COLOR MODELS

OverView

- Color model
- Visible light Spectrum
- Color terminology
- Energy Spectrum
- Additive & Subtractive Mixing
- CIE standard
- RGB color model
- CMY color model (also, CMYK)
- HSV color model
- HLS color model

COLOR MODELS

- A color model is a method for explaining the properties or behavior of color within some particular context.
  - Mathematical model in which a color is represented as numbers.
  - Forms a 3D coordinate system and each point represents a color
- No single color model explains all aspects of color, so different models are used to describe the different perceived characteristics of color

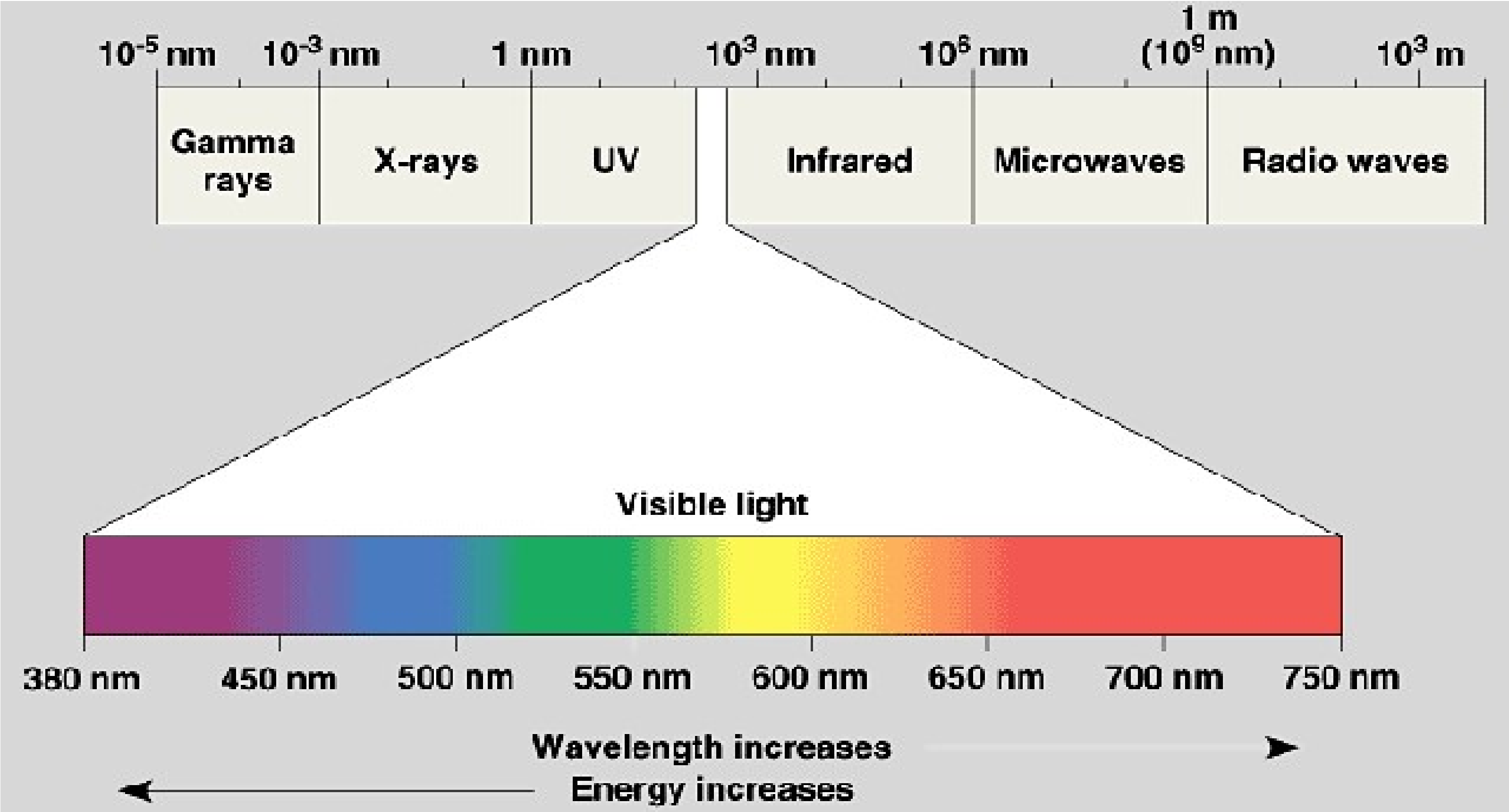
Color

- Light is a narrow frequency band within the electromagnetic spectrum (380-750 nm).
- Each frequency value within the visible band corresponds to a distinct color.
- At low frequency end is red color and highest frequency is violet color.
- The various colors are described in terms of either frequency f or wavelength λ of electromagnetic wave.
- The colors that we see in the world around us are generally not pure colors consisting of a single wavelength.

Color

- The combination of frequencies present in the reflected light determines what we perceive as the color of the object.
- Rather, color sensation results from the *dominant wavelength* of the light reflecting off or emanating from an object.
- The dominant frequency is called as HUE .

Color



10^{-5} nm
10^{-3} nm
1 nm
10^{3} nm
10^{6} nm
1 m
(10^{9} nm)
10^{3} m
Gamma rays
X-rays
UV
Infrared
Microwaves
Radio waves
Visible light
380 nm
450 nm
500 nm
550 nm
600 nm
650 nm
700 nm
750 nm
Wavelength increases
Energy increases

Color Terminology

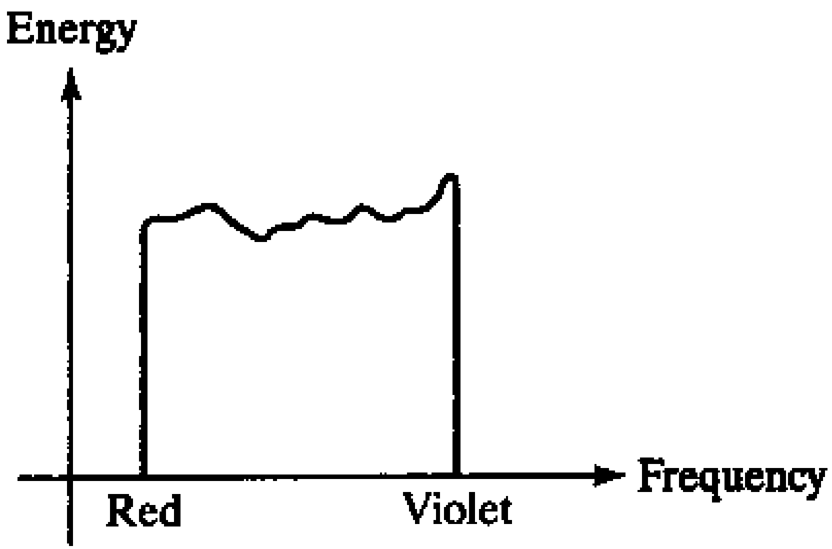
- **Hue** – the **dominant frequency** is called hue or simply color
- **Monochromatic color** – a color that is created from only one wavelength.
- **Brightness or Luminance** : perceived intensity of light.
- **Purity or saturation** : Describes how "pure" the color of light appears. *Saturation* is a matter of how much white light is added in. The less white light, the more saturated the color.(how strong a color is)
- ***Lightness*** is how much black is in the color.
- **Chromaticity**: Refers to two properties of color characteristics purity and dominant frequency
- Hue and saturation are elements of *chrominance*. Lightness is a matter of *luminance*.

Color Terminology

- **Additive color systems** – based on adding colored light (as in computer monitors). A combination of all colors gives white.
- **Subtractive color systems** – based on adding pigments (as in printing). A combination of all colors gives black.

Physical properties of light

- Energy emitted by a white-light source has a distribution over the visible frequencies as shown
- The distribution showing the relation between energy and wavelength (or frequency) is called *energy spectrum.*
- *Each frequency component from red to violet contributes more or less equally to total energy.*
- *The color of source are descibred as white.*



Physical properties of light

- *The light has color corresponding to the dominant frequency*

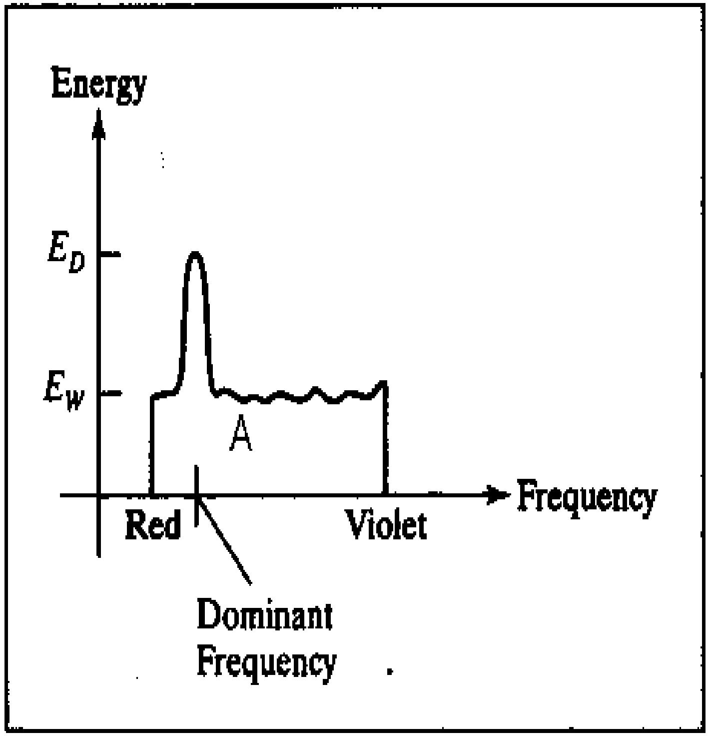
This distribution may indicate:

1) a <u>dominant wavelength</u> (or frequency) which is the color of the light (*hue*),E_D

2) Contributions from the other frequencies produces white light of energy density E_w

3) <u>brightness</u> (luminance), intensity of the light (*value*), is the area *A* under curve.

4) <u>purity</u> (*saturation*), E_D - E_W



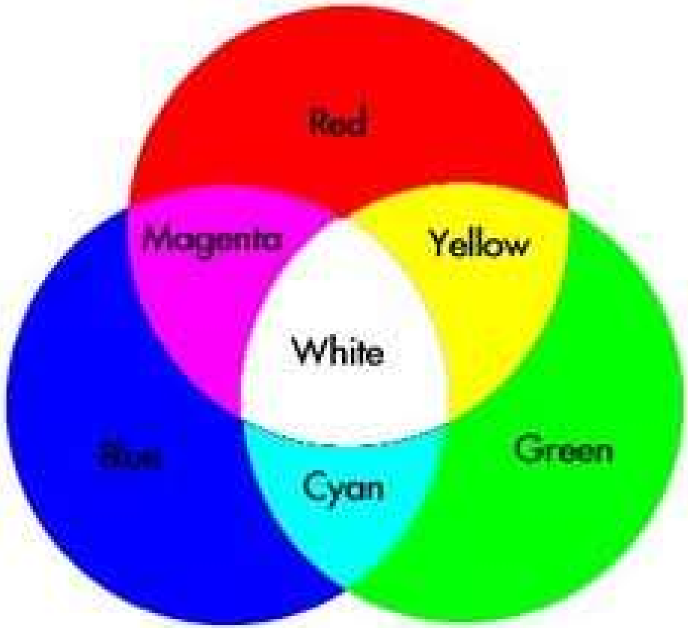
Energy spectrum for a light source with a dominant frequency near the red color

Color definitions

- Two different color light sources with suitable chosen intensities can be used to produce other range of colors.
- ***Complementary colors*** - two colors combine to produce white light.
  - Eg: red and cyan, green and magenta, blue and yellow
- **Color Gamut:**color models used to describe combination of light, in terms of hue, use three colors to obtain wide range of colors.
- ***Primary colors*** - (two or) three colors used for describing other colors
- Two main principles for mixing colors:
  - *Additive mixing & Subtractive mixing*

Additive mixing

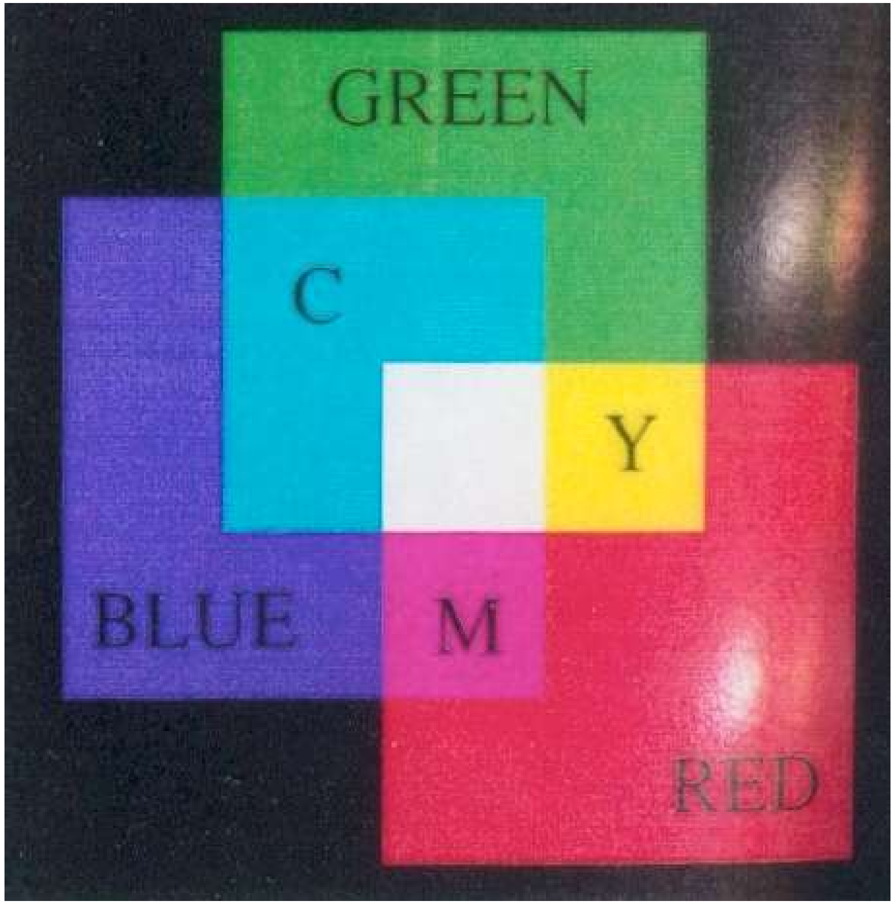
- This system express a color D, as the sum of certain amount of primaries.
- Overlapping gives yellow, cyan, magenta and white
- Typical technique used on color displays

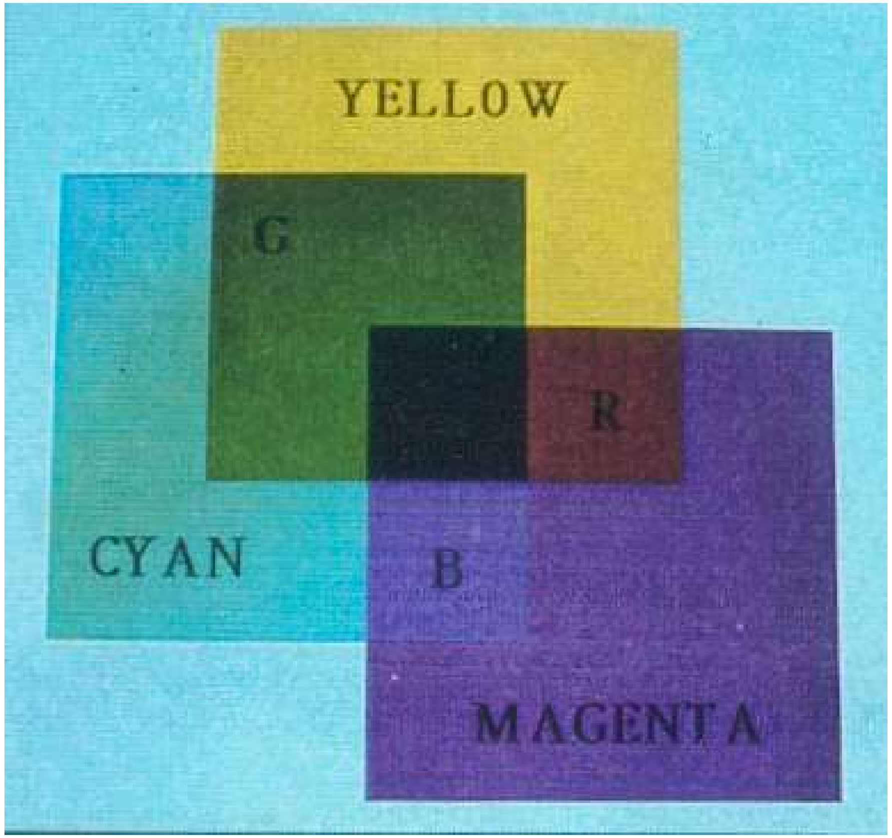


Subtractive mixing

- Color pigments are mixed directly in some liquid, e.g. Ink
- Primary colors: **cyan, magenta and yellow**, i.e. CMY
- The typical technique in printers/plotters
- This system expresses a color, D by means of three tuple in which each of the three values specifies how much of certain color to remove from white in order to produce D.

Additive/subtractive mixing





Overview of color models

The human eye can perceive about 382000(!) different colors

Some kind of classification system is necessary; all models use three coordinates as a basis:

1) CIE standard (XYZ model)
2) RGB color model
3) CMY color model (also, CMYK)
4) YIQ color model
5) HSV color model
6) HLS color model

CIE Color Primaries

- The CIE (International Commission on Illumination) color primaries is referred as X, Y, and Z .
- X, Y, and Z are "artificial primaries,"(imaginary) not visible colors like R, G, and B.
  - Just a hypothetical model; to make it machine independent
- These primaries can be combined in various proportions to produce all the colors the human eye can see.
- In the CIE color model ,a color **C** is given by

  C = X1***X** + Y1***Y** + Z1***Z**

  XYZ – Vectors in color space X1Y1Z1 – amt of standard primaries needed to match C

CIE Color Model on the X+Y+Z = 1 Plane

- If we want to consider each component as a percentage of the total amount of light, we can "normalize" the values:

$$x = \frac{X}{X + Y + Z} \quad (1)$$

$$y = \frac{Y}{X + Y + Z} \quad (2)$$

$$z = \frac{Z}{X + Y + Z} \quad (3)$$

Note: X + Y + Z is the luminance
Also note that x + y + z = 1

CIE Color Model on the X+Y+Z = 1 Plane

- x, y represent chromaticity values and depend on hue and purity.
- If we specify colors only with x and y values, we cannot obtain the amounts X, Y, and Z
- So, for complete description of any color, we need x, y & Y.

$$(X, Y, Z) = \left(\frac{xY}{y}, Y, \frac{(1-x-y)Y}{y} \right).$$

(1) *can be written as* $X = x\,(X + Y + Z)$

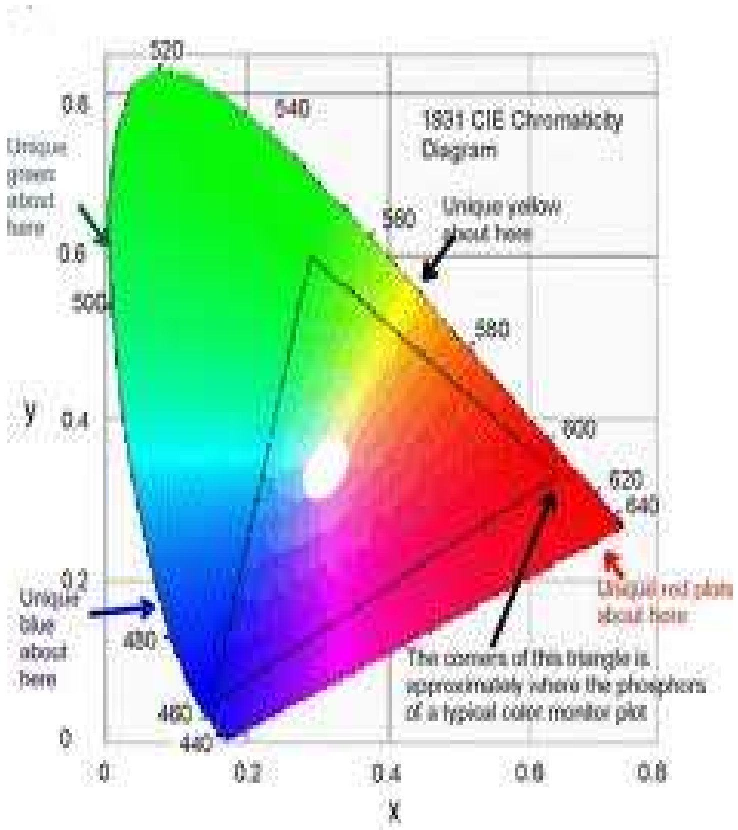
from (2) we know that, X+Y+Z = Y/y

Therefore, X = x (Y/y)

Similarly for Z

CIE Chromaticity Diagram

Plotting x vs. y for colors in the visible spectrum ,we obtain tongue shaped curve called *CIE Chromaticity diagram*



·Points along the curve are the 'pure' colors in the spectrum.

•The Line Joining red to violet is called *purple line*, and is not a part of the spectrum

•Interior points specify all the visible color combinations.

•The dot corresponds to white light position.

Chromaticity Diagram

- The CIE Chromaticity diagram is found useful in the following situations
  - Comparing *color gamuts* of different set of primaries
  - Identifying *complementary colors*
  - Determining *dominant wavelength* & *purity* of different colors

Dominant Wavelength on CIE Color Diagram

- Color Gamut are represented in the chromaticity diagram as straight line segments or polygons.
- To determine the dominant wavelength of a color C1, draw a line between C through C1 to intersect the spectral curve at Cs. The dominant wavelength is at Cs.
- The purity is given by the ratio of distance of C to C1 and distance of C to Cs.
- The closer C1 is to the perimeter, the more saturated the color.
- Dominant wavelength of C2 is Csp(compliment of Cp) – 'coz Cp is on the purple line which is not a part of visible spectrum

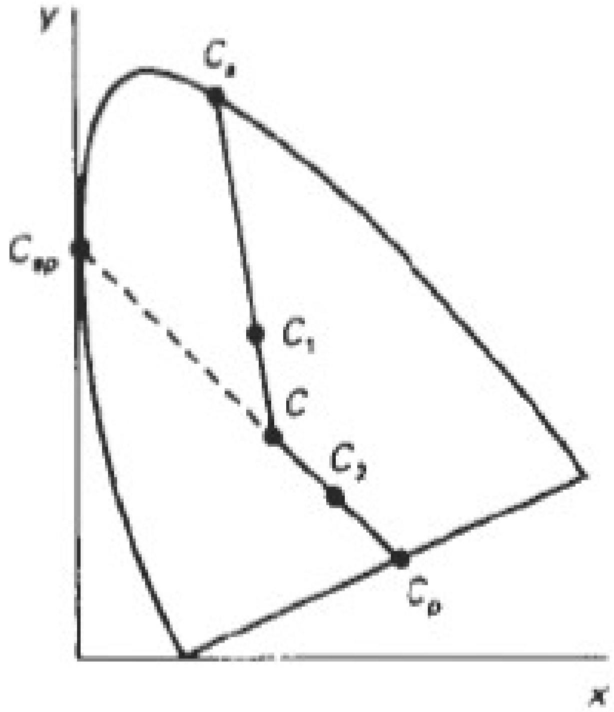
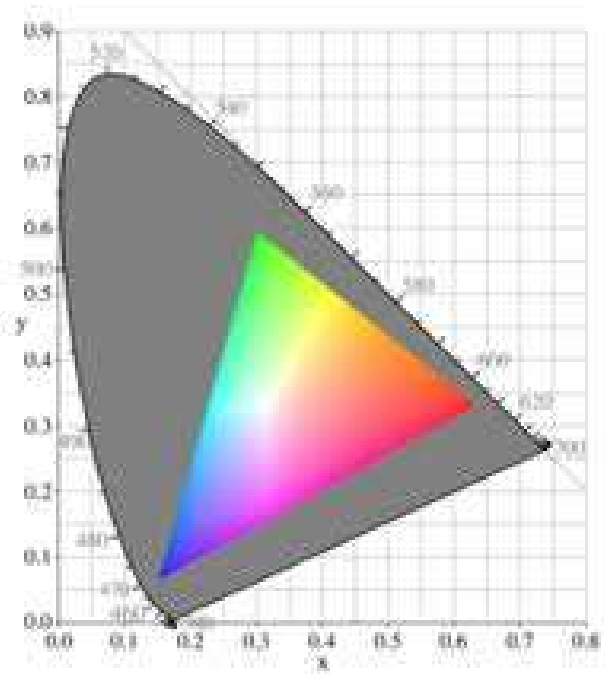
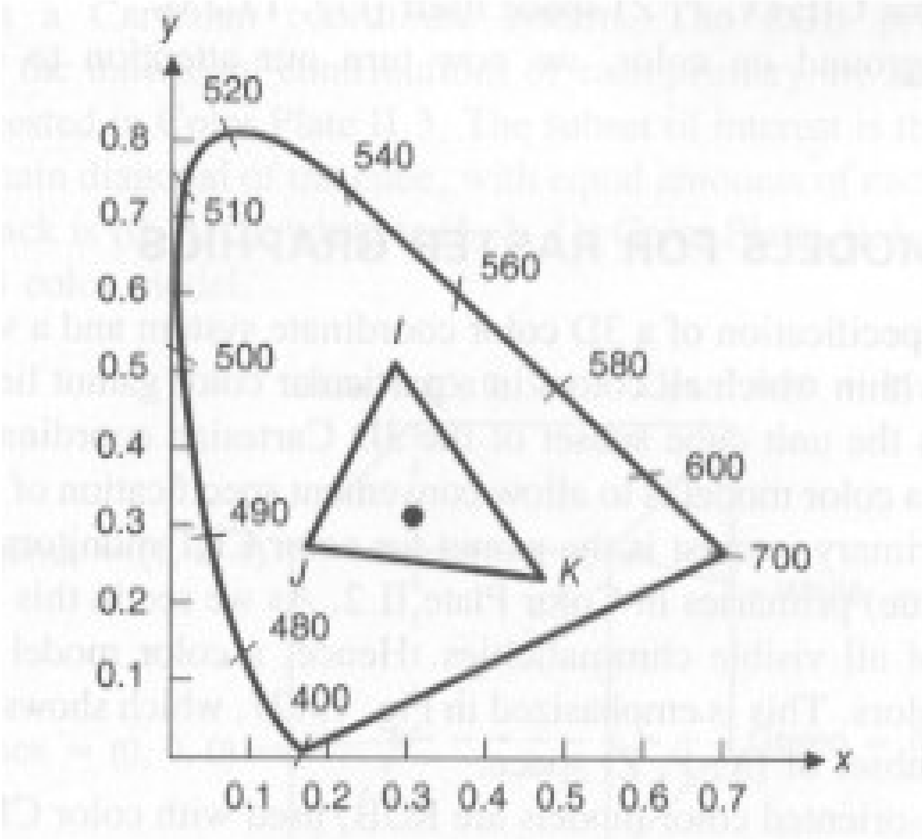


Figure 15-10
Determining dominant wavelength and purity with the chromaticity diagram.

Color Gamuts Represented on CIE Diagram

- All colors on the line IJ can be created by additively mixing colors I and J; all colors in the triangle IJK can be created by mixing colors I, J, and K.





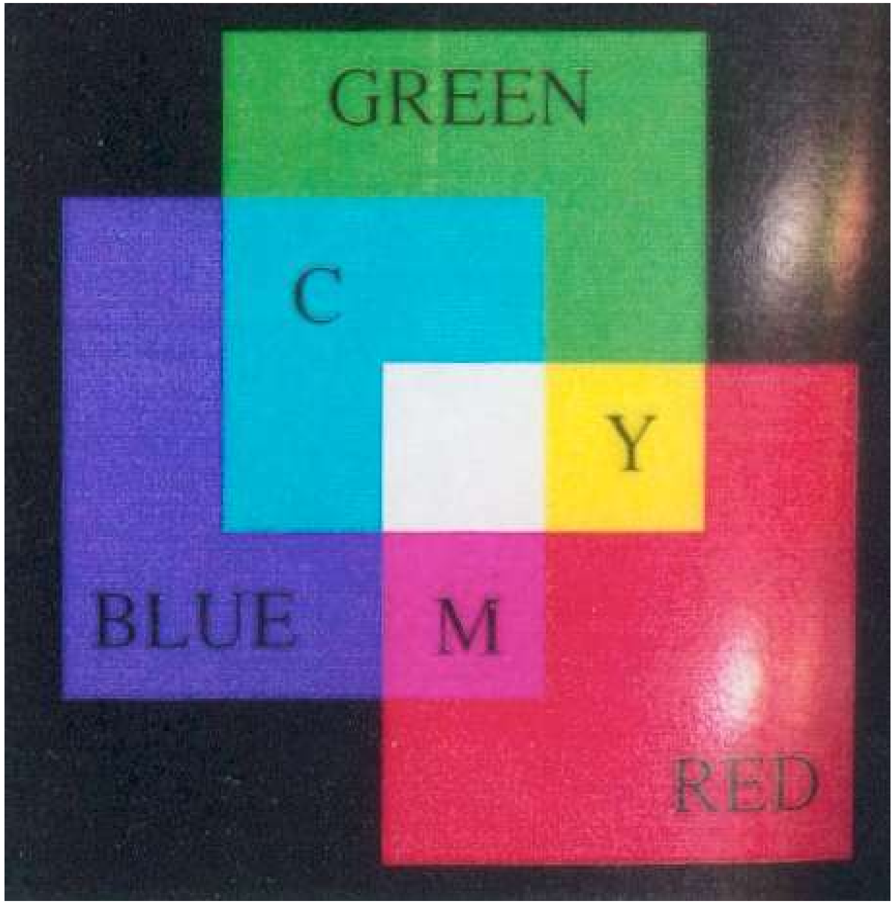
Color Concepts

- **An artist creates a color painting by mixing color pigments with white and black pigments**

- **Shades**: Pure color + Black pigment
- **Tints** : White Pigment + original color
- **Tones** : original color + Black +White pigments

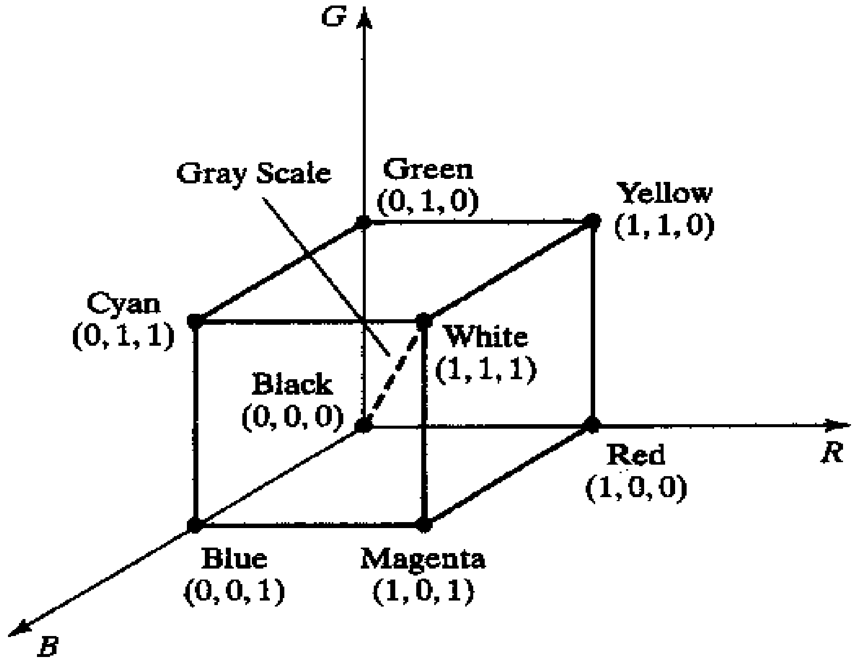
RGB model

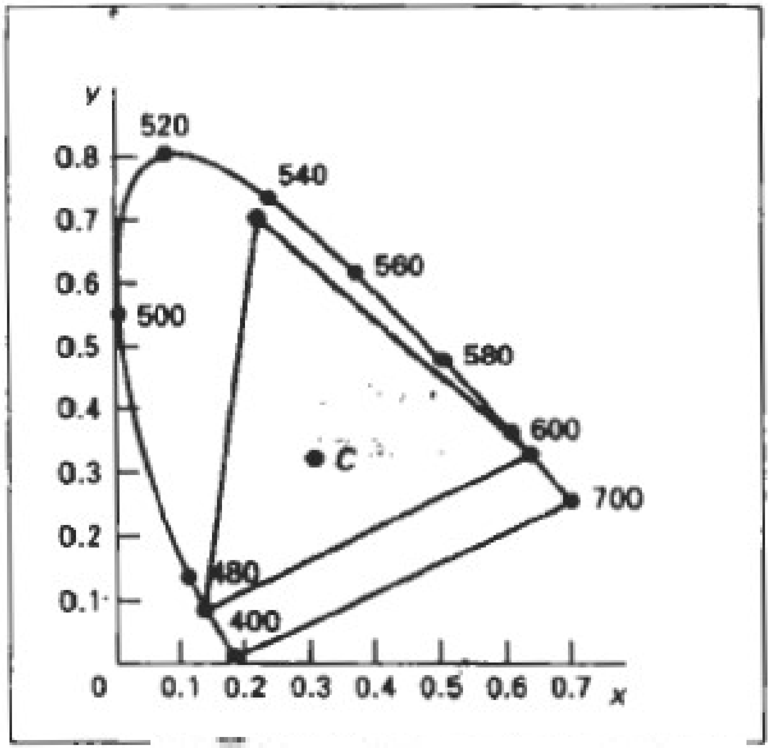
- All colors are generated from the three primaries R,G,B.
- various colors are obtained by changing the amount of each primary
- Additive mixing (r,g,b), $0 \leq r,g,b \leq 1$ referred to RGB color model.



RGB Model

- The *RGB unit cube defined with R,G,B axes. Each color point within the cube is given as (R,G,B)*
- *A color is expressed as C=R**R**+G**G**+B**B***
- Orgin=>black, 1,1,1=>white, .5,.5,.5=>gray
- Vertices of cube axes=> primary colors
- Other vertices=> complementary colors





RGB color gamut.

YIQ Colour Model

- Whereas an RGB monitor requires separate signals for the red, green, and blue components of an image, a television monitor uses a single composite signal
- The NTSC colour model for forming the composite video signal is the YIQ model. Same as XYZ model and used in television.
- Y represents the luminance IQ represents the hue and purity.
- A combination of red, blue and green are chosen for Y parameter to yield standard luminosity curve
- Since Y represents the luminance information black-white monitors use only the Y signal.
- I contains orange-cyan hue info (flesh-tone) Q contains green-magenta hue information.

YIQ Colour Model

- Conversion of RGB values to YIQ values

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

Calculated using the chromaticity coordinates of the RGB phosphor

- Conversion of YIQ values to RGB values can be done with the inverse matrix transformation

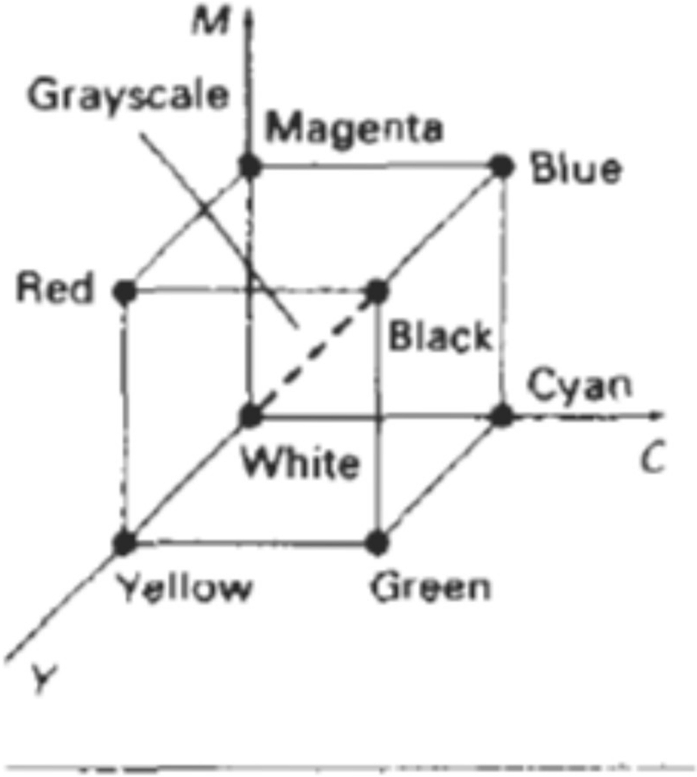
$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1.000 & 0.956 & 0.620 \\ 1.000 & -0.272 & -0.647 \\ 1.000 & -1.108 & 1.705 \end{bmatrix} \cdot \begin{bmatrix} Y \\ I \\ Q \end{bmatrix}$$

CMYK model

- CMYK is primarily a printing color model.
- Cyan, magenta, and yellow are called the subtractive primaries.
- The hard-copy devices produces color pictures by coating a paper with color pigment.
- Human eye - See the colors by reflected light which is a subtractive process.

CMYK Model

- Cyan, magenta, yellow, and black
- Cyan is white light with red taken out.
  C = G + B = W – R
- cyan can be formed by adding green and blue light. Therefore, when white light is reflected from cyan-colored ink, the reflected light must have no red component. That is red light is absorbed, or subtracted



CMYK Model

- Magenta is white light with green taken out.
  M = R + B = W - G
- Yellow is white light with blue taken out.
  Y = R + G = W – B
- 1,1,1 => black (since all components of incident light are subtracted)
- Orgin=>white
- CMY model generates a color point with a collection of four ink dots, like a RGB monitor uses a collection of three phosphor dots.
- Cyan, magenta, yellow and black dots (black dot coz cyan+magenta+yellow=dark gray instead of black)

CMYK vs. RGB

- RGB tO CMY conversion:

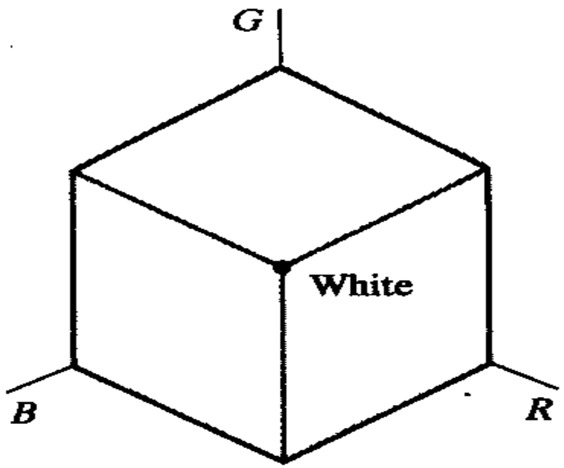
$$\begin{pmatrix} C \\ M \\ Y \end{pmatrix} = \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix} - \begin{pmatrix} R \\ G \\ B \end{pmatrix}.$$

CMY to RGB conversion can be done with matrix transformation

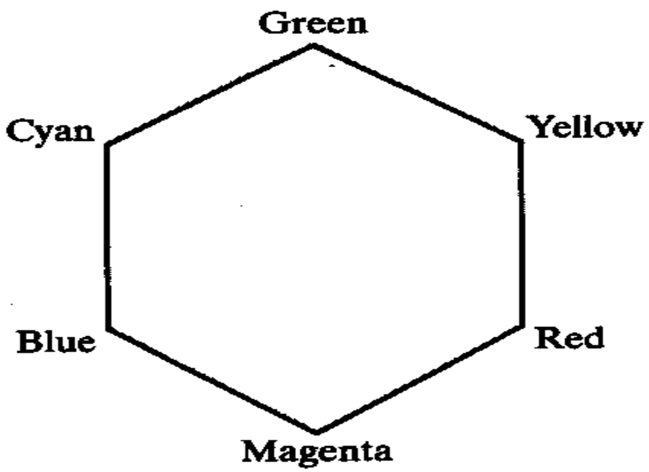
$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} C \\ M \\ Y \end{bmatrix}$$

HSV model

- Uses color descriptions that are more intuitive to user. User selects a spectral color and then decides a shade, tint and tone
- HSV stands for Hue-Saturation-Value
- described by a hexcone derived from the RGB cube



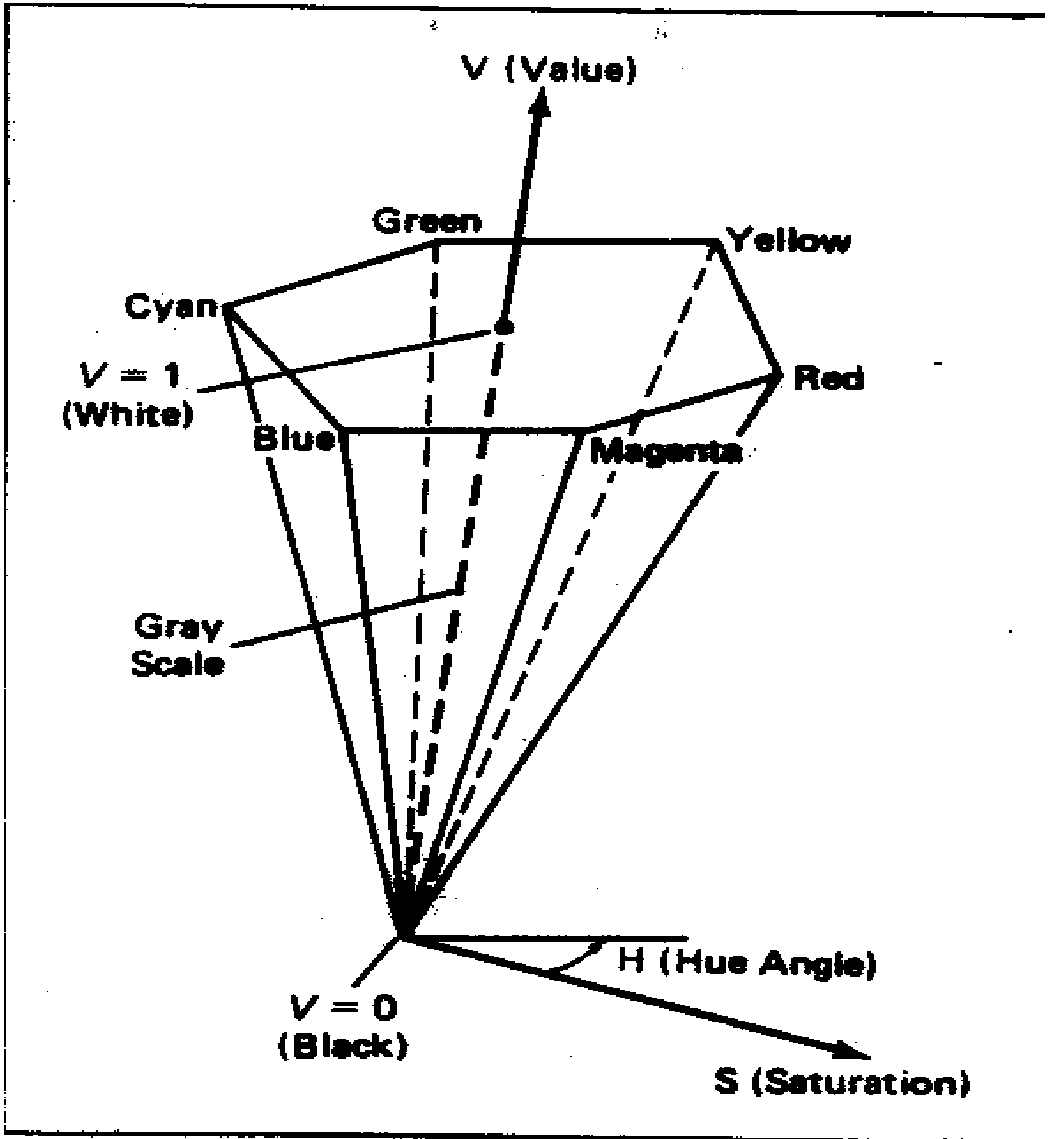
RGB Color Cube
(a)



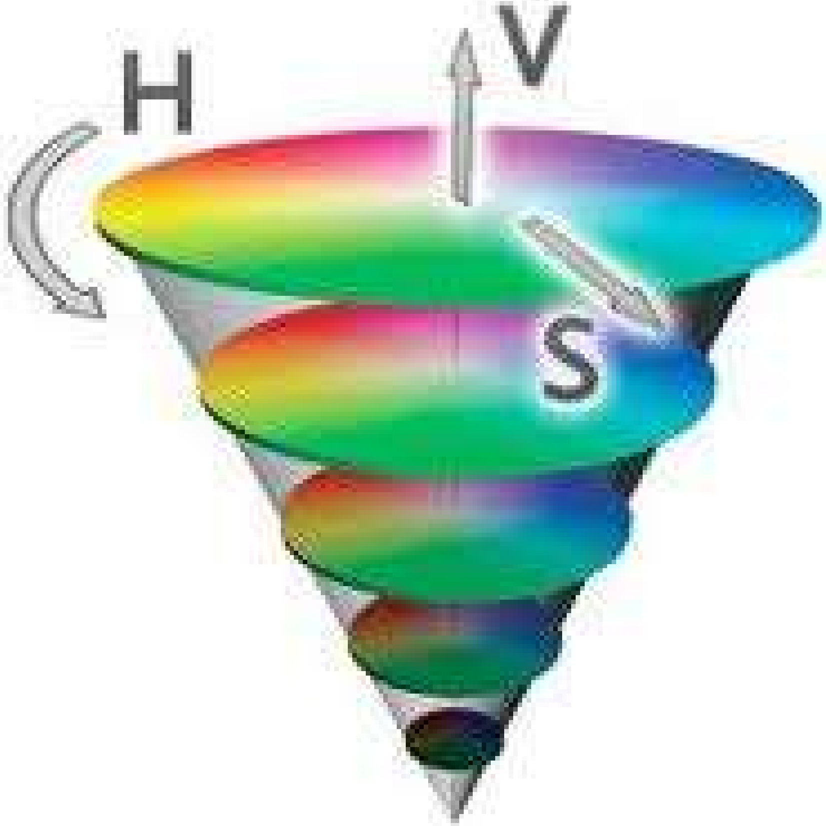
Color Hexagon
(b)

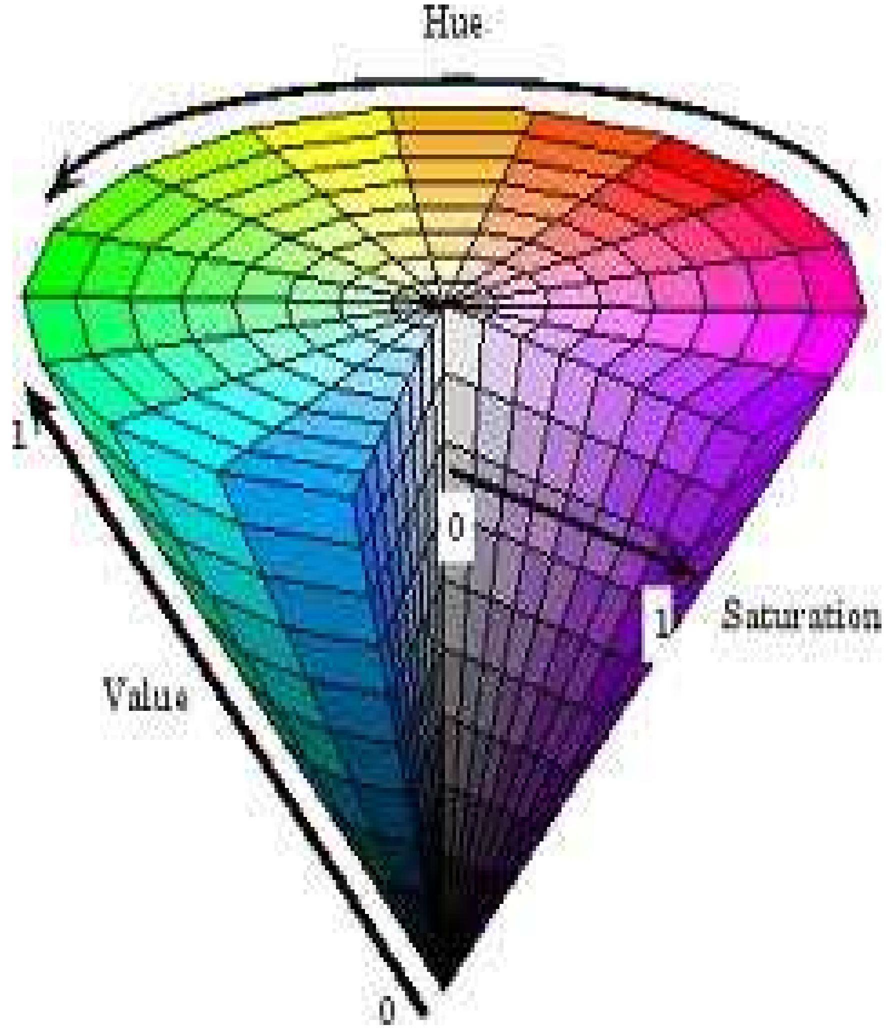
HSV model

- Hue (0-360°); "the color",
- Saturation (0-1); "the amount of white"
- Value (0-1); "the amount of black"
- Top of HSV hex cone is projection seen by looking along principal diagonal of RGB color



HSV Color Model





HSV color model

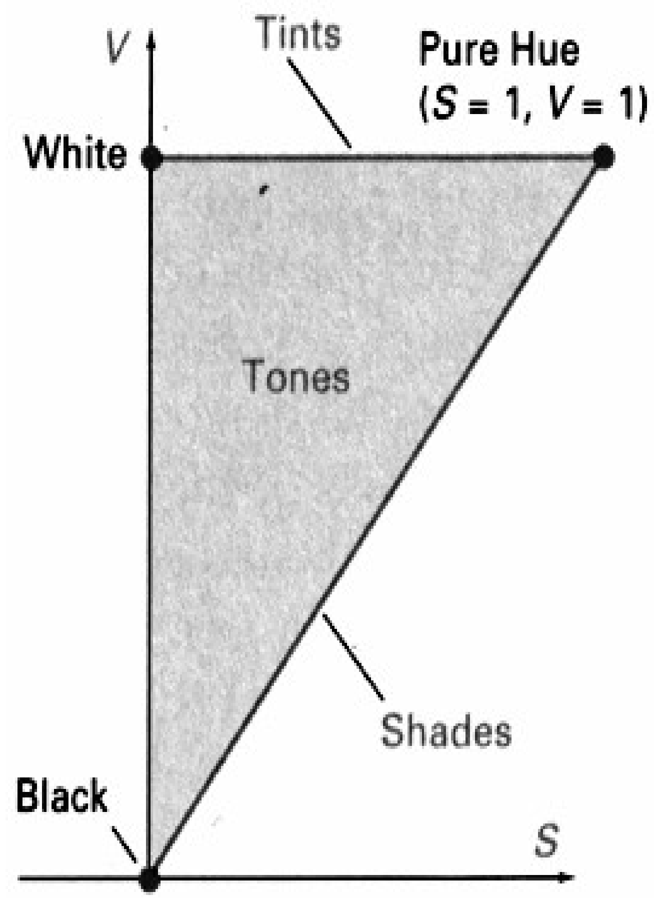
- Hue: ranges from 0° at red through 360°
- Vertices of the hexagon are separated by 60° intervals-Y at 60°, G at 120° etc
- Complementary colors 180° opposite
- Saturation S ranges from 0 to 1 – ratio of purity of a selected hue to its maximum purity at S=1.
- Value V varies from 0 at apex(black) to 1 at top(white).
- At
  - V=1 and S=1, pure hues
  - V=1 and S=0, white
  - V=0 and S=0 black

HSV Color model

- To get Dark Blue:
  - H=240, say V= 0.4 and S= 1
  - Adding black decreases V while S is constant
- To get Light Blue:
  - H=240, V=1 and say S=0.3
  - Adding white decreases S while V is constant

HSV Color Definition

- Cross section of the HSV hex cone showing regions for shades, tints, and tones.
- Shades: S=1 $0 \leq V \leq 1$
- Tints: V=1 $0 \leq S \leq 1$

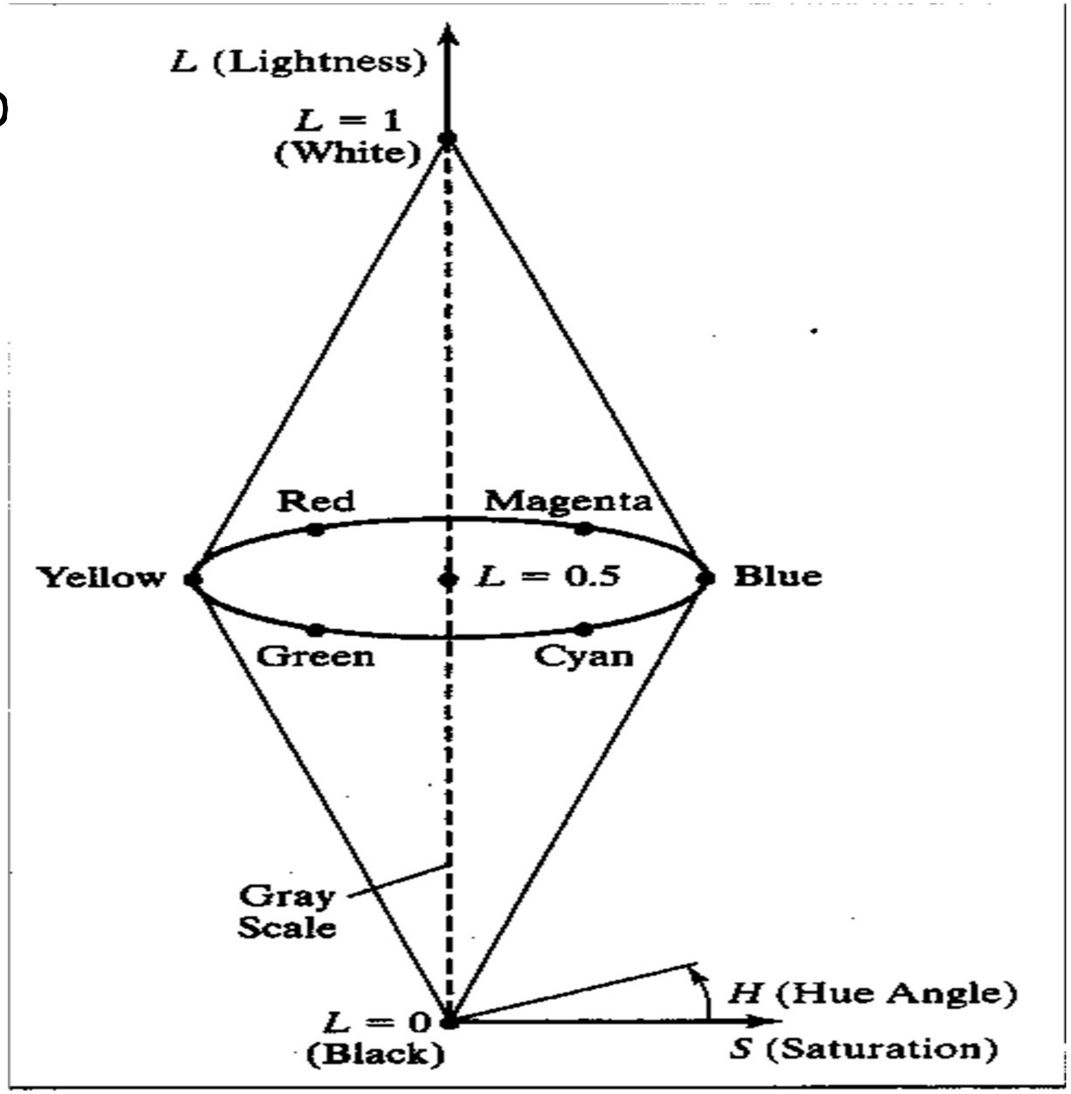


HLS model

Another model similar to HSV

L stands for *Lightness*

- color components:
- hue (H)∈ [0°, 360°]
- lightness (L)∈ [0, 1]
- saturation (S)∈ [0, 1]



Color Models Summary

- **CIE-XYZ: standard color description**
- **RGB: for monitors**
- **CMY, CMYK: for printers**
- **HSV, HLS: for user interfaces**
- **YIQ: for television (NTSC)** (Y=luminance, I=R-Y, Q=B-Y)