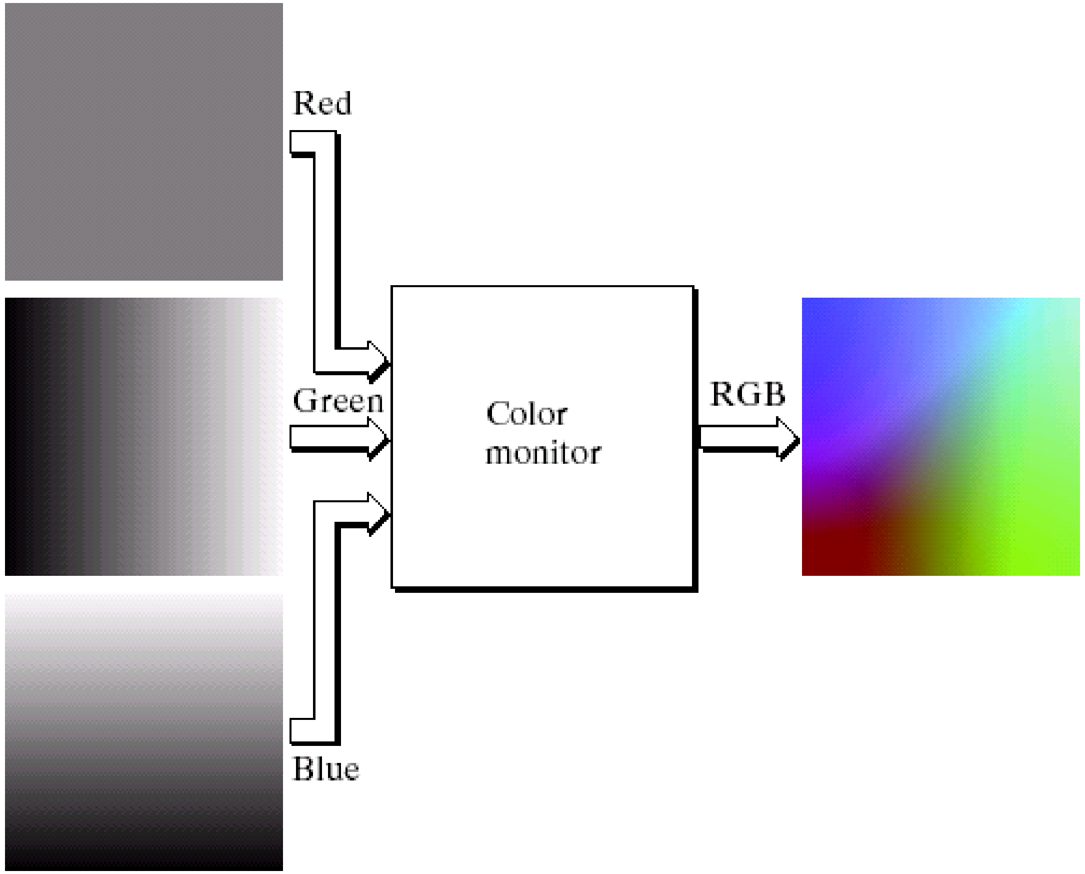


a
b

FIGURE 6.4 Primary and secondary colors of light and pigments. (Courtesy of the General Electric Co., Lamp Business Division.)

Application of additive nature of light colors

- Color TV



Application of **subtractive color** model

- Printers: the usual primary colors are cyan, magenta and yellow (CMY)
- Cyan → serves as a filter that absorbs red
- Amount of cyan applied controls how much of the red in white light will be reflected back
- Cyan is completely transparent to green and blue light and has no effect on those parts of the spectrum

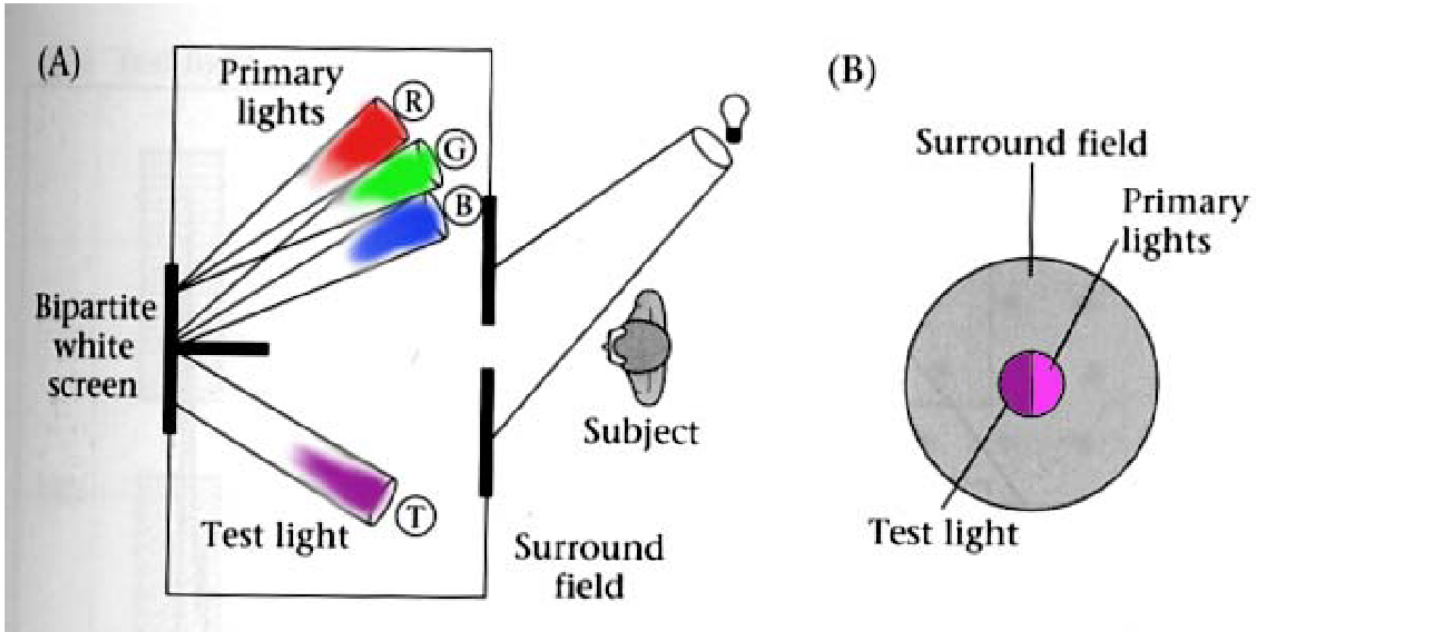
Application of **subtractive color** model

- Magenta is the complement of green, and yellow the complement of blue.
- Combinations of different amounts of the three can produce a wide range of colors with good saturation.

Why specify color numerically?

- Accurate color reproduction is commercially valuable
  - Many products are identified by color
- Few color names are widely recognized by English speakers -
  - About 10; other languages have fewer/more, but not many more.
  - It's common to disagree on appropriate color names.
- Color reproduction problems increased by prevalence of digital imaging - eg. digital libraries of art.
  - How do we ensure that everyone sees the same color?

Color matching experiment

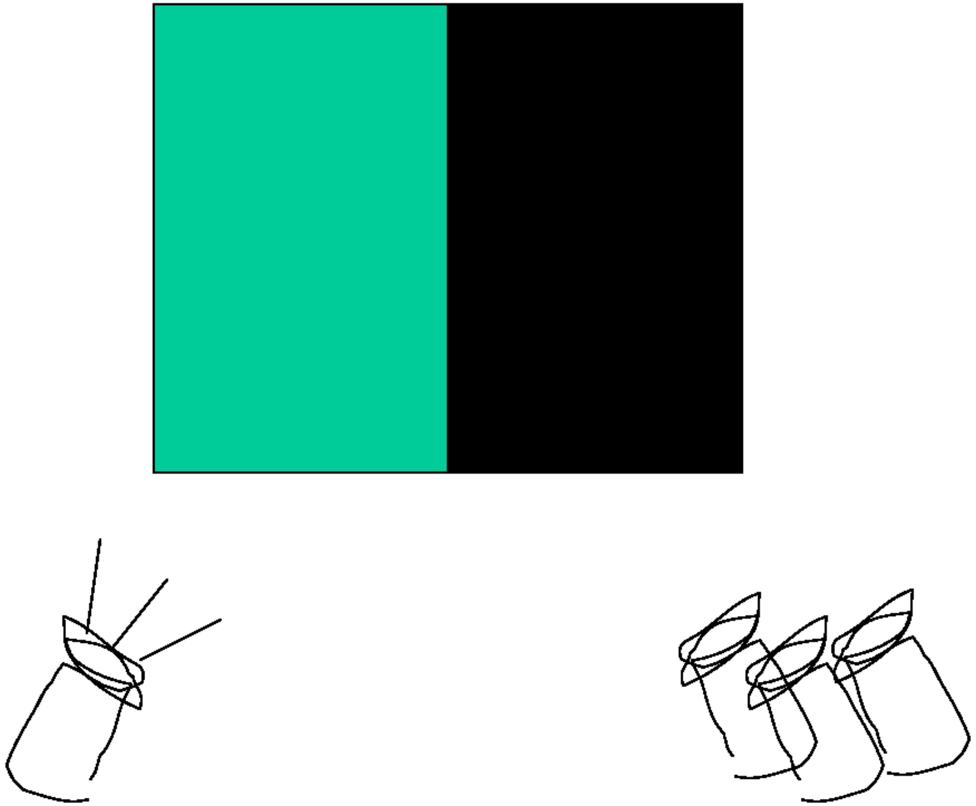


4.10 THE COLOR-MATCHING EXPERIMENT. The observer views a bipartite field and adjusts the intensities of the three primary lights to match the appearance of the test light. (A) A top view of the experimental apparatus. (B) The appearance of the stimuli to the observer. After Judd and Wyszecki, 1975.

Foundations of Vision, by Brian Wandell, Sinauer Assoc., 1995

slide from T. Darrel

Color matching experiment 1



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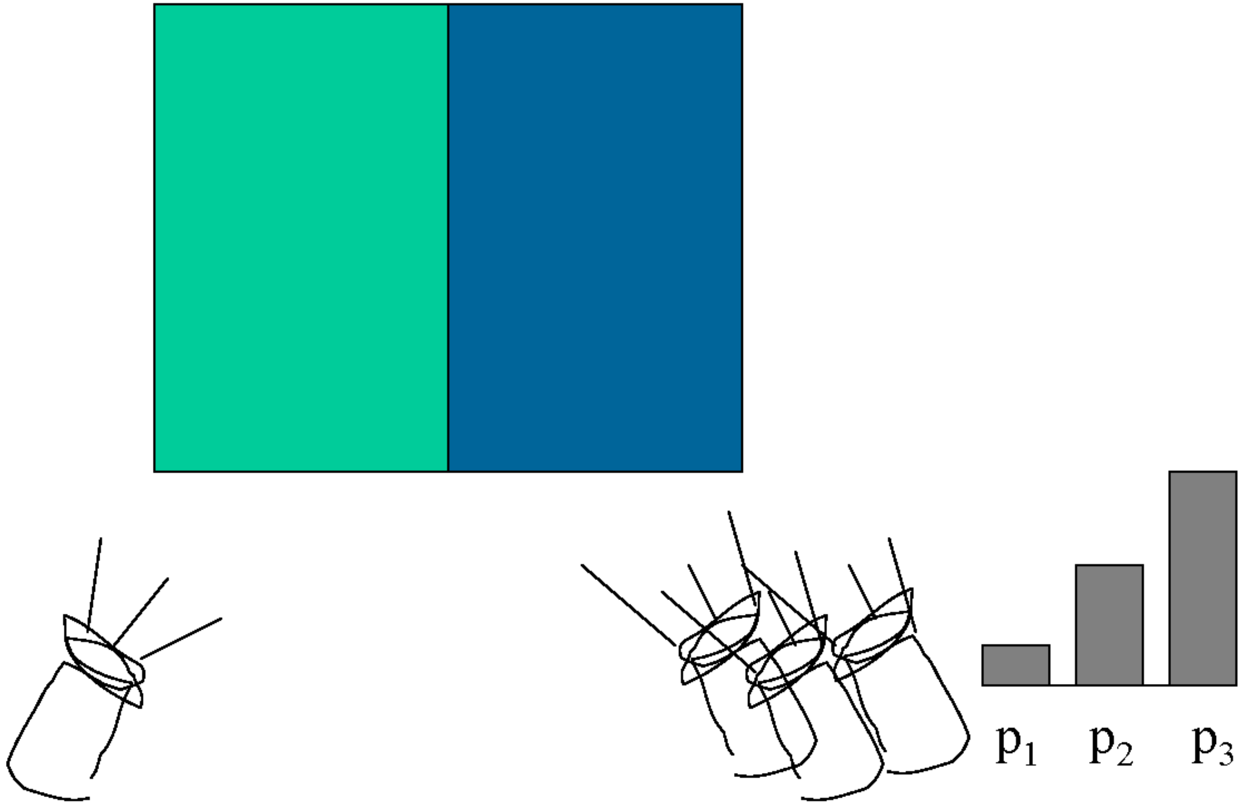
Color matching experiment 1



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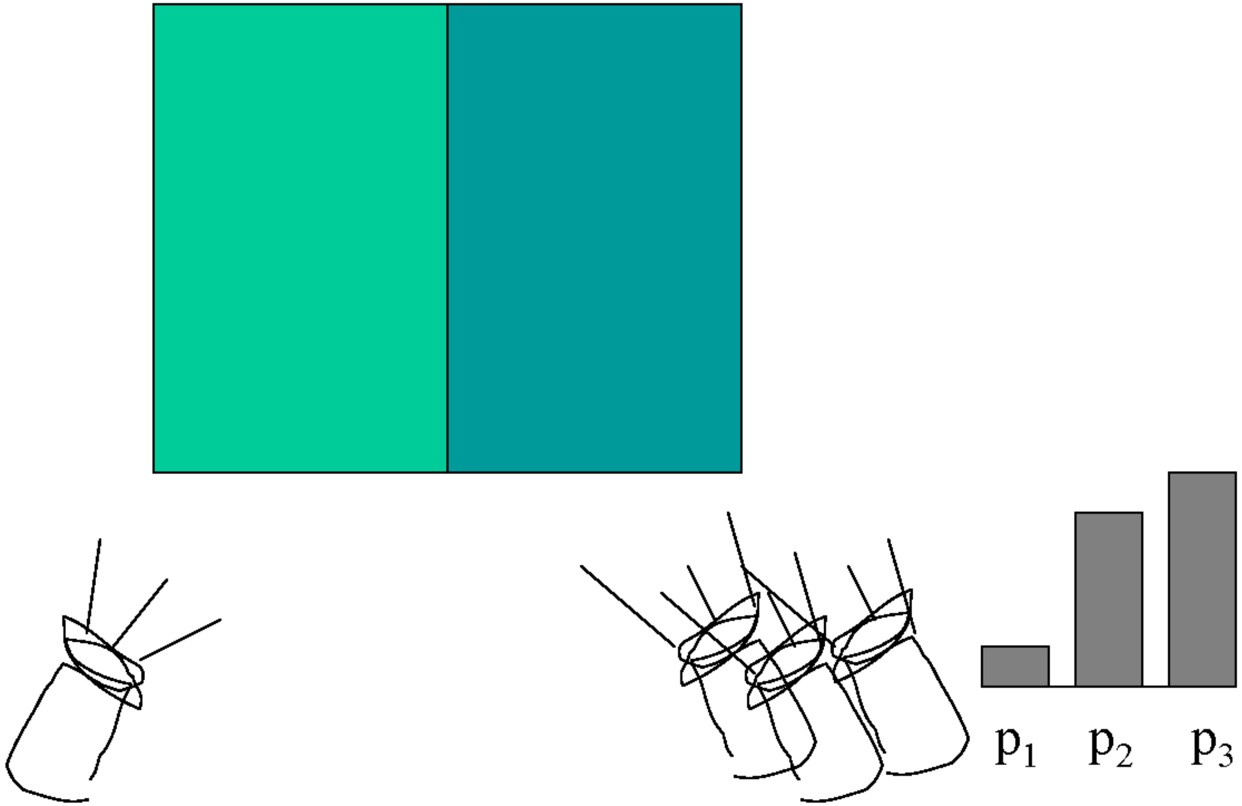
Color matching experiment 1



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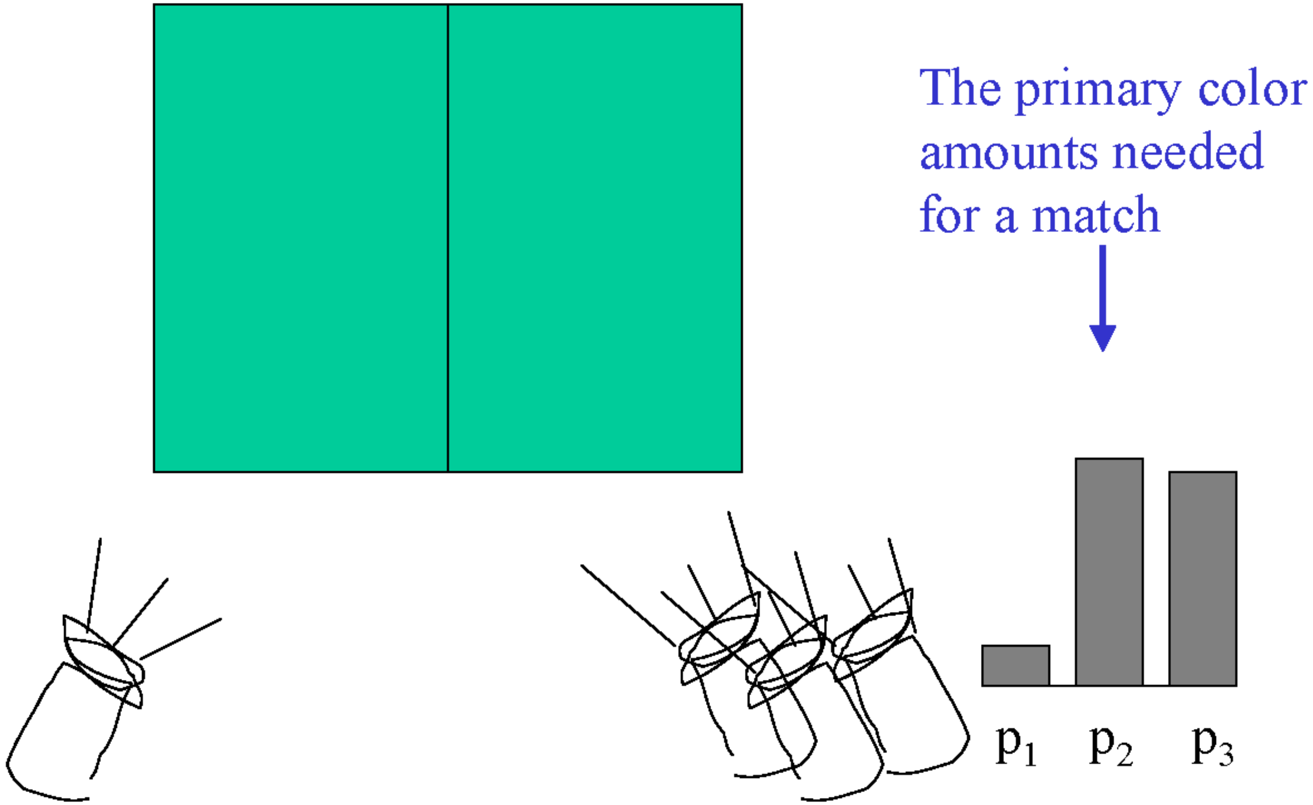
Color matching experiment 1



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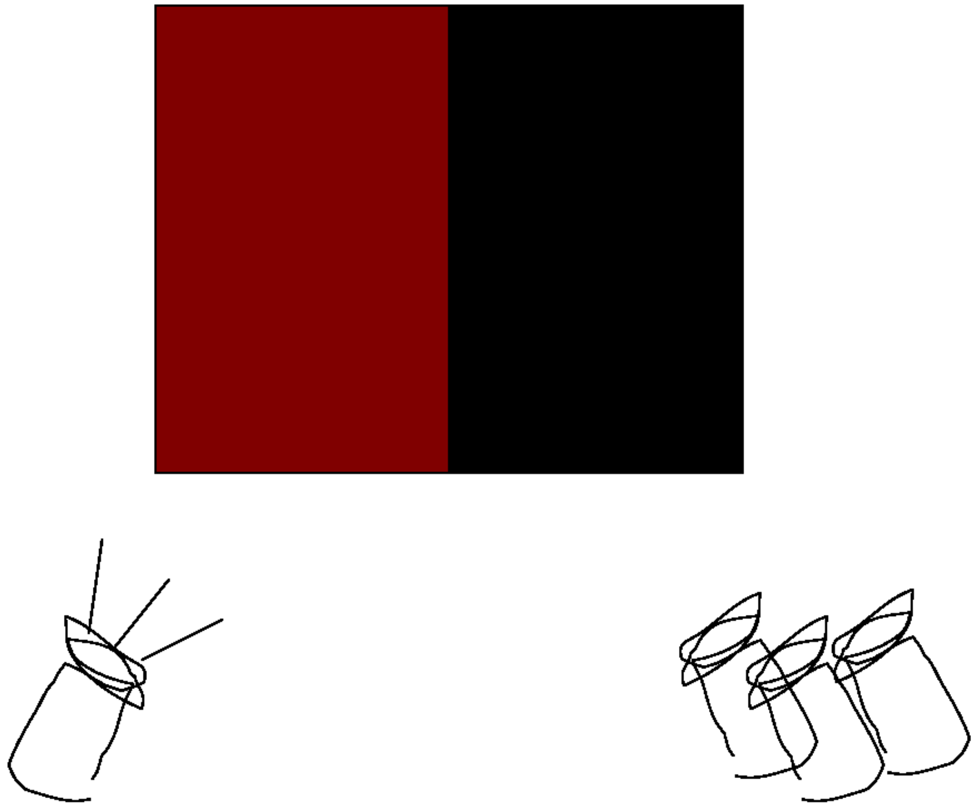
Color matching experiment 2



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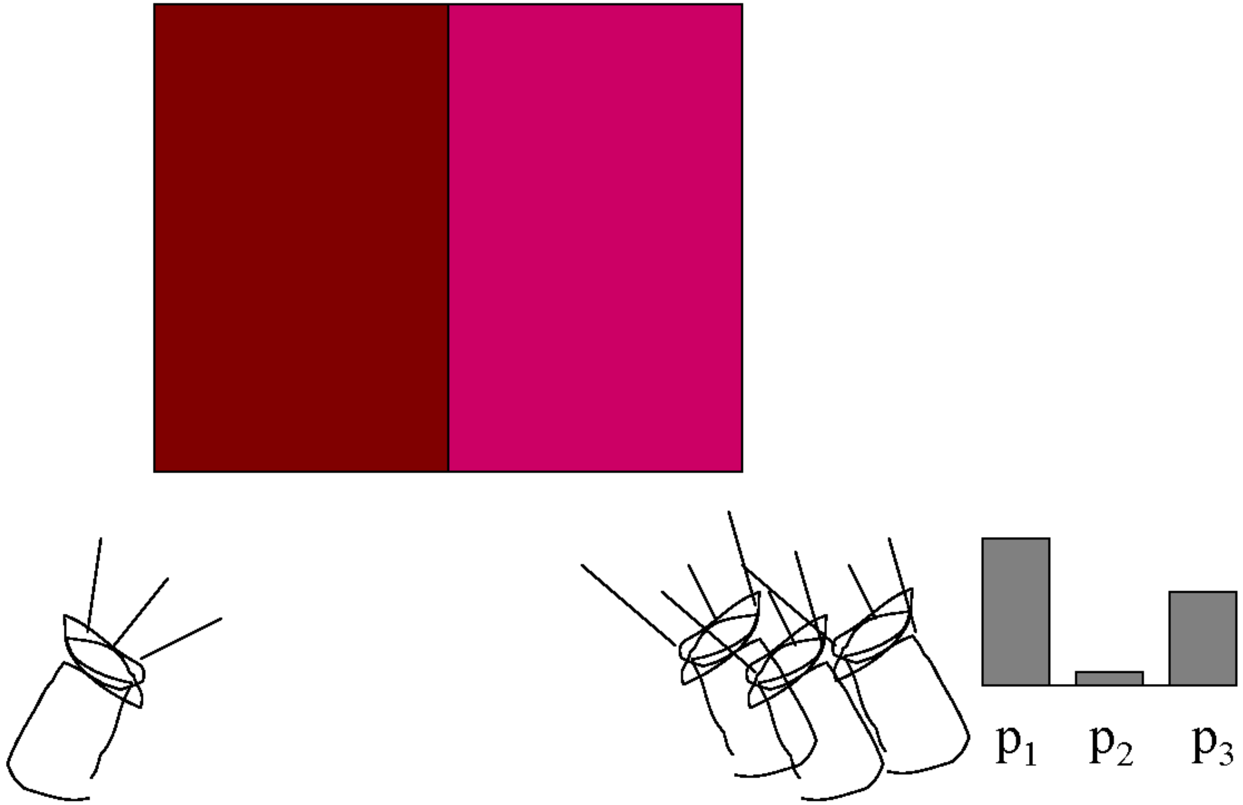
Color matching experiment 2



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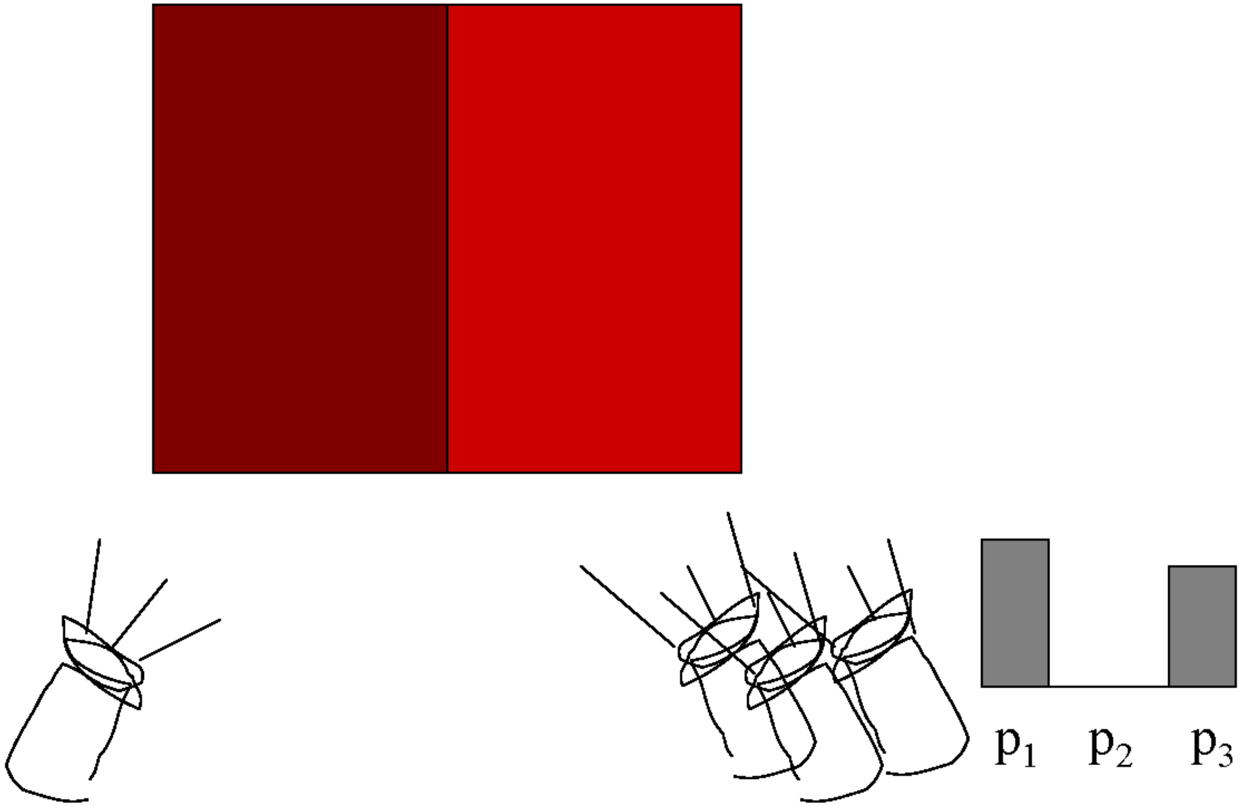
Color matching experiment 2



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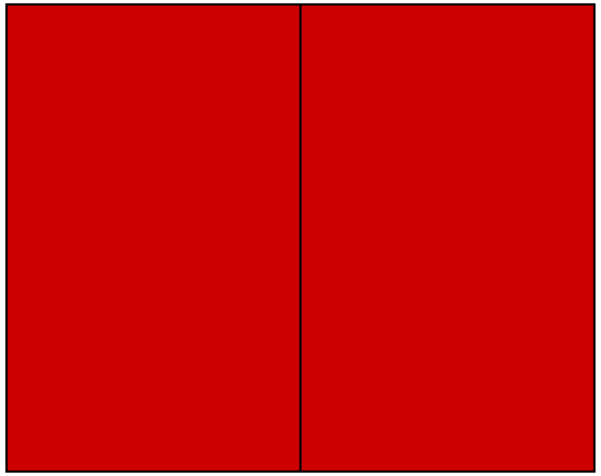
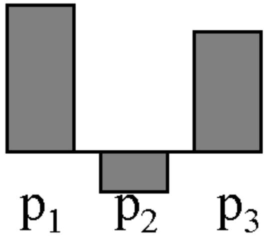
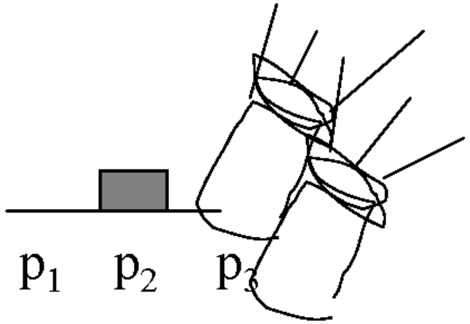
Color matching experiment 2

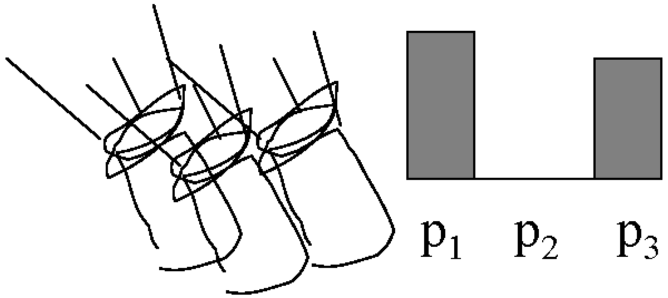
We say a "negative" amount of p_2 was needed to make the match, because we added it to the test color's side.



The primary color amounts needed for a match:







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The principle of trichromacy

- Experimental facts:
  - Three primaries will work for most people if we allow subtractive matching
  - Most people make the same matches.

Grassman's Laws

- Color matching is (approximately) linear
  - symmetry: U=V <=>V=U
  - transitivity: U=V and V=W => U=W
  - proportionality: U=V <=> tU=tV
  - additivity: if any two (or more) of the statements

    U=V,

    W=X,

    (U+W)=(V+X) are true, then so is the third
- These statements are as true as any biological law. They mean that color matching under these conditions is linear.

Measure color by color-matching paradigm

- Pick a set of 3 primary color lights.
- Find the amounts of each primary, e_1, e_2, e_3, needed to match some spectral signal, t.
- Those amounts, e_1, e_2, e_3, describe the color of t. If you have some other spectral signal, s, and s matches t perceptually, then e_1, e_2, e_3 will also match s.

slide from T. Darrel

CIE RGB

- Tri-stimulus values: Color defined by three value (R,G,B)
- The amount of Red, Green and Blue needed to form any particular color

CIE XYZ

- New color matching functions were to be everywhere greater than or equal to zero.
- For the constant energy white point, it was required that $x = y = z = 1/3$.

CIE XYZ model

- RGB -> CIE XYZ model

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.431 & 0.342 & 0.178 \\ 0.222 & 0.707 & 0.071 \\ 0.020 & 0.130 & 0.939 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

- Normalized tristimulus values

$$x = \frac{X}{X+Y+Z} \quad y = \frac{Y}{X+Y+Z} \quad z = \frac{Z}{X+Y+Z}$$

=> x+y+z=1. Thus, x, y (chromaticity coordinate) is enough to describe all colors

CIE XYZ model

- Tristimulus

Red, green, and blue are denoted X, Y, and Z, respectively. A color is defined by its trichromatic coefficients, defined as

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

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

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

CIE Chromaticity Diagram

It shows color composition as a function of x (red) and y (green)

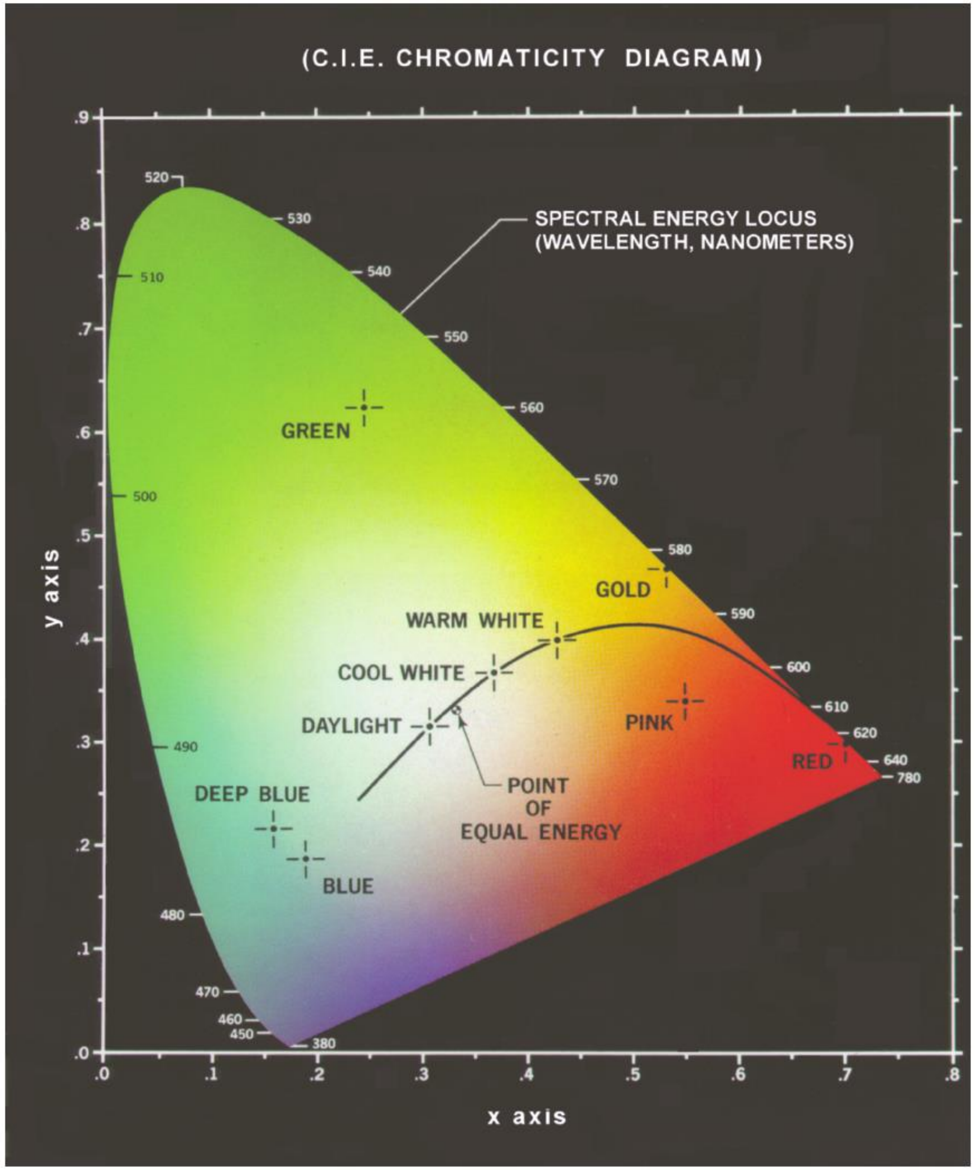
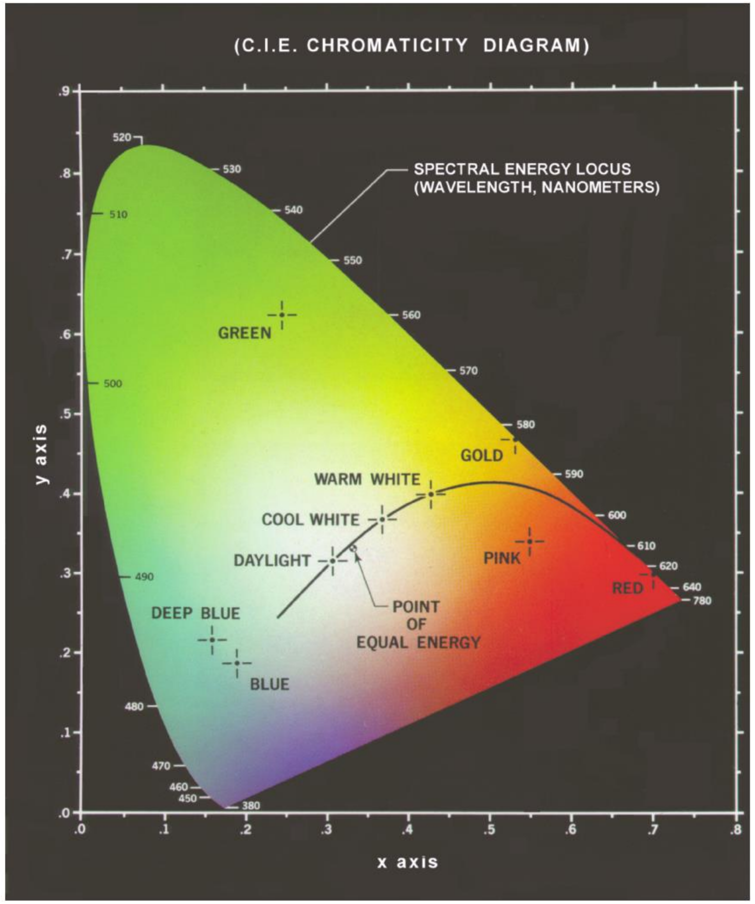


FIGURE 6.5 Chromaticity diagram. (Courtesy of the General Electric Co., Lamp Business Division.)

CIE Chromaticity Diagram

1. For any value of x, y the value of z can be obtained using $z = 1 - (x + y)$



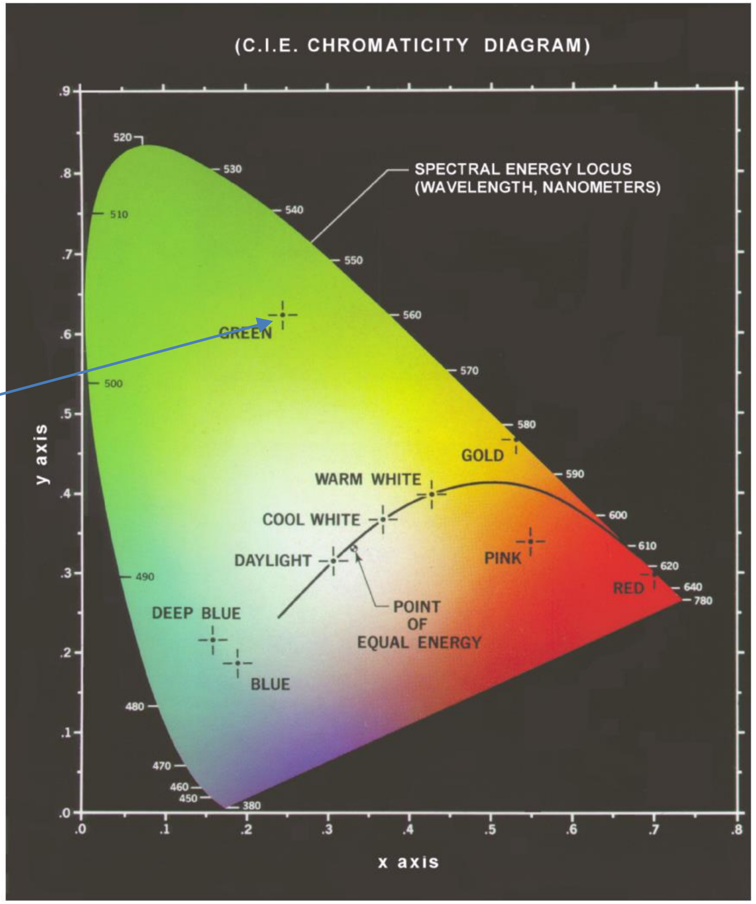
CIE Chromaticity Diagram

1. For any value of x, y the value of z can be obtained using $z = 1 - (x + y)$

Green: 62%

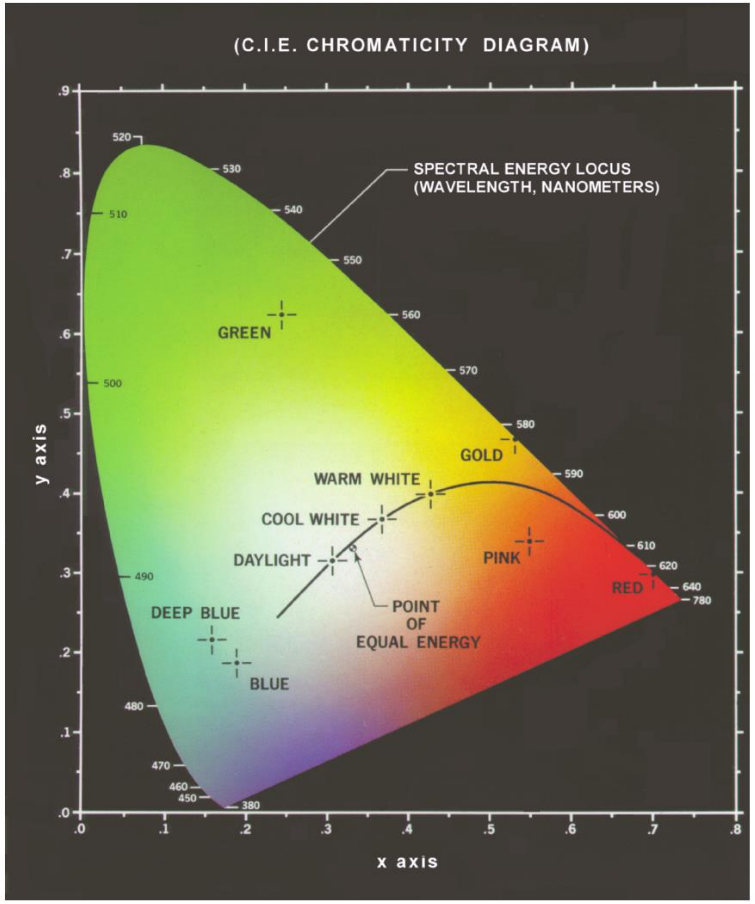
Red: 25%

Blue: (1- (62+25))= 13%



CIE Chromaticity Diagram

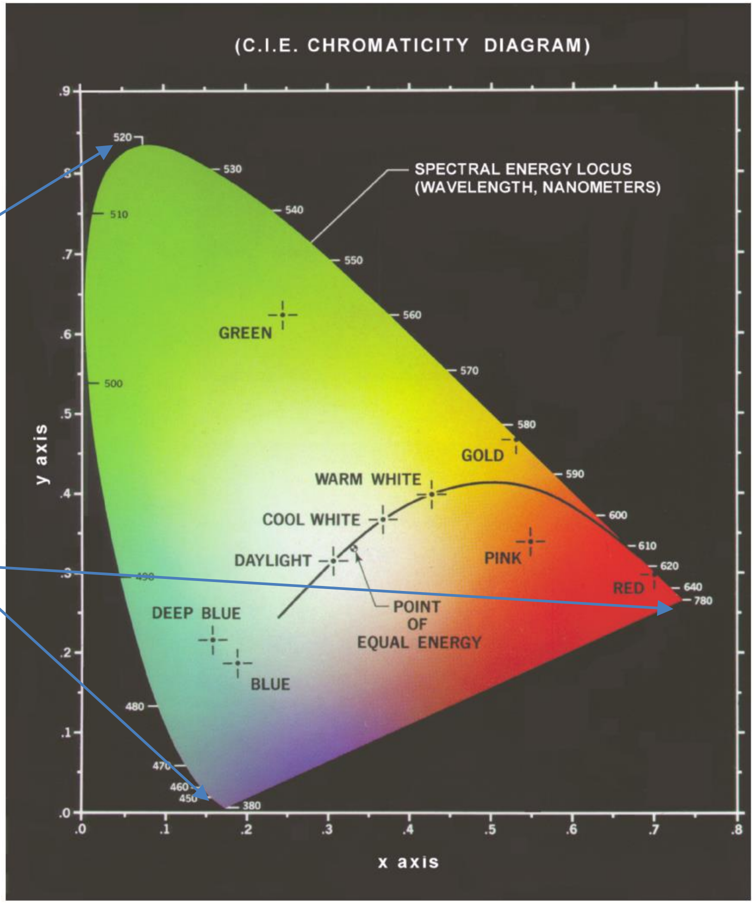
1. For any value of x, y the value of z can be obtained using $z = 1 - (x + y)$
2. Boundary various spectrum colors (violet to red)



CIE Chromaticity Diagram

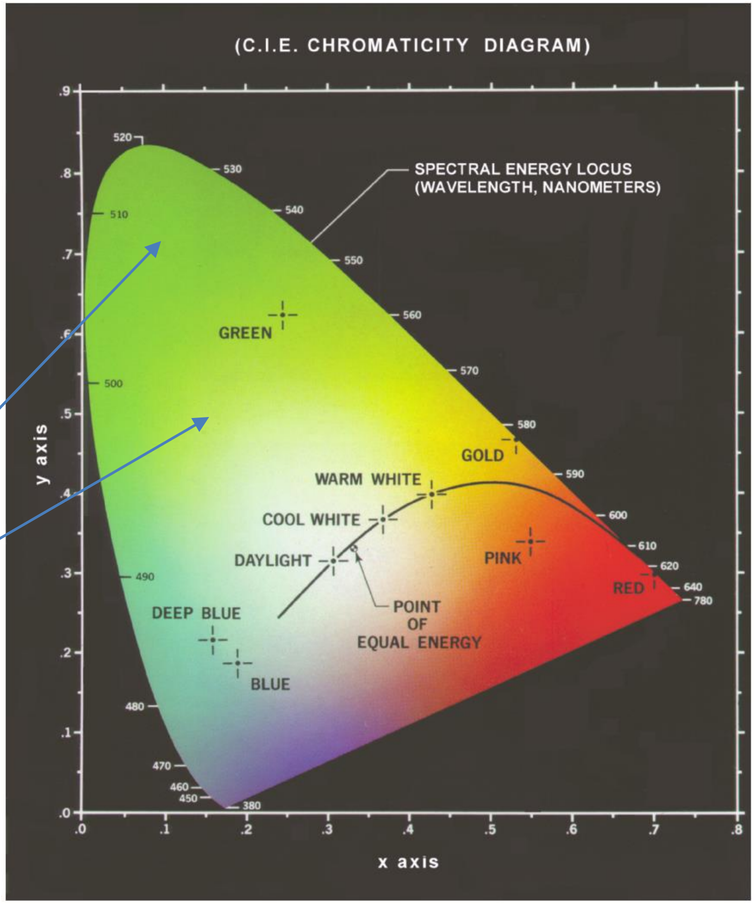
1. For any value of x, y the value of z can be obtained using $z = 1 - (x + y)$
2. Boundary various spectrum colors (violet to red)

Pure colors



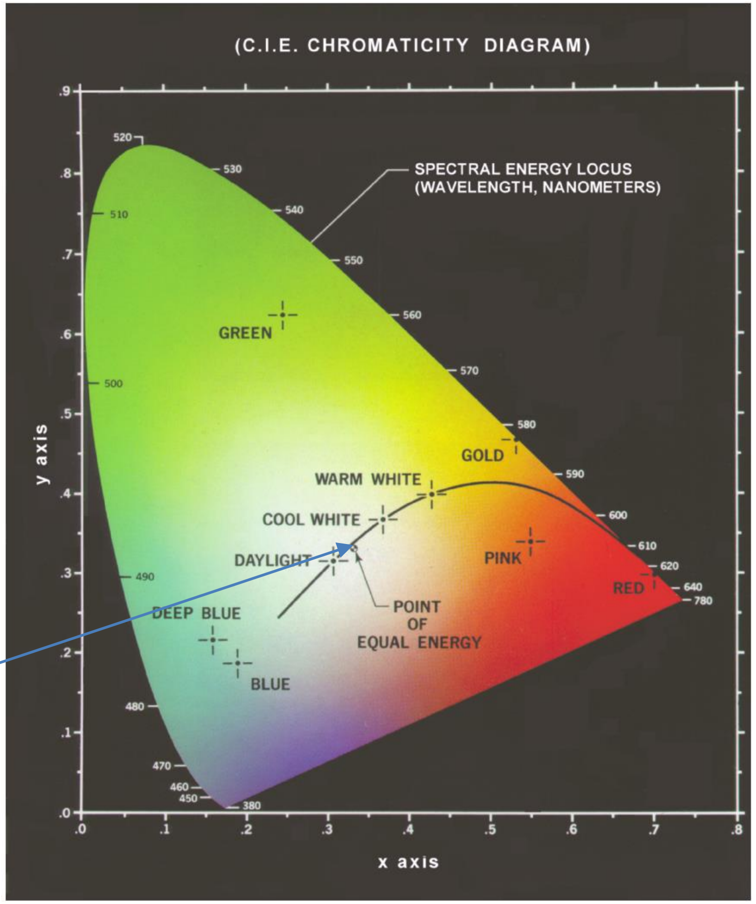
CIE Chromaticity Diagram

1. For any value of x, y the value of z can be obtained using $z = 1 - (x + y)$
2. Boundary various spectrum colors (violet to red)
3. Any point inside the boundary is some mixture of spectrum colors



CIE Chromaticity Diagram

1. For any value of x, y the value of z can be obtained using $z = 1 - (x + y)$
2. Boundary various spectrum colors (violet to red)
3. Any point inside the boundary is some mixture of spectrum colors
4. Point of equal energy (white)



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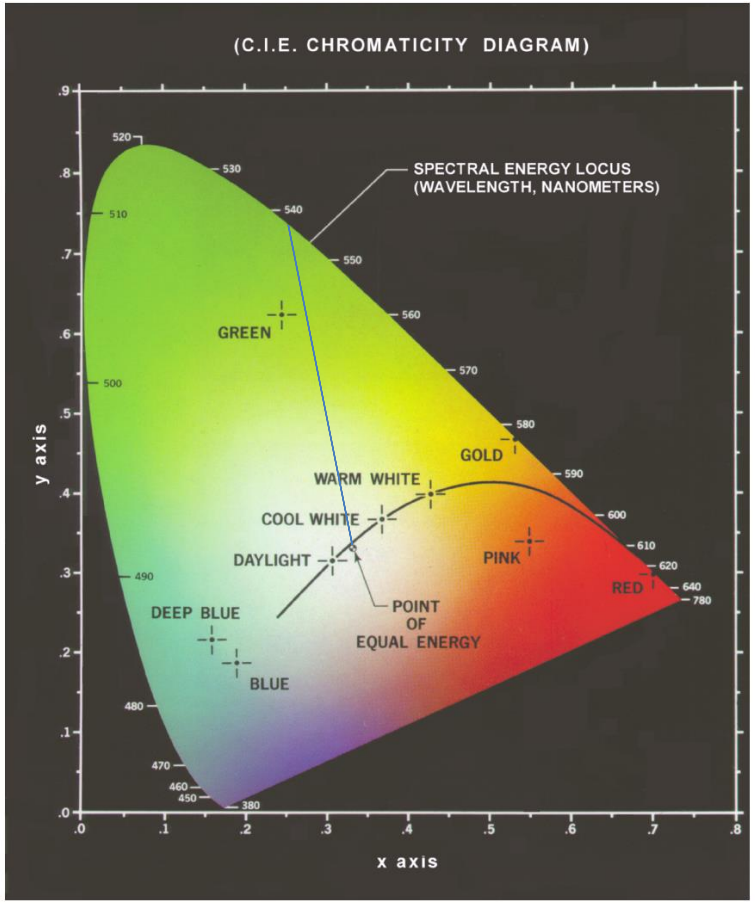
4. Point of equal energy (white)
5. Saturation Boundary to point of equal energy



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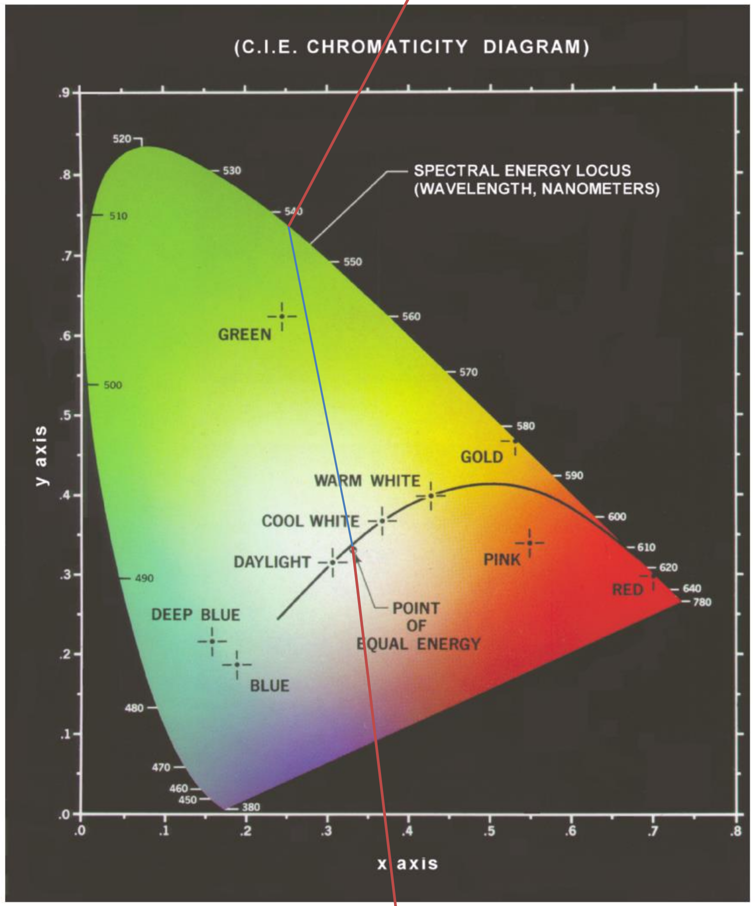
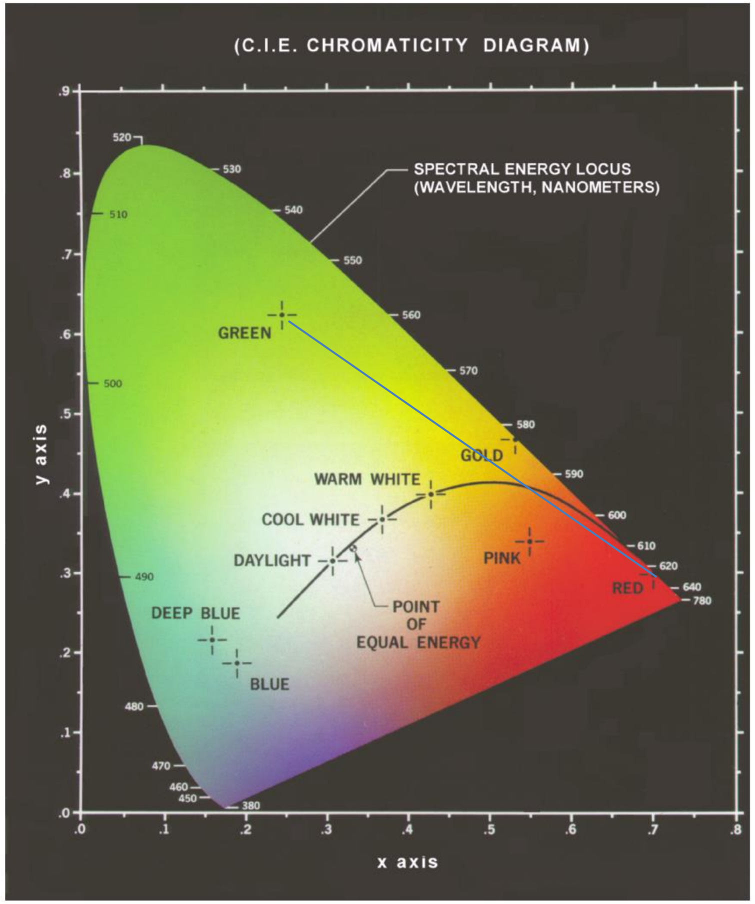
Fully saturated



zero saturated

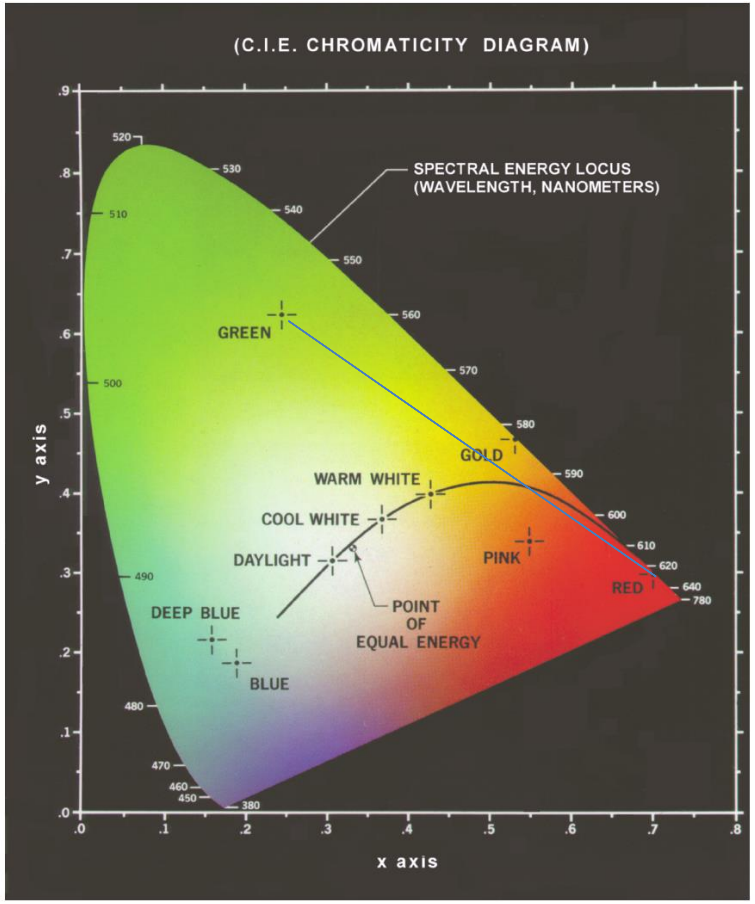
Color mixing using CIE Chromaticity Diagram

1. Line joining two points: all possible colors possible by combining the two colors



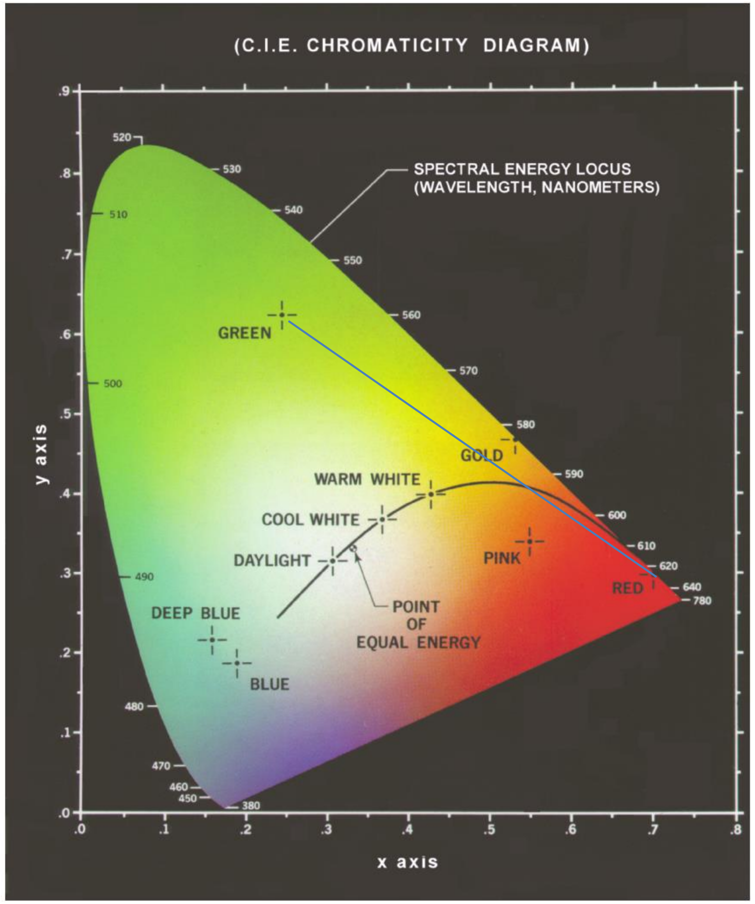
Color mixing using CIE Chromaticity Diagram

1. Line joining two points: all possible colors possible by combining the two colors



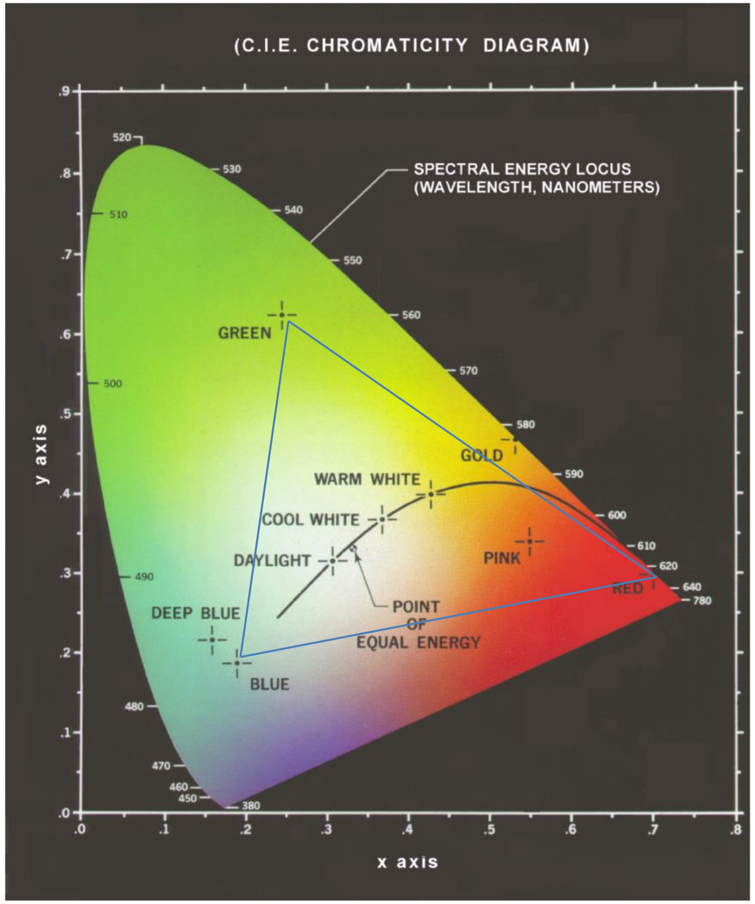
Color mixing using CIE Chromaticity Diagram

1. Line joining two points: all possible colors possible by combining the two colors
2. Extend to three points:



Color mixing using CIE Chromaticity Diagram

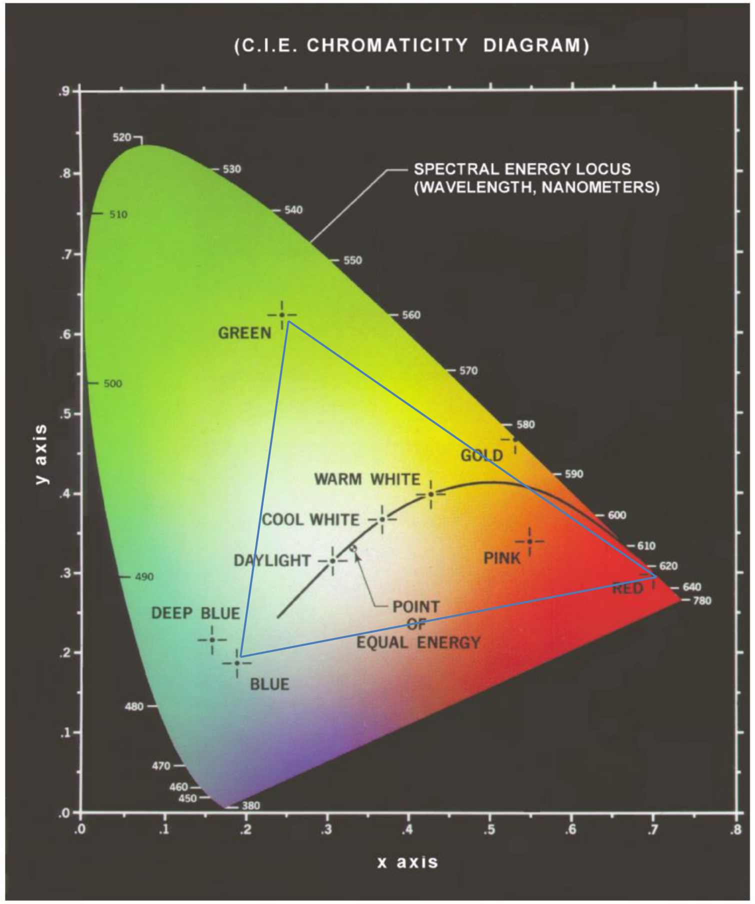
1. Line joining two points: all possible colors possible by combining the two colors
2. Extend to three points: Any color in the triangle can be obtained by combing the three vertices



Color mixing using CIE Chromaticity Diagram

1. Line joining two points: all possible colors possible by combining the two colors
2. Extend to three points: Any color in the triangle can be obtained by combing the three vertices

No three points that encompass the entire gamut of colors.



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Color mixing using CIE Chromaticity Diagram

1. Line joining two points: all possible colors possible by combining the two colors
2. Extend to three points: Any color in the triangle can be obtained by combing the three vertices

No three points that encompass the entire gamut of colors.
All colors cannot be created by adding R, G and B