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

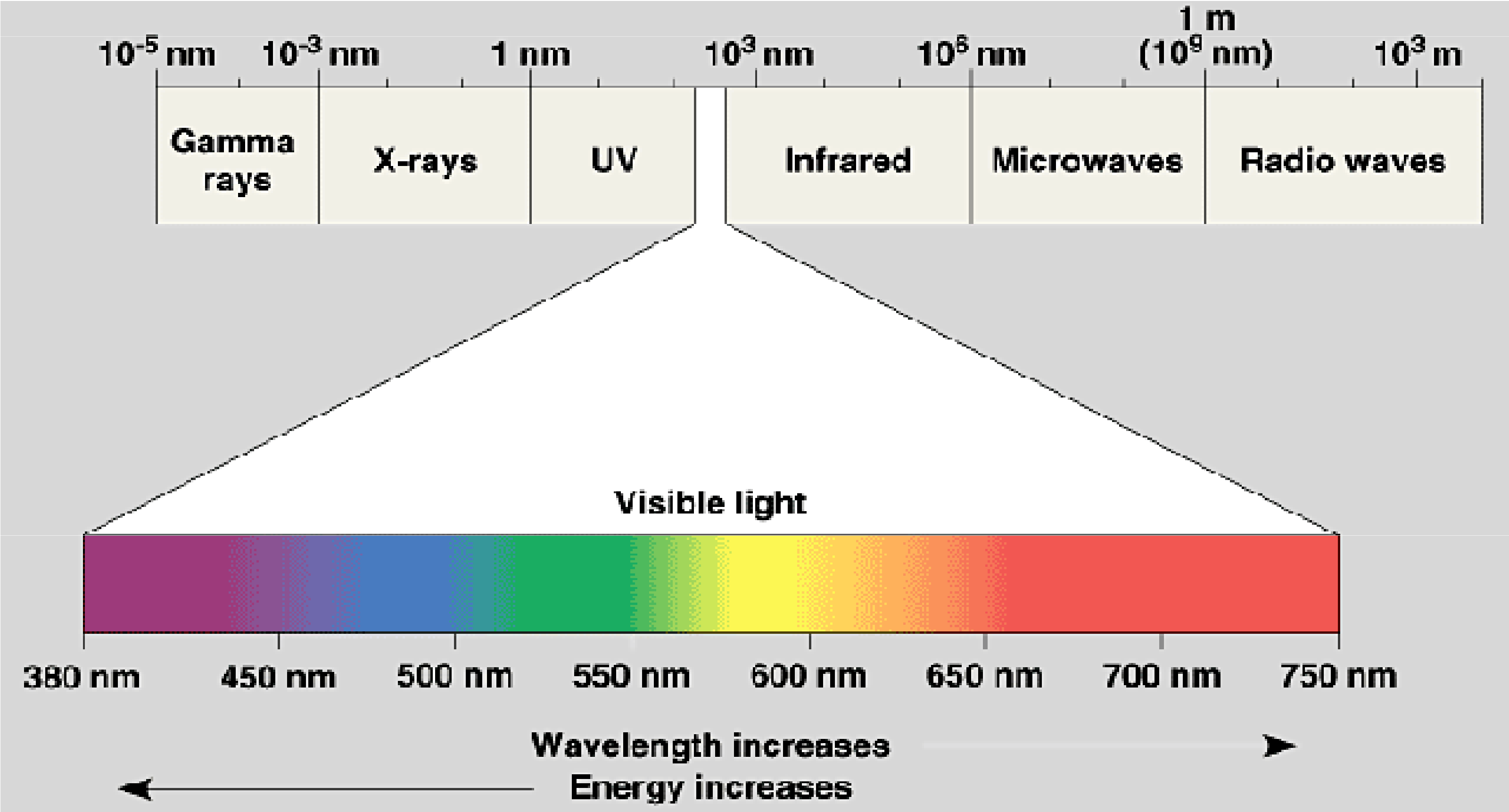
COLOR MODELS

- 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

Color

- Visible light is part of the electromagnetic spectrum (380-750 nm)
- Light, an electromagnetic energy is perceived as colors in the visible parts ranging from violet, indigo, blue, green, yellow, orange, and red.
- The colors that we see in the world around us are generally not pure colors consisting of a single wavelength.
- Rather, color sensation results from the *dominant wavelength* of the light reflecting off or emanating from an object.

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

- Each frequency value within the visible band corresponds to a distinct color.
- The various colors are described in terms of frequency f or the wavelength λ of the wave.
- Red light has longer wavelength in the visible light & blue the shorter

Color Terminology

- **Hue** – the **dominant frequency** is called hue or simply color
- **Monochromatic color** – a color that is created from only one wavelength. (Most colors result from a combination of wavelengths.)
- **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

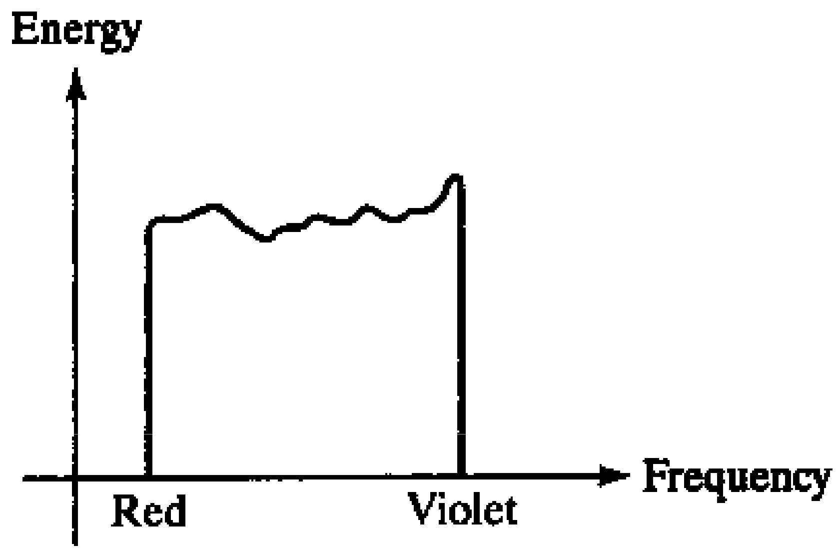
- **Additive color systems** – based on adding colored light (as in computer monitors). A combination of all colors gives white.
- **Subtractive color systems** – based on adding pigments (as in printing). A combination of all colors gives black.

Physical properties of light

All kinds of light can be described by the energy of each wavelength

The distribution showing the relation between energy and wavelength (or frequency) is called *energy spectrum.*

The light has color corresponding to the dominant frequency



Physical properties of light

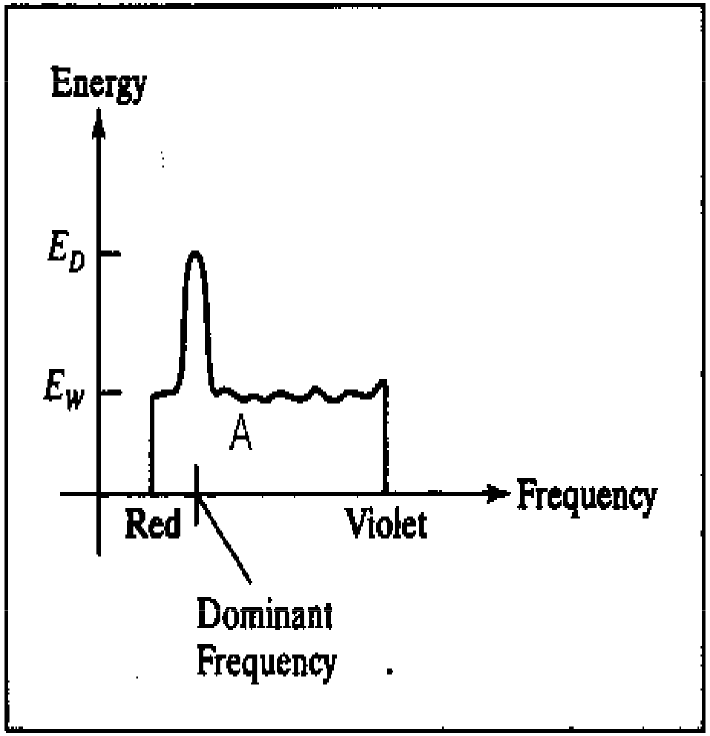
This distribution may indicate:

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

Complementary colors - two colors combine to produce white light

Eg: red and cyan, grren and magenta, blue and yellow

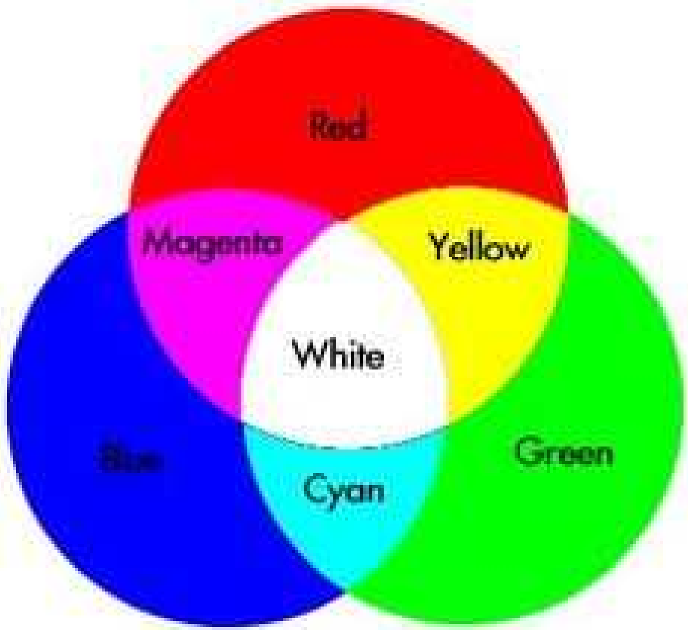
Primary colors - (two or) three colors used for describing other colors

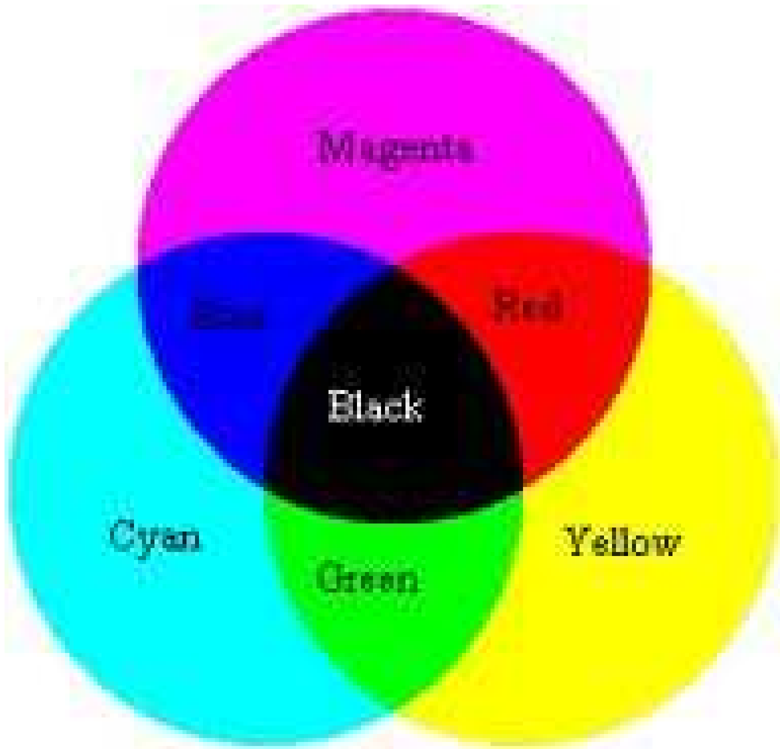
Two main principles for mixing colors:

- *Additive mixing*
- *Subtractive mixing*

Additive mixing

- Pure colors are put close to each other => a mix on the retina of the human eye (cp. RGB)
- Overlapping gives yellow, cyan, magenta and white
- Typical technique used on color displays

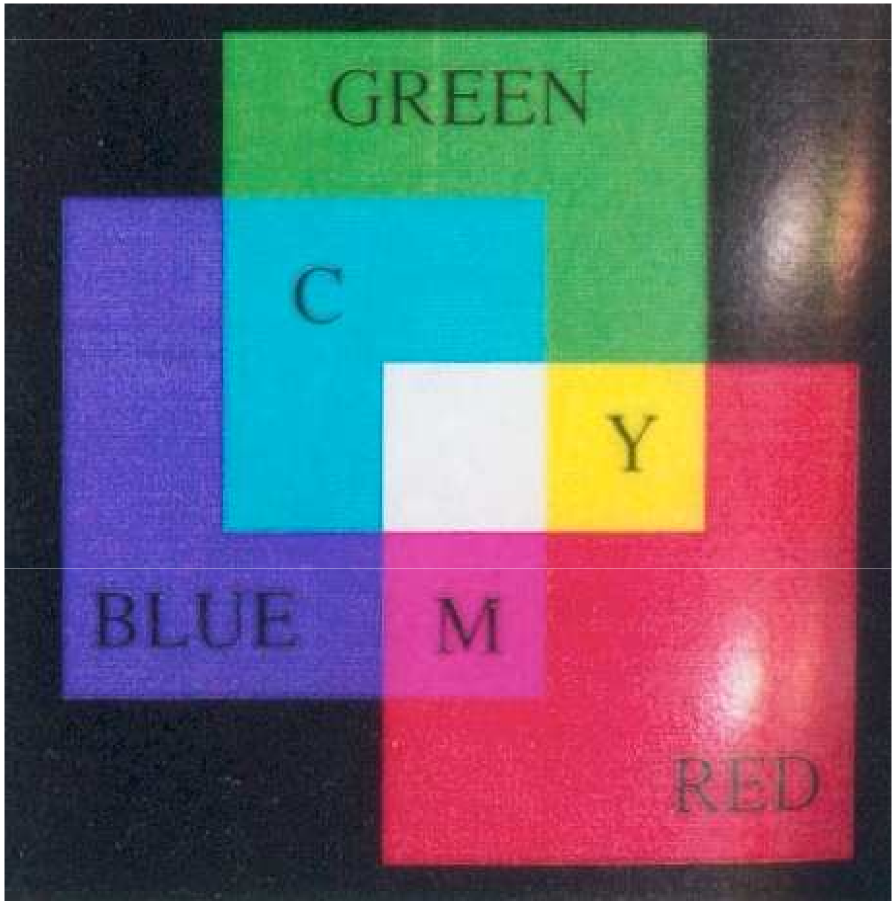


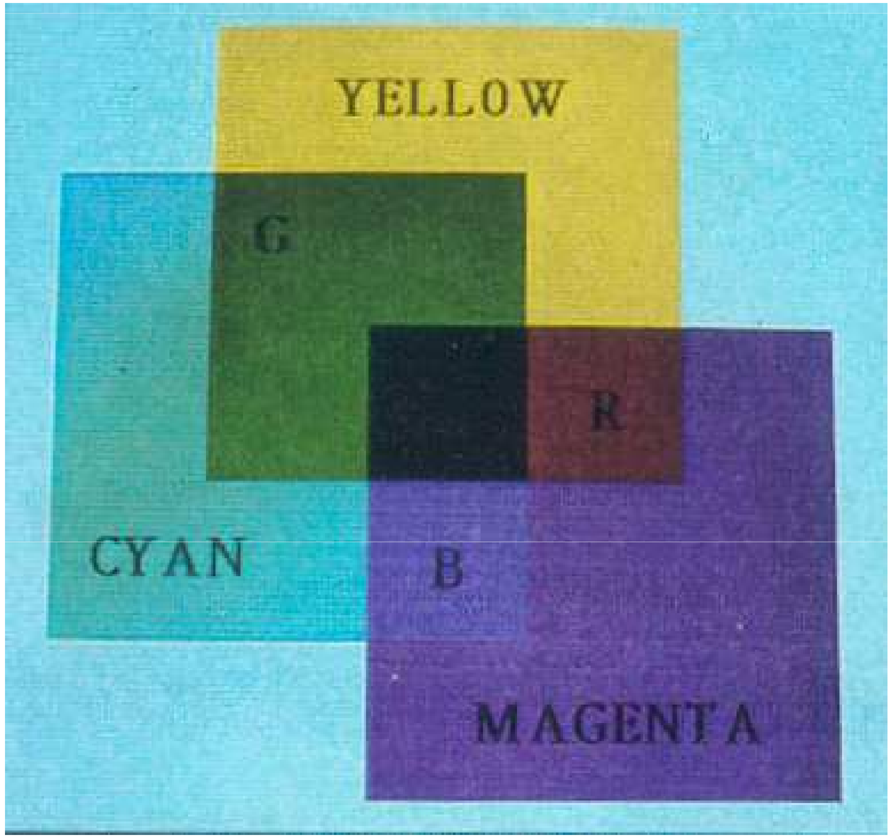


Subtractive mixing

- 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
- Each color in the mixture absorbs its specific part of the incident light and reflects others
- The color the surface displays depends on which colors of the electromagnetic spectrum are reflected by it and made visible.

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

  $\mathbf{C} = X*\mathbf{X} + Y*\mathbf{Y} + Z*\mathbf{Z}$

  XYZ – Vectors in color space XYZ – 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:

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

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

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

Note: X + Y + Z is the total amount of light energy.
Also note that x + y + z = 1

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

- x, y represent chromaticity & Y represent luminance(designed that way)
- For complete description of color, we need x, y & Y.

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

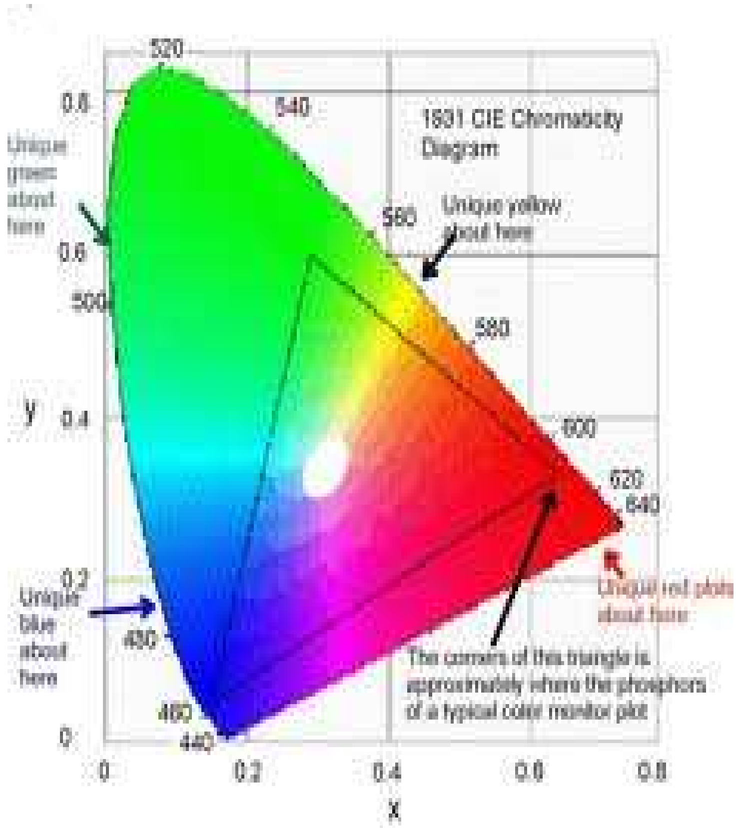
CIE Chromaticity Diagram

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

•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 gamut*s of different set of primaries
  - Identifying *complementary colors*
  - Determining *dominant wavelength* & *purity* of different colors

Dominant Wavelength on CIE Color Diagram

- Gamut refers to the subset of colors which can be accurately represented in a given color space
- 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

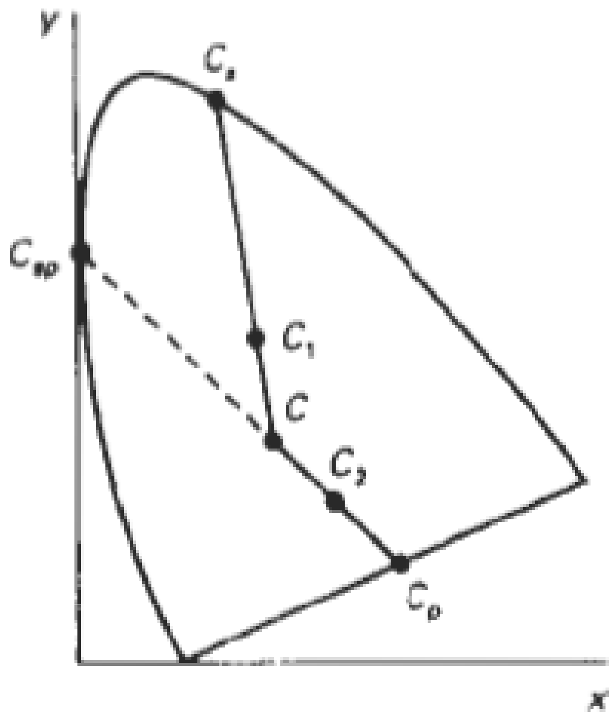
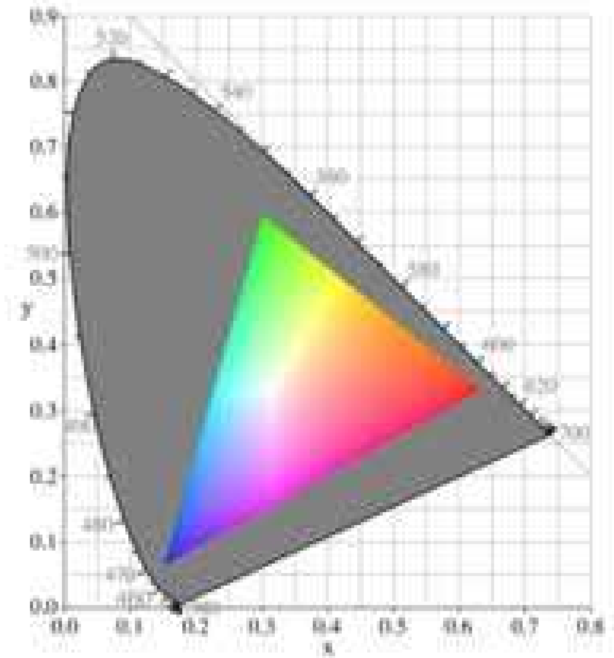
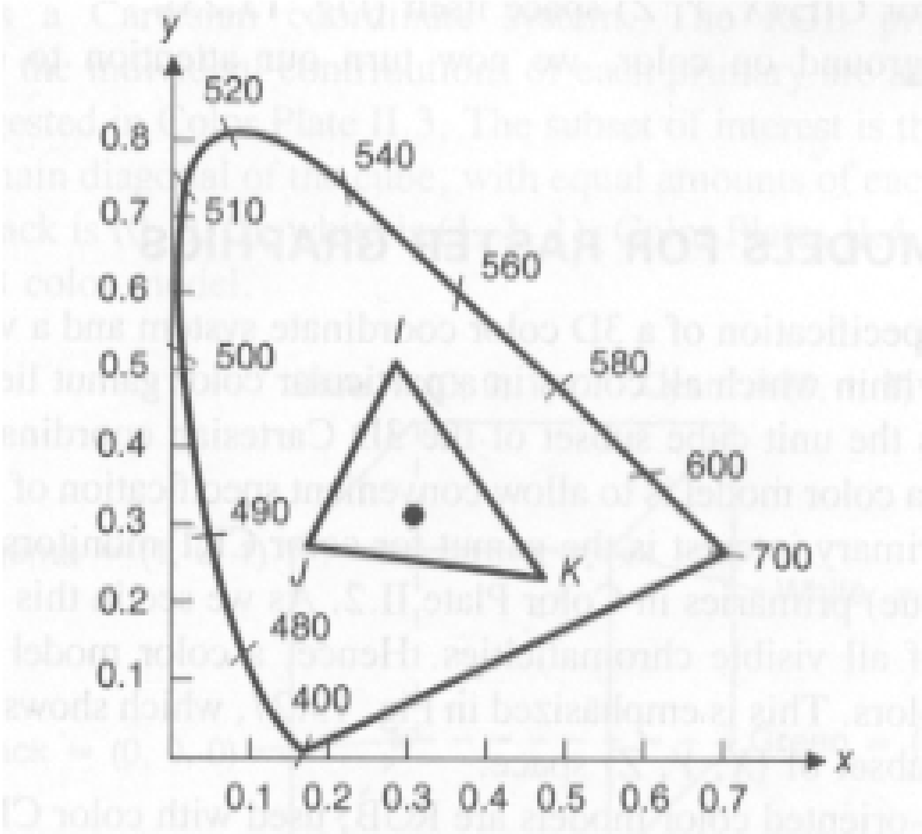


Figure 15-10
Determining dominant wavelength and purity with the chromaticity diagram.

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.





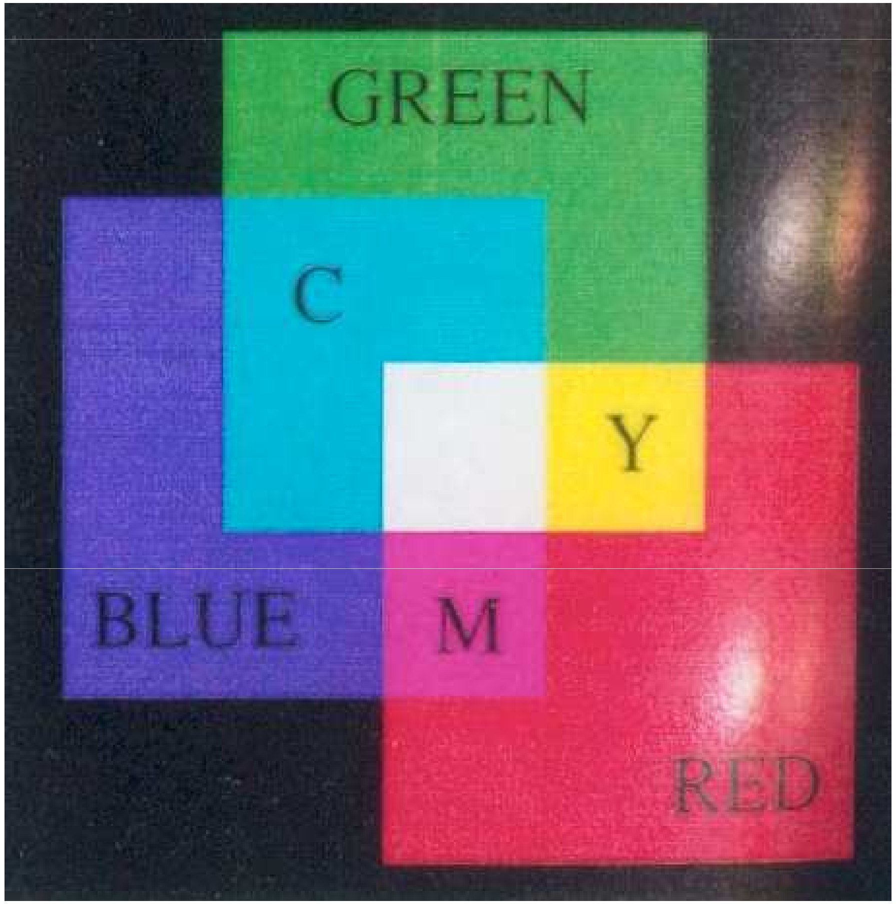
Color Concepts

- **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

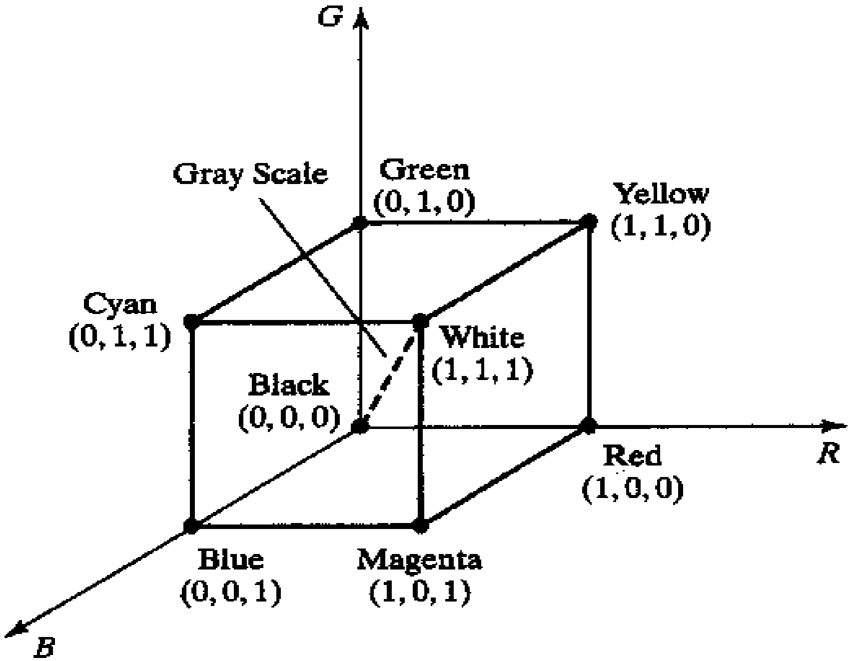
RGB model

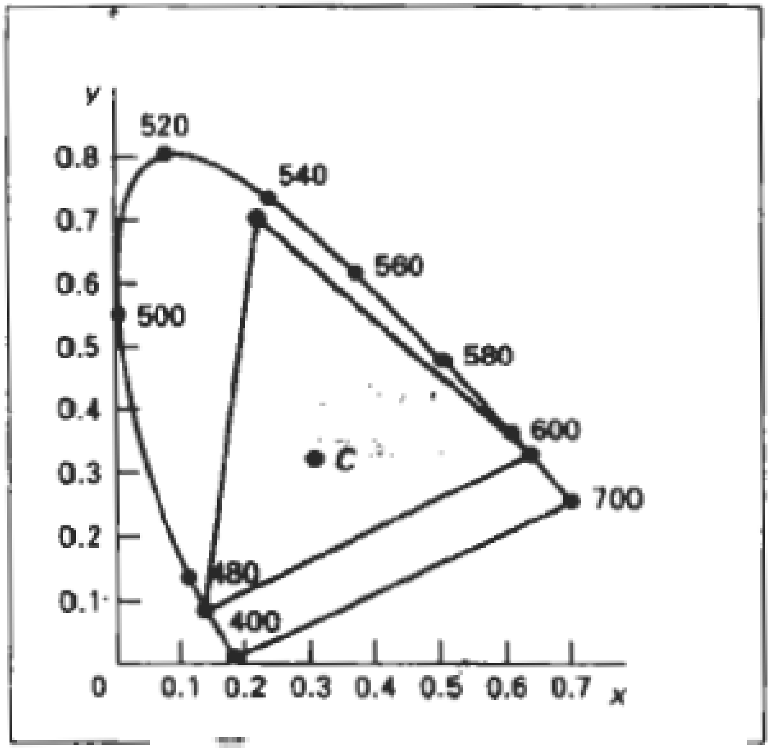
- All colors are generated from the three primaries R,G,B.
- various colors are obtained by changing the amount of each primary
- Additive mixing (r,g,b), $0 \leq r,g,b \leq 1$



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

- The NTSC colour model for forming the composite video signal is the YIQ model.
- An RGB signal can be converted to a television signal using an NTSC encoder.
- Same as XYZ model.
- Y represents the luminance IQ represents the hue and purity.
- I contains orange-cyan hue info Q contains green-magenta hue information.
- Black and white TV contains only Y signal

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

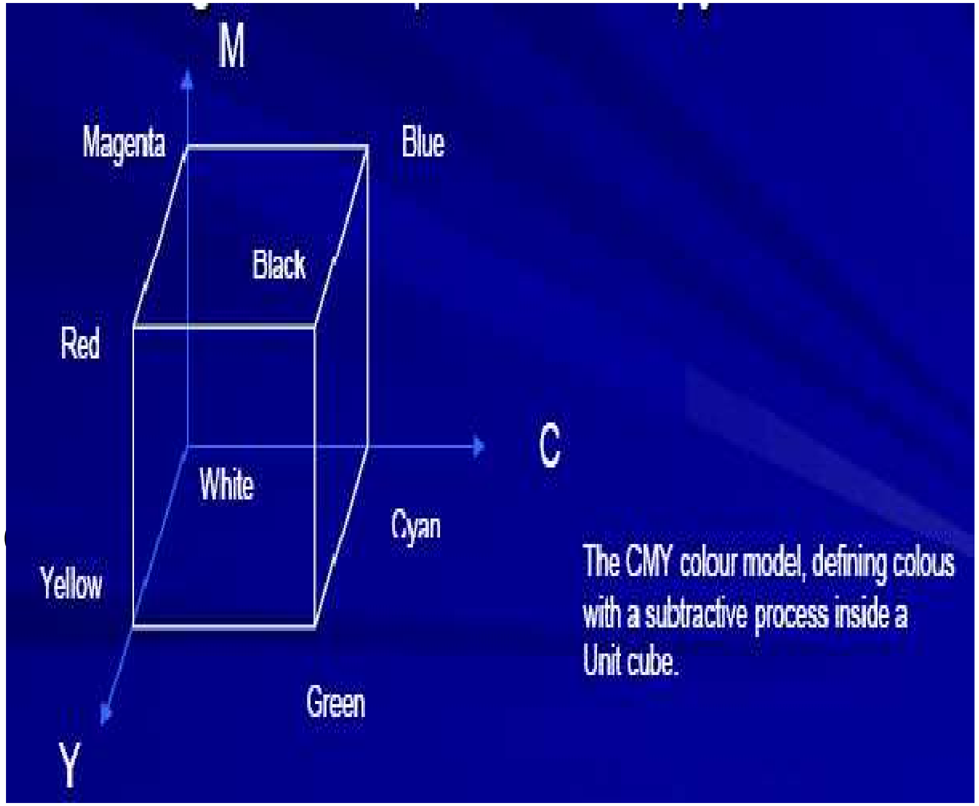
$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1.000 & 0.956 & 0.620 \\ 1.000 & -0.272 & -0.647 \\ 1.000 & -1.108 & 1.705 \end{bmatrix} \cdot \begin{bmatrix} Y \\ I \\ Q \end{bmatrix}$$

CMYK model

- CMYK is primarily a printing color model.
- Cyan, magenta, and yellow are called the subtractive primaries.
- In practice, cyan, magenta, and yellow don’t produce all the colors needed for printing.

CMYK Model

- Cyan, magenta, yellow, and black
- Cyan is white light with red taken out.
  C = G + B = W - R
- Magenta is white light with green taken out.
  M = R + B = W - G
- Yellow is white light with blu taken out.
  Y = R + G = W – B
- 1,1,1 => black
- Orgin=>white



CMYK vs. RGB

- RGB tO CMY conversion:

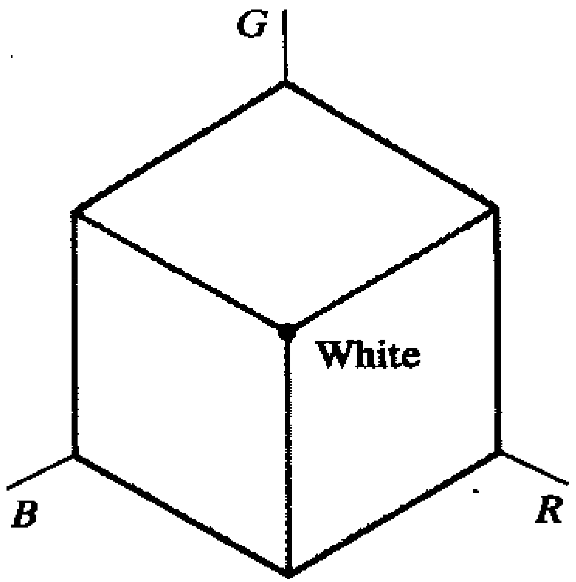
$$\begin{pmatrix} C \\ M \\ Y \end{pmatrix} = \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix} - \begin{pmatrix} R \\ G \\ B \end{pmatrix}.$$

CMY to RGB conversion can be done with matrix transformation

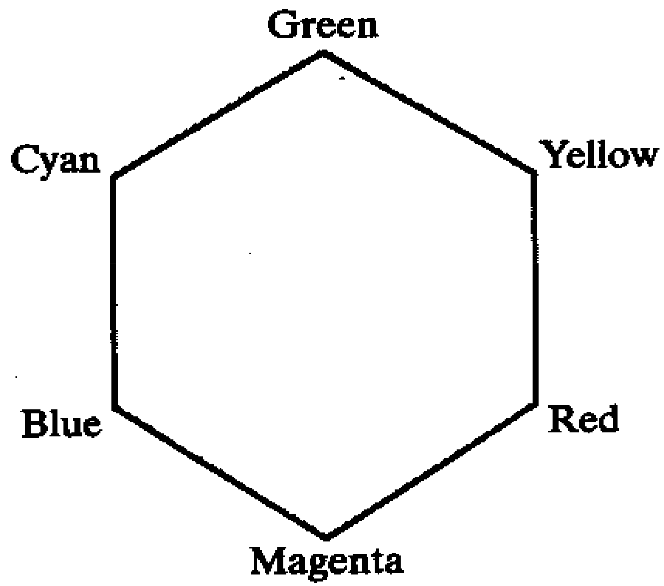
$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} C \\ M \\ Y \end{bmatrix}$$

HSV model

- HSV stands for Hue-Saturation-Value
- described by a hexcone derived from the RGB cube



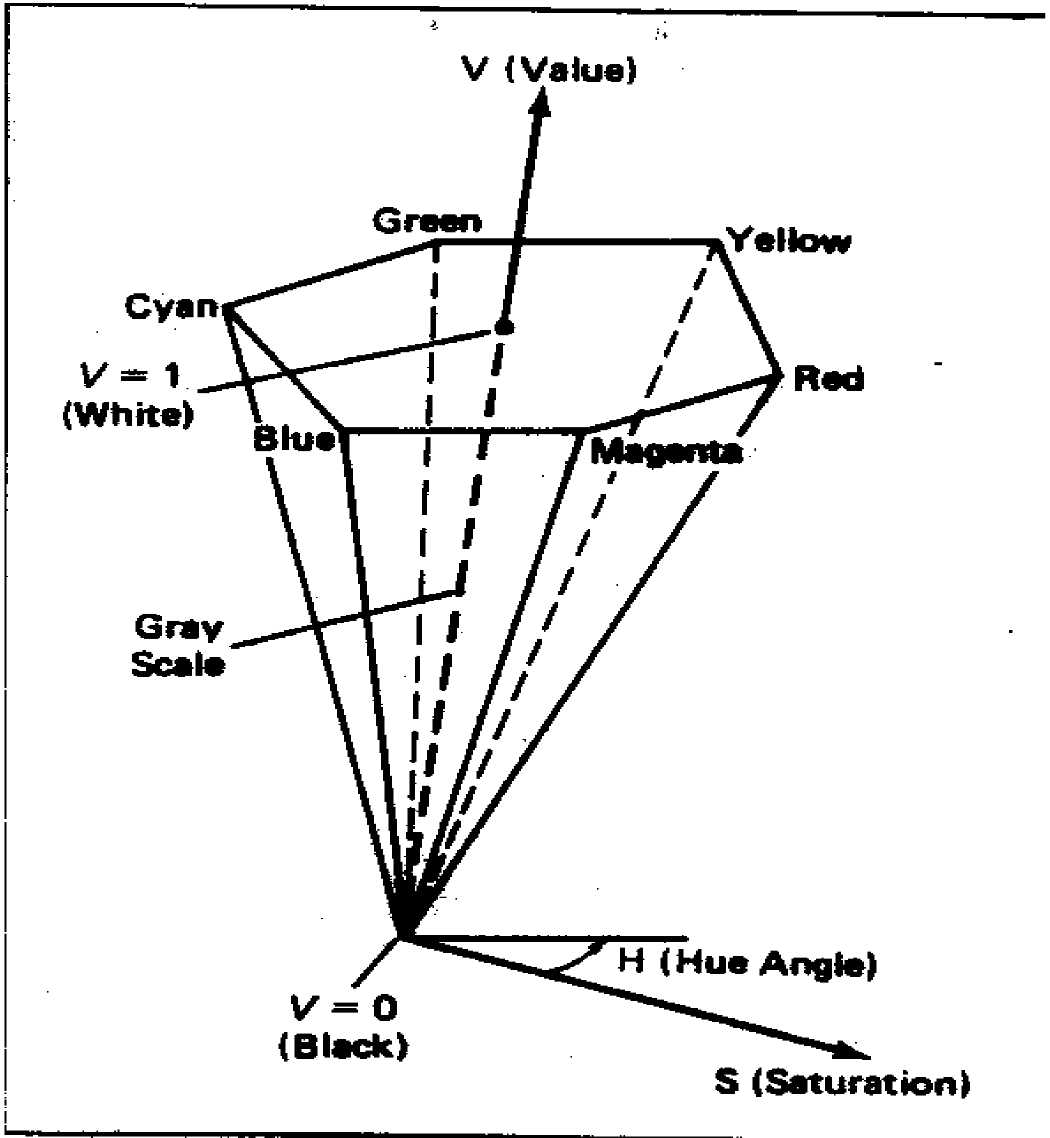
RGB Color Cube
(a)



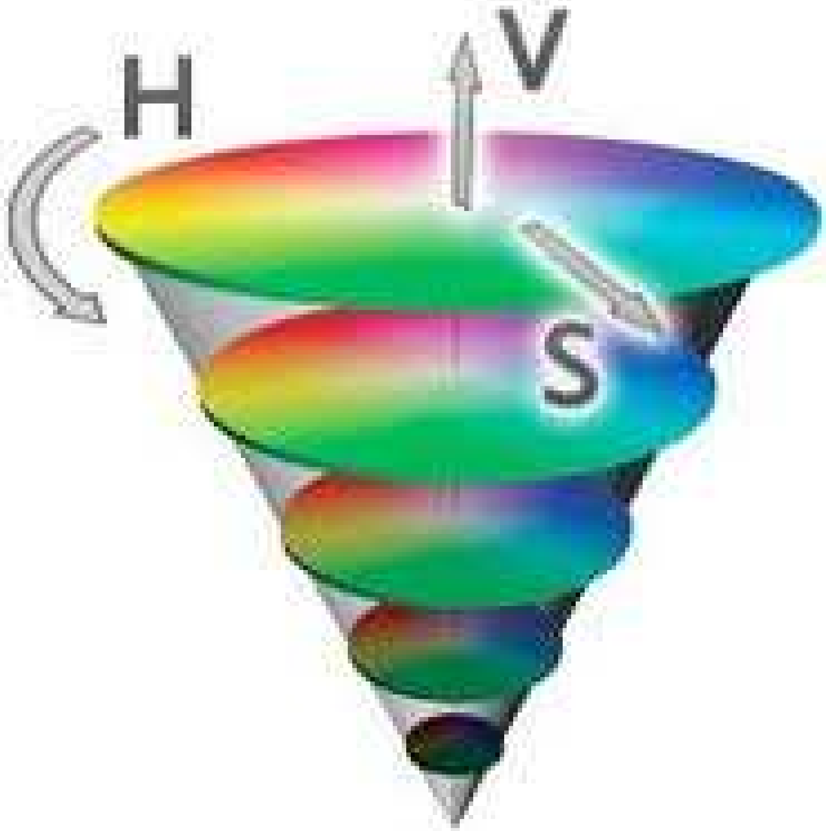
Color Hexagon
(b)

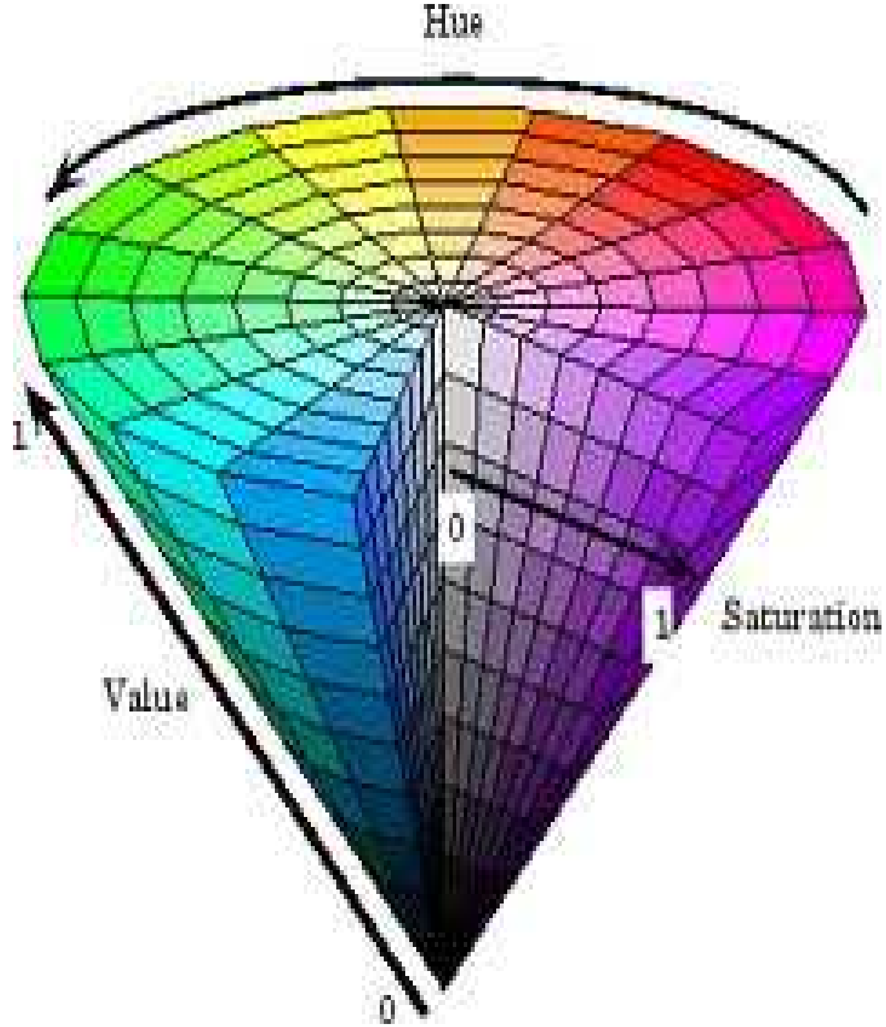
HSV model

- 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 model,cont'd

A human eye can distinguish 128 hues, 130 saturation levels.

For each of these, a number of shades can be selected depending upon the hue selected.

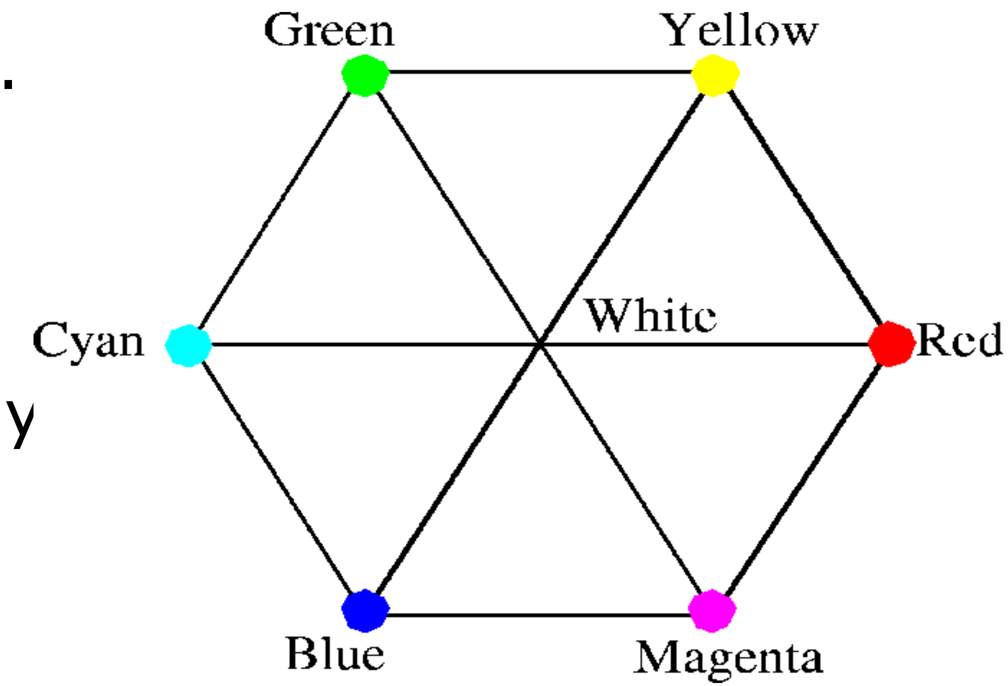
For eg., 23 shades for yellow.

128*130*23 = 382720

H S SH

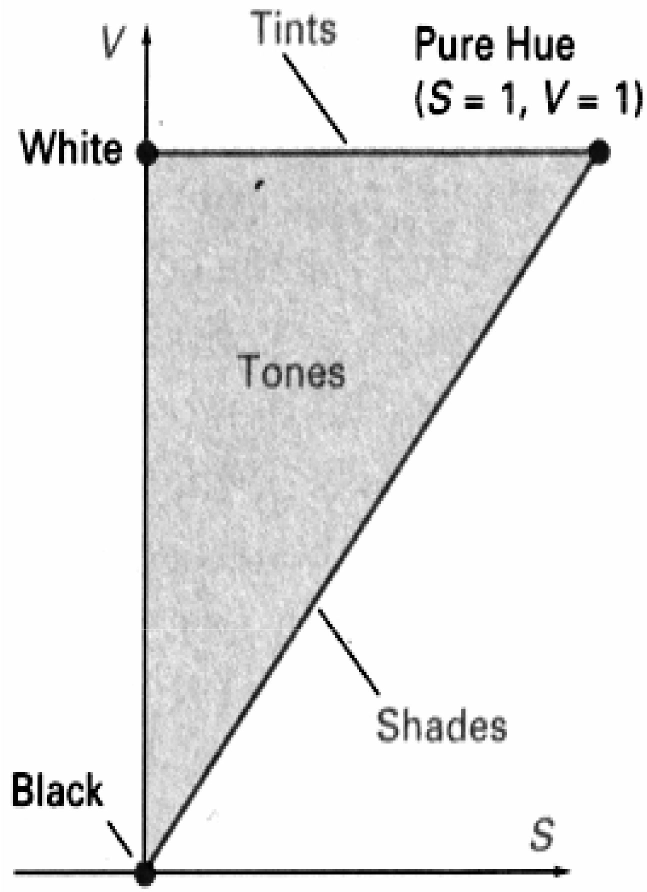
In Computer Graphics, usually

128*8*15 = 16384



HSV Color Definition

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

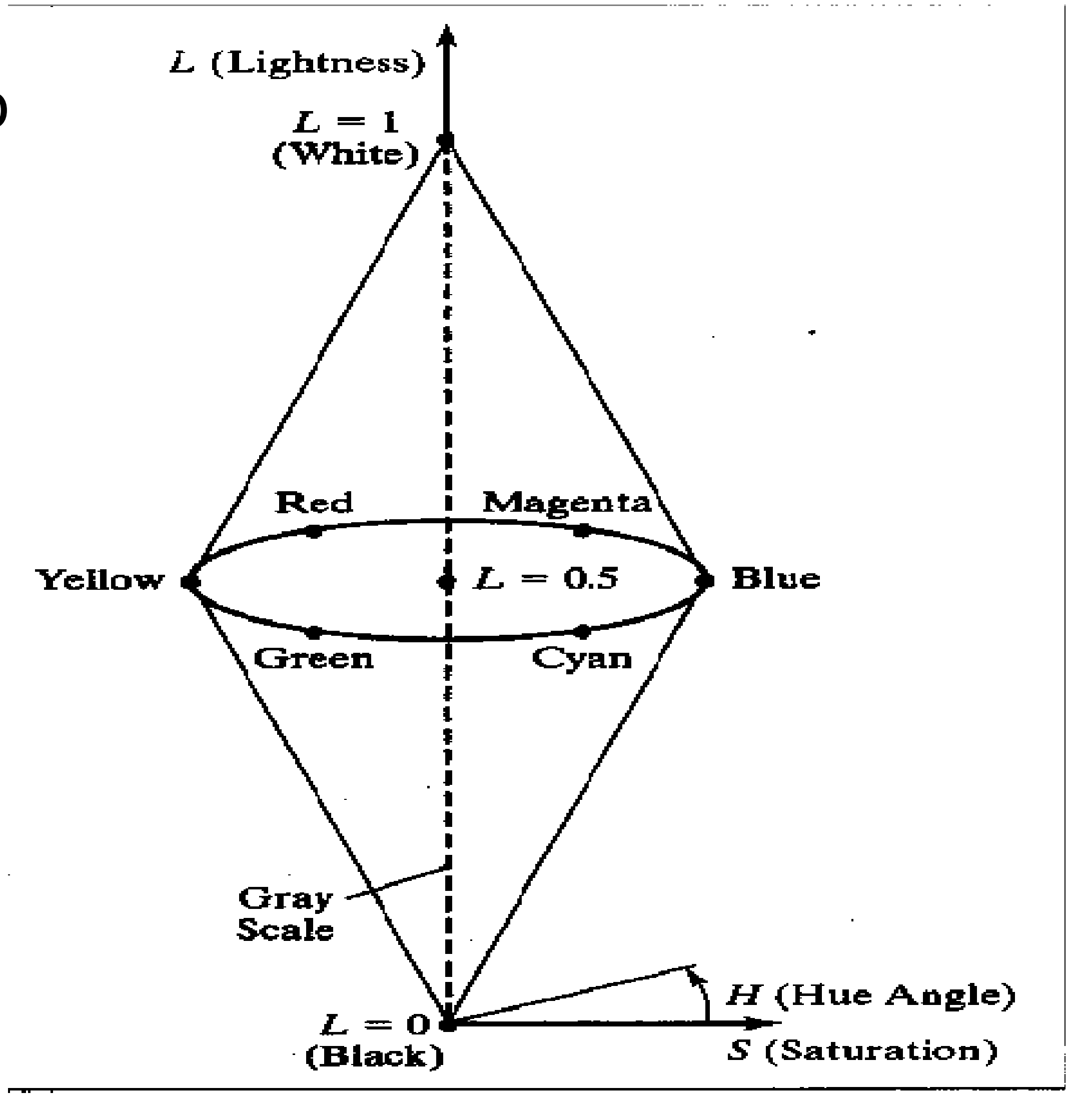


HLS model

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)

- Thank YOU