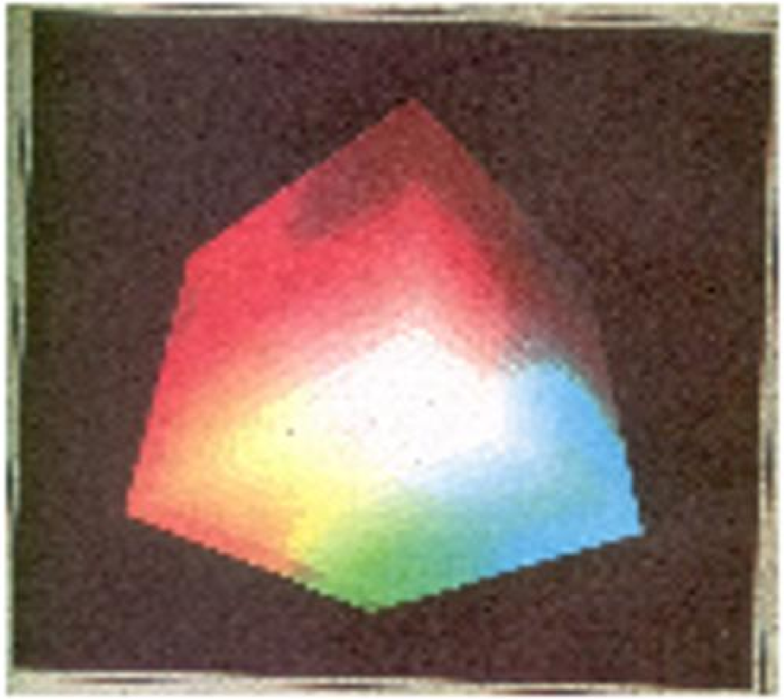
Color Theory and Color Models.



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A **color model** is a method for explaning the properties and behavior of color within some particular context.

Several color models are existing.

Some models are used to describe color output on printers and plotters, and other models provide a more intuitive color-parameter interface for the user.

No single color model can explain all aspects of color, so we make use of different models to help describe the different perceived characteristics of color

PROPERTIES OF LIGHT

- Light or different colors, is a narrow frequency band within the electromagnetic spectrum.
- A few of the other frequency bands within this spectrum is called radio waves, microwaves, infrared waves,and x-rays.

PROPERTIES OF LIGHT

- **Each frequency value within the visible band corresponds to a distinct color.**
- **At the low-frequency end is a red color ($4.3 * 10^{14}$ Hz)and highest frequency is a violet color ($7.5 * 10^{14}$ Hz).**
- **Figure below shows the approximate frequency ranges for some of the electromagnetic bands.**

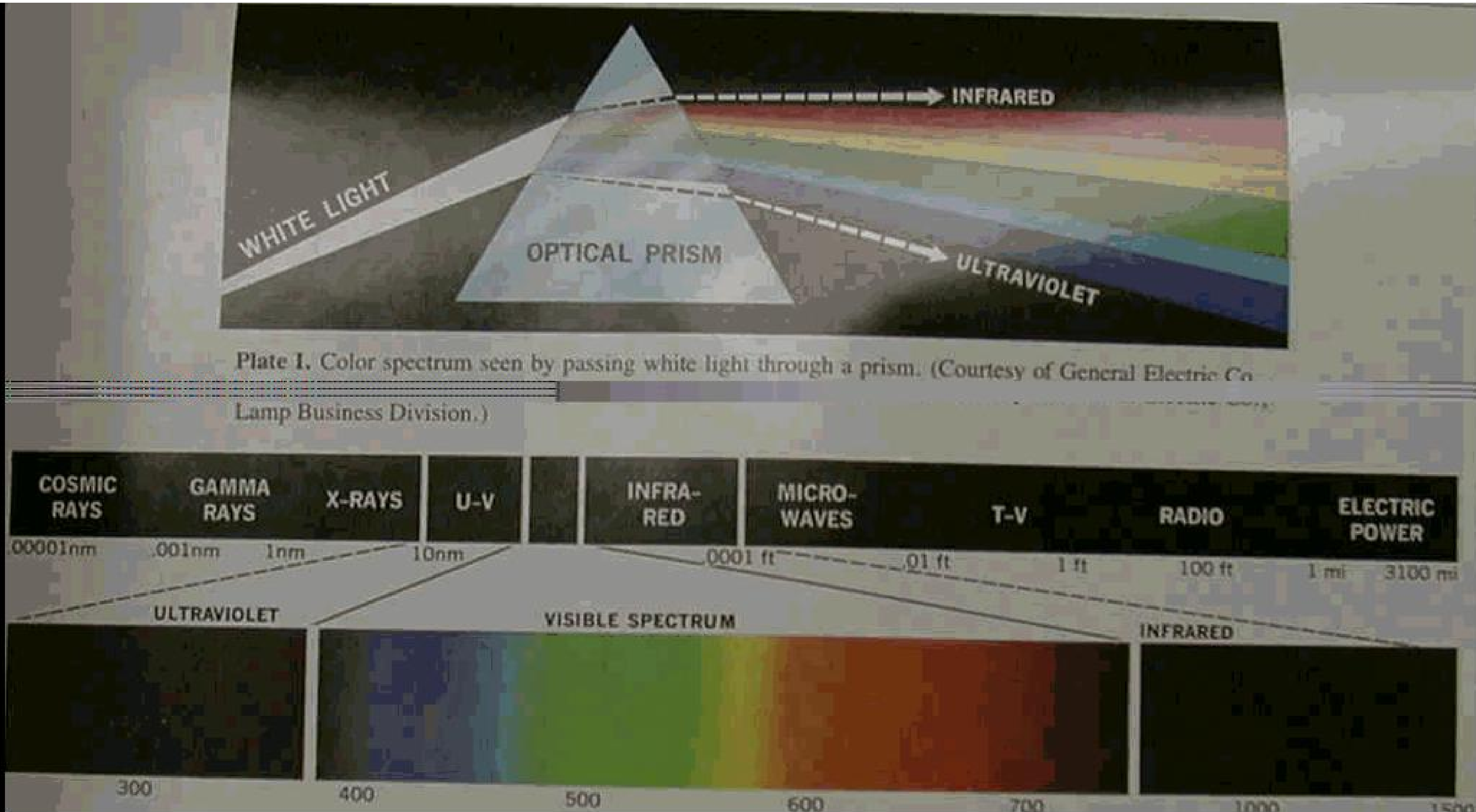


Figure shows the approximate frequency ranges of the electromagnetic bands

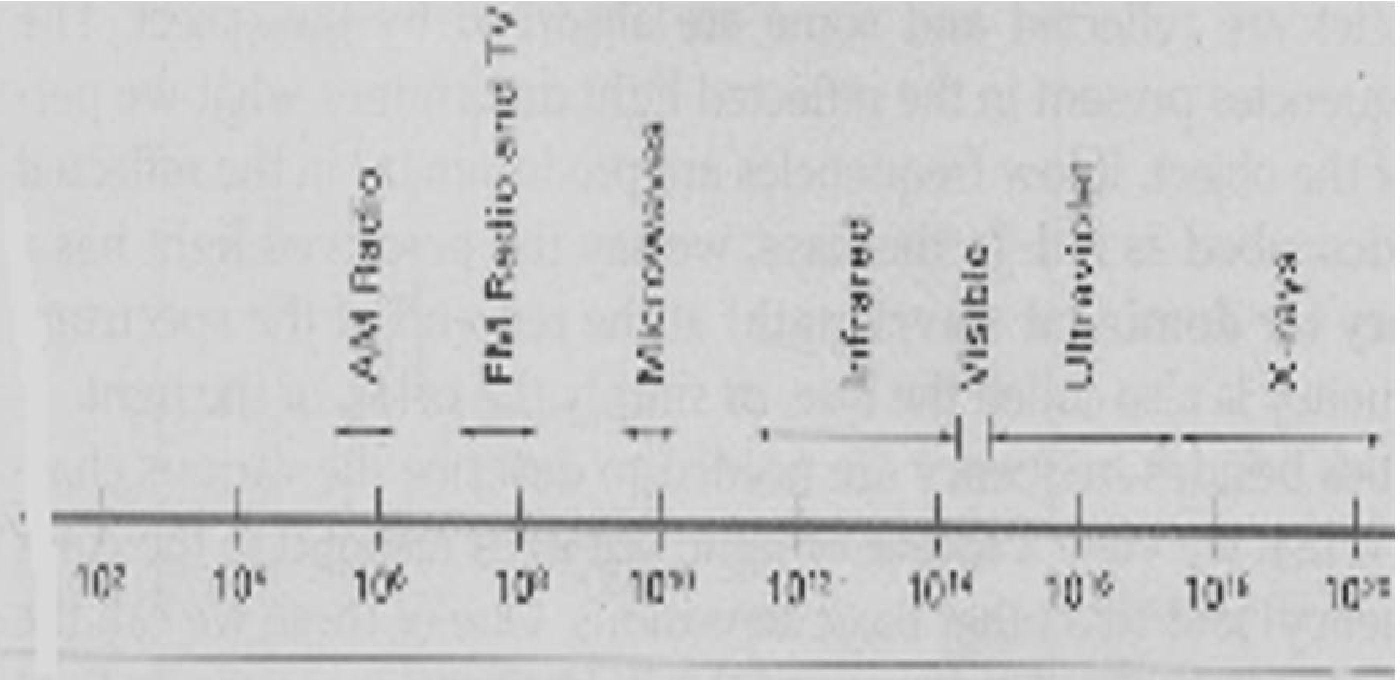


Figure 15-1
Electromagnetic spectrum.

Since light is an electromagnetic wave, one can describe the various colors in terms of either the frequency f or the wavelength λ of the wave..

The wavelength and frequency of the monochrometic wave are inversely proportional to each other, with the propotionality constant as the speed of light c: $c=\lambda f$

Figure below illustrates the oscillations present in a monochromatic electromegnetic wave, polarized so that the electric oscillations are in one plane.

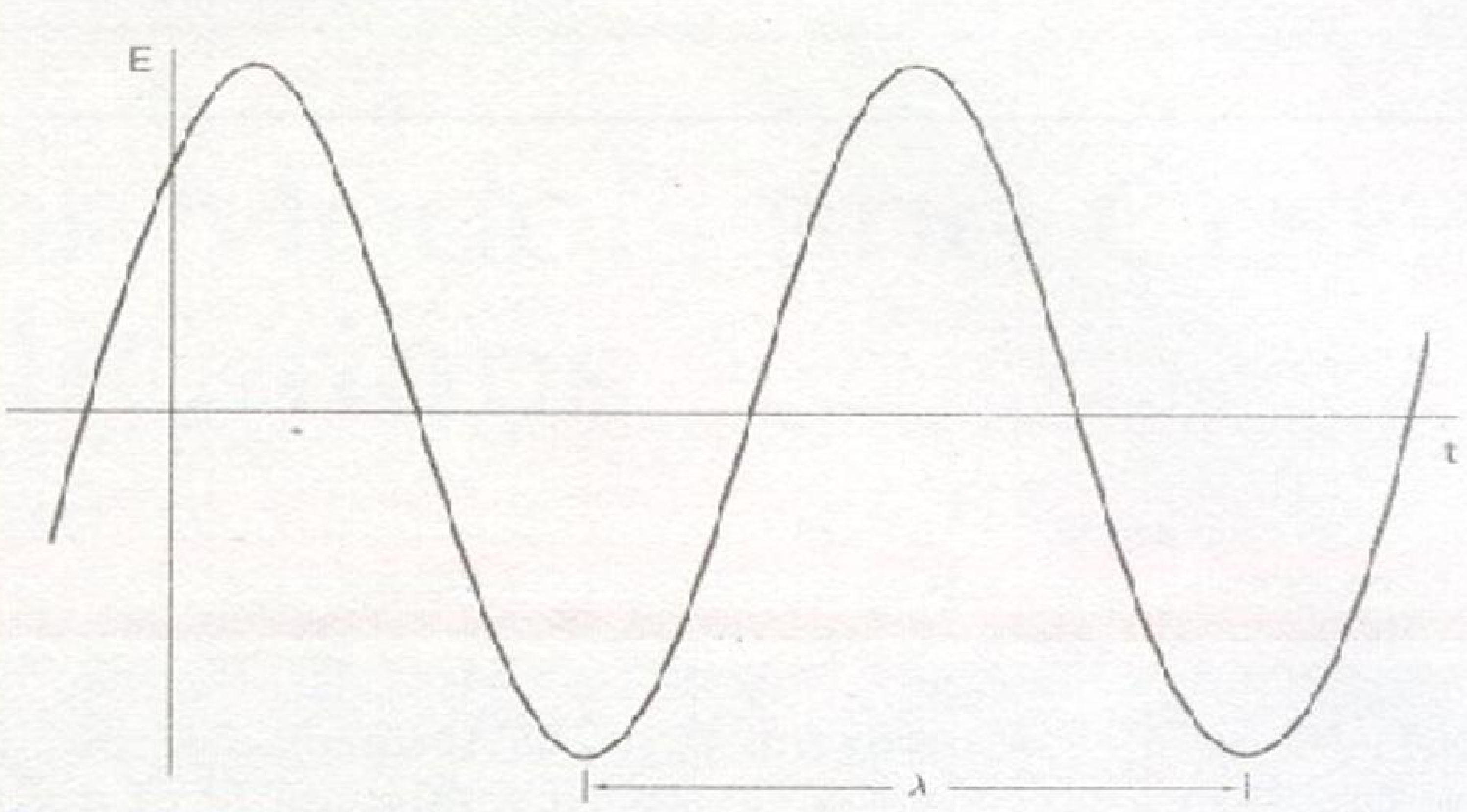


Figure 15-2

Time variations for one electric frequency component of a plane polarized electromagnetic wave.

Frequency is constant for all materials, but the speed of the light and wavelength are material-dependent. In vacuum c= 3 * 10**10 cm/sec. Light wavelengths are very small so length units for designating spectral colors are usually angstroms or nanometers (mill micron).

A light source such as the sun or a light of bulb emits all frequencies within the visible range to produce white light. When light is incident upon an object, some frequencies are reflected and some are absorbed by the object. The combination of frequencies present in the reflected light determines what we perceive as the color of the object.

If low frequencies are predominant in the reflected light, the obj. is described as red. We can say that the perceived light has a dominant frequency (wavelength) at the red end of the spectrum.

The dominant frequency is called the ***hue*** or simply the color, of the light.

Other properties besides frequency are also needed to describe characteristic of light. When we view a source light, our eyes respond to the color (or dominant frequency) and other two basic sensations.

They are ***brightness*** and ***saturation or purity.***

Brightness is the perceived intensity of the light. Intensity is the radiant energy emitted per unit time, per unit solid angle and per unit projected area of the source. Radiant energy is related to the ***luminance*** of the source.

Purity or saturation describes how washed out or how "pure" the color of the light appears. Pastels and pale colors are described as less pure.

These three char., *dominant frequency, brightness and purity* are commonly used to describe the different properties perceive in a source of light.

The term ***Chromaticity*** is used to refer collectively the two properties describing color characteristics : Purity and dominant frequency.

Color models that are used to describe combinations of light in terms of dominant freq. (hue) use three colors to obtain a reasonably wide range of colors, called **color gamut** for that model. The colors used by this model is known a s **primary colors.**

STANDARD PRIMARIES AND THE CHROMATICITY DIAGRAM

- Since no finite set of color light sources can be combined to display all possible colors, three standard primaries were defined in 1931 referred to as the CIE(Commission International del'Eclairage).
- The three standard primaries are imaginary colors. They are defined mathematically with positive color-matching functions as shown in the below figure.

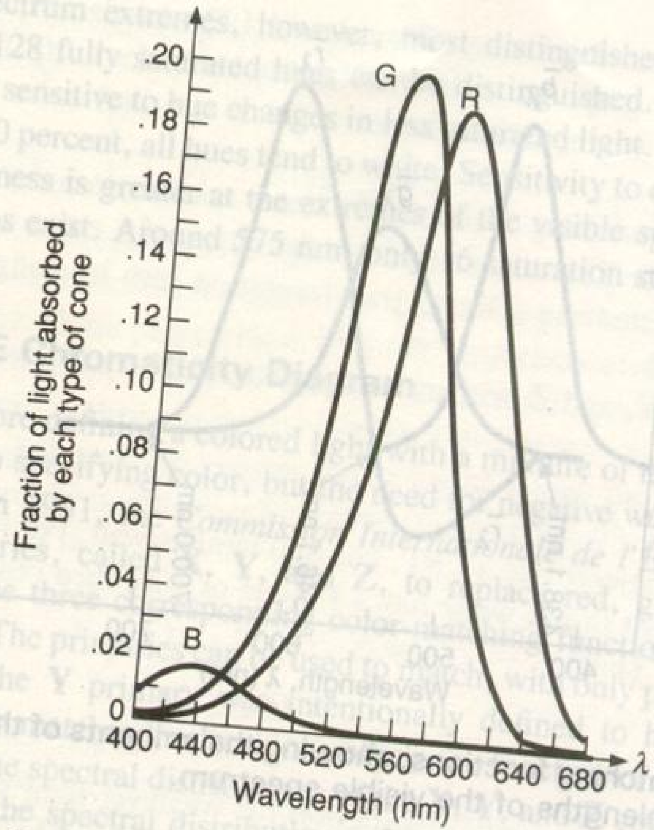


Fig. 13.18 Spectral-response functions of each of the three types of cones on the human retina.

Fig. 13.20

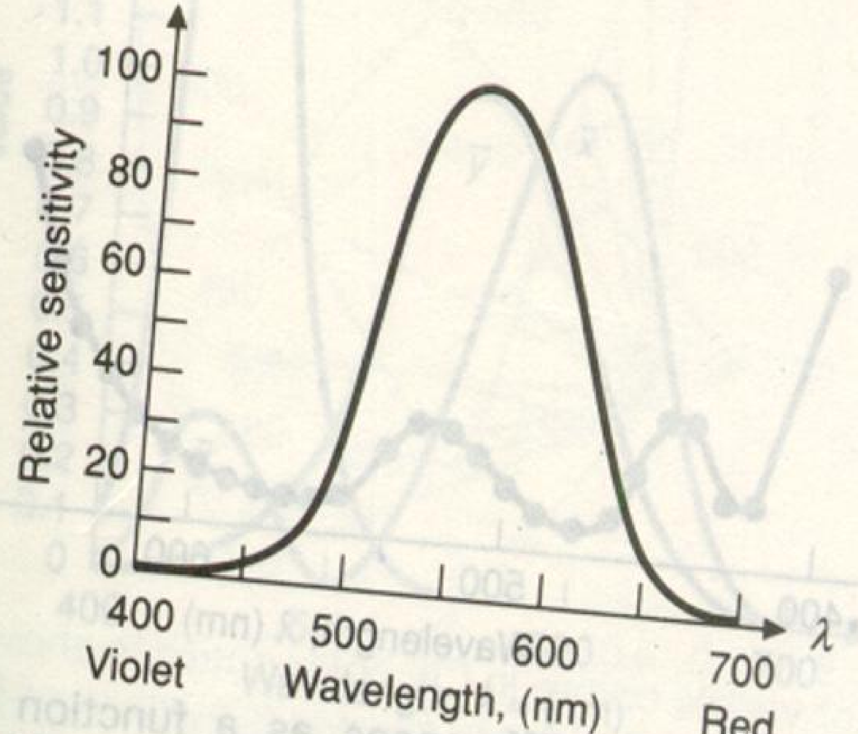


Fig. 13.19 Luminous-efficiency function for the human eye.

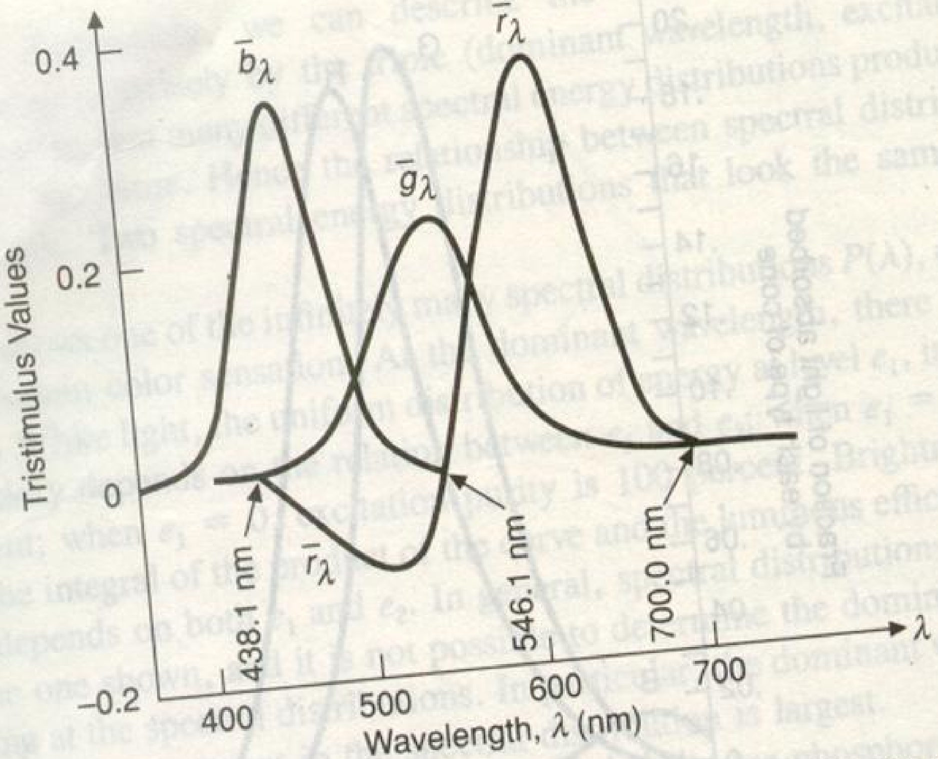
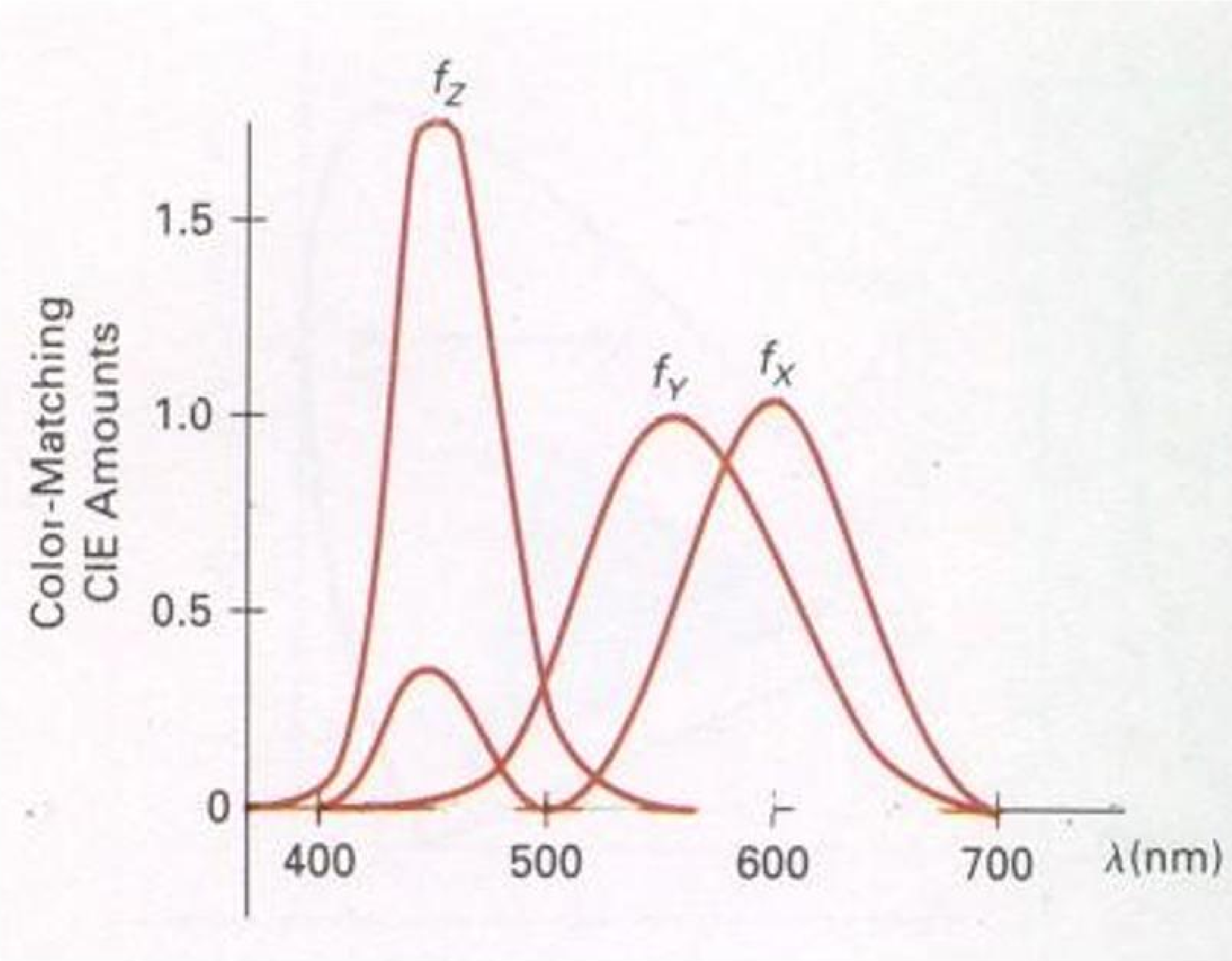


Fig. 13.20 Color-matching functions, showing the amounts of three primaries needed to match all the wavelengths of the visible spectrum.

colors can be matched by positive



f_Z
f_Y
f_X
Color-Matching
CIE Amounts
1.5
1.0
0.5
0
400
500
600
700
λ(nm)

XYZ COLOR MODEL

- The set of CIE primaries is generally referred to as the XYZ color model where X,Y,Z represent vectors in a three-dimensional, additive color space. Any color $c\lambda$ is expressed as,
- $c\lambda = xX + yY + zZ$
- Where x,y,z are designate the amounts of the standard primaries needed.
- Normalized amount are thus calculated as ,

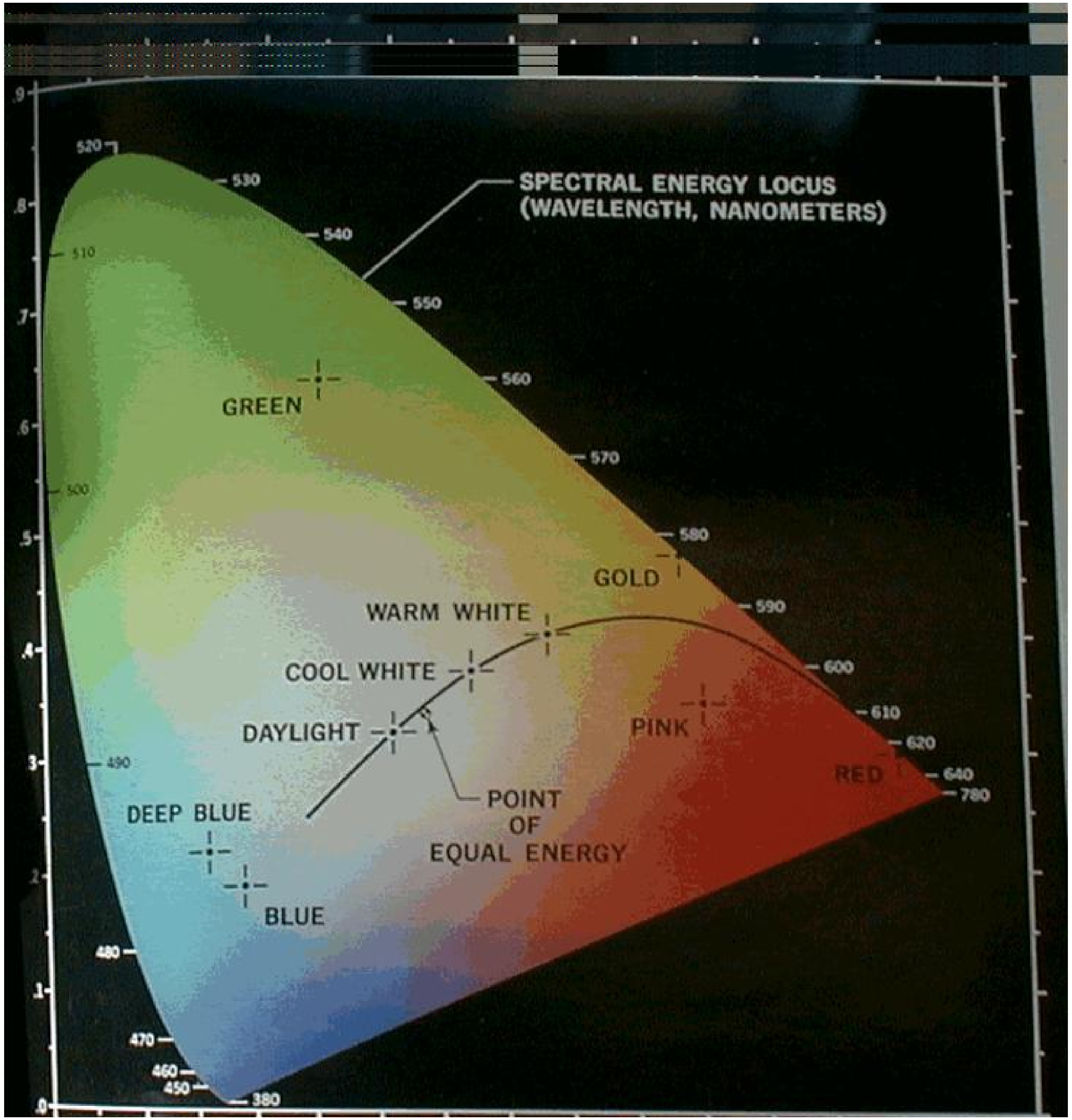
Where $x+y+z = 1$.

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

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

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

obviously, **x + y + z = 1**


SPECTRAL ENERGY LOCUS
(WAVELENGTH, NANOMETERS)
520
530
540
550
560
570
580
590
600
610
620
640
780
510
500
490
480
470
460
450
380
GREEN
GOLD
WARM WHITE
COOL WHITE
DAYLIGHT
PINK
RED
POINT
OF
EQUAL ENERGY
DEEP BLUE
BLUE
.9
.8
.7
.6
.5
.4
.3
.2
.1
.0

CIE CHROMATICITY DIAGRAM

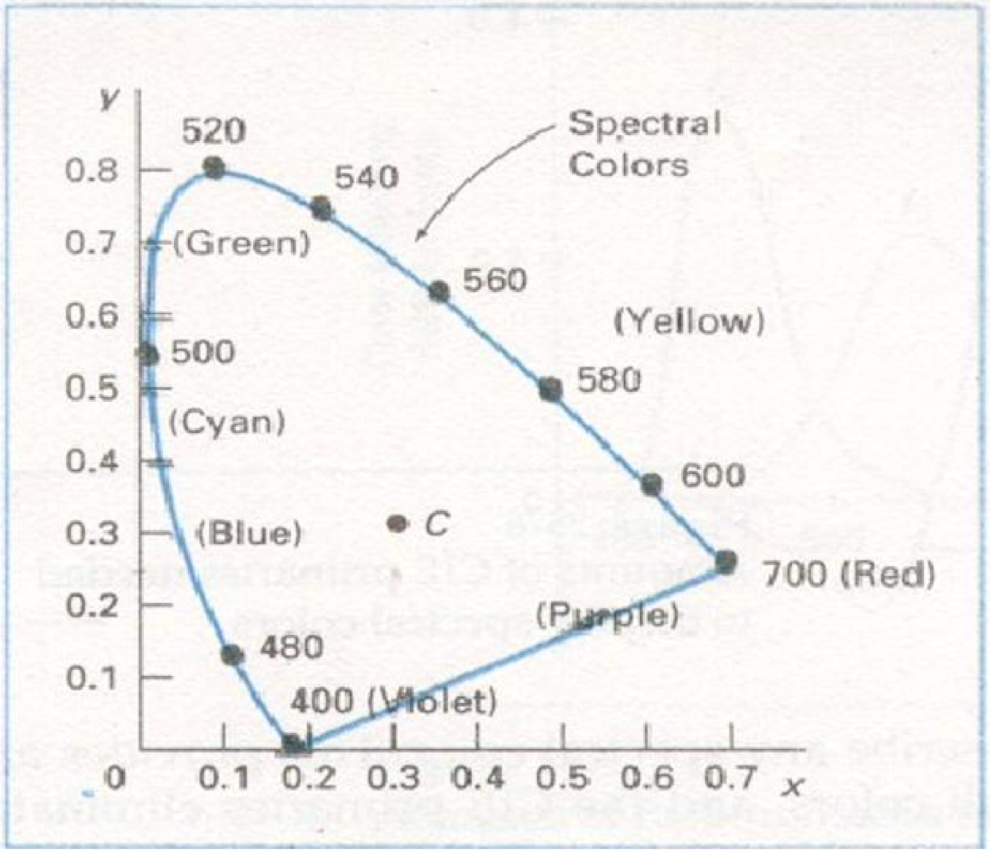


Figure 15-7
CIE chromaticity diagr
color positions along th
labeled in wavelength

This curve is called the CIE chromaticity diagram. Points along

the curve are the 'pure' colors in the electromagnetic spectrum, labeled according to wavelength in nanometers from red end to the violet end of the spectrum. Point c in the diagram corresponds to the white-light position.

How Colors Are Represented

- Color systems can be separated into two categories: ***additive*** color systems and ***subtractive*** color systems.
- Colors in **additive** systems are created by adding colors to black to create new colors.
- The more color that is added, the more the resulting color tends towards white.

How Colors Are Represented

- The presence of all the primary colors in sufficient amounts creates pure white, while the absence of all the primary colors creates pure black.
- Additive color environments are self-luminous.
- Color on monitors, for instance, is additive.

How Colors Are Represented

- Color **subtraction** works in the opposite way.
- Conceptually, primary colors are subtracted from white to create new colors.
- The more color that is subtracted, the more the resulting color tends towards black.
- Thus, the presence of all the primary colors theoretically creates pure black, while the absence of all primary colors theoretically creates pure white.

How Colors Are Represented

- Another way of looking at this process is that black is the total absorption of all light by color pigments.
- Subtractive environments are reflective in nature, and color is conveyed to us by reflecting light from an external source.
- Any color image reproduced on paper is an example of the use of a subtractive color system.

A Word About Color Spaces

- Colors are defined by specifying several, usually three, values.
- These values specify the amount of each of a set of fundamental colors, sometimes called *color channels*, which are mixed to produce composite colors.
- A *composite color* is then specified as an ordered set of values.

Color Models

- A color model is a method for explaining the properties and behavior of color within some particular context.
- Several color models are available. Some models are used to describe color output on printers and plotters, and other models provide a more intuitive color parameter interface for the user.
- No single color model can explain all aspects of color, so we make use of different models to help describe the different perceived characteristics of color

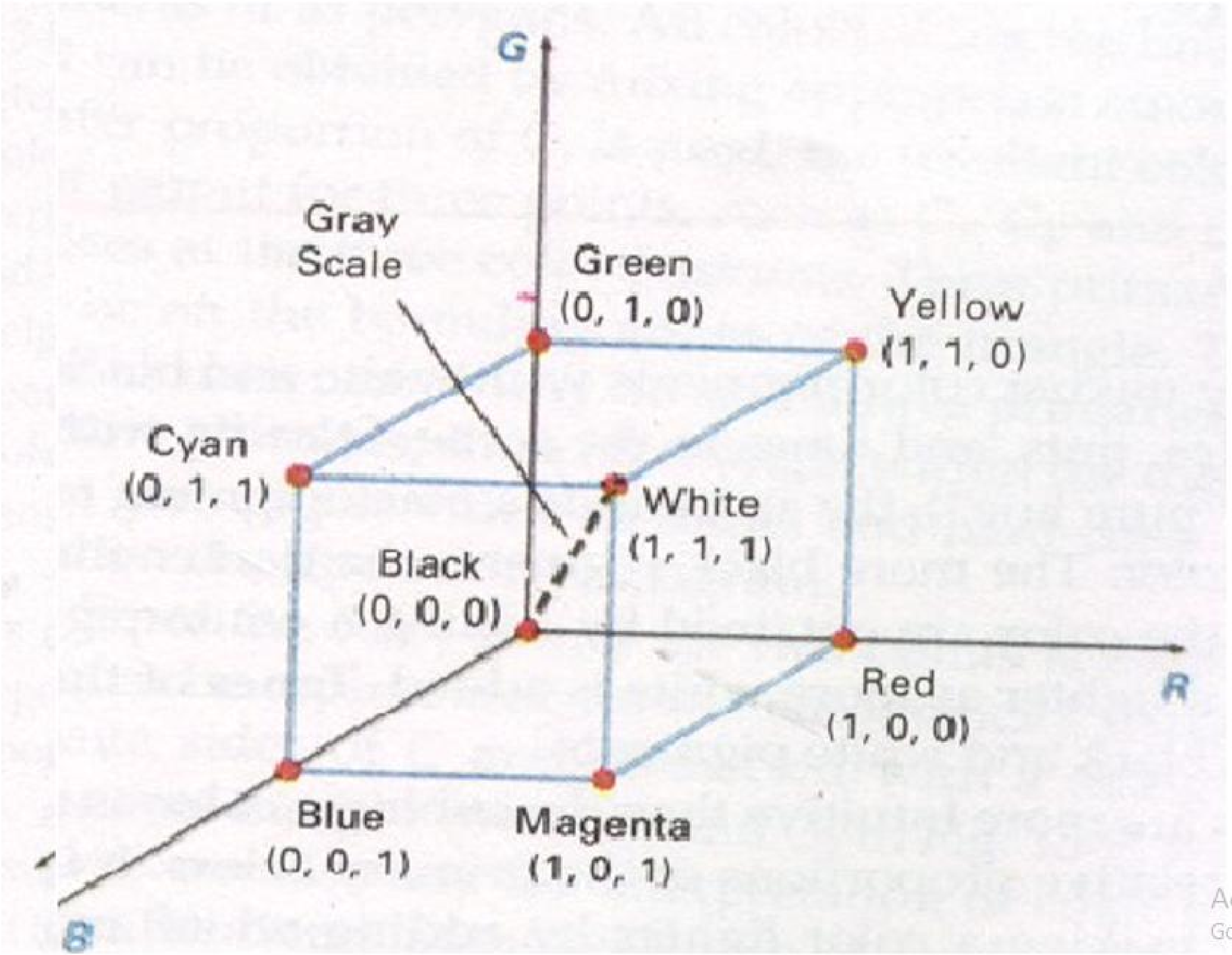
RGB COLOR MODEL

- Based on the tristimulus theory of vision, our eyes perceive color through the stimulation of the three visual pigments in the cones of the retina. These visual pigments have a peak sensitivity at wavelengths of about 630 nm (red), 530 nm(green) and 450 nm(blue). By comparing intensities in a light source, we perceive the color of the light.

This theory of vision is the basis for displaying color output on a video moniter using the three color primaries red,green and blue referred to as the RGB color model.

RGB COLOR MODEL

- We can represent this model with the unit cube defined on R,G,B axes, as shown in below figure.
- The origin represents black, and the vertex with coordinate(1,1,1) is white. Vertices of the cube on the axes represent the primary colors, and the remaining vertices represent the complementary color for each of the primary colors.



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Thus the color $c\lambda$ expressed in RGB components as,

$$c\,\lambda = rR + gG + bB$$

The magenta vertex is obtained by adding red and blue to produce the triple(1,0,1) and white at (1,1,1) is the sum of the red,green and blue vertices. Shades of gray are represented along the main diagonal of the cube from the origin black to white vertex. Each point along this diagonal has an equal contribution from each primary color, so that a gray shade halfway between black and white are represented as (0.5,0.5,0.5).

YIQ Color model

- The NTSC color system , is used in television in the US, uses YIQ color model.
- Data consists of three components luminance (Y), hue (I) and saturation(Q).
- The luminance component represents gray-scale information and other two carry another color information of a TV signal.

YIQ COLOR MODEL

In the YIQ color model,parameter Y is the same as in the XYZ model.Luminance(brightness) information is contained in the Y parameter, while the chromaticity information is incorporated into I and Q parameters.

Y contains the luminance information,black and white television moniters use only the Y signal.

I contains the orange-cyan hue information that provides the flesh-tone shading,and occupies a bandwidth of approximately 1.5 MHZ.

Q contains green-magenta hue information in a bandwidth of about 0.6 MHZ.

RGB TO NTSC

$$\begin{matrix} Y \\ I \\ Q \end{matrix} = \begin{matrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.274 & -0.322 \\ 0.211 & -0.523 & 0.312 \end{matrix} \quad \begin{matrix} R \\ G \\ B \end{matrix}$$

NTSC TO RGB

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1.000 & 0.956 & 0.621 \\ 1.000 & -0.272 & -0.647 \\ 1.000 & -1.106 & 1.703 \end{bmatrix} \begin{bmatrix} Y \\ I \\ Q \end{bmatrix}$$

YCbCr COLOR MODEL

- It is used in digital video. In this format, luminance information is represented by a single component Y, and color information is stored as two color difference components, Cb and Cr.
- Cb = diff. Between the blue component and a reference value and
- Cr = difference between red component and a reference value.

RGB TO YCbCr

$$\begin{matrix} Y \\ C_b \\ C_r \end{matrix} \begin{matrix} = \\ = \\ = \end{matrix} \begin{matrix} 16 \\ 128 \\ 128 \end{matrix} + \begin{matrix} 65.481 & 128.553 & 24.966 \\ -37.797 & -74.203 & 112.000 \\ 112.000 & -93.786 & -18.214 \end{matrix} \quad \begin{matrix} R \\ G \\ B \end{matrix}$$

YCbCr TO RGB

$R =$ Y

$G =$ C_b

$B =$ C_r

CMY COLOR MODEL

- A color model defined with the primary colors cyan ,magenta and yellow is useful for describing color output to hard-copy devices. Unlike video moniters,which produces a color pattern by combining light from the screen phosphors, hard-copy devices such as plotters produce a color picture by coating a paper with color pigments.
- A unit of cube representing for the CMY model is as shown in the figure.

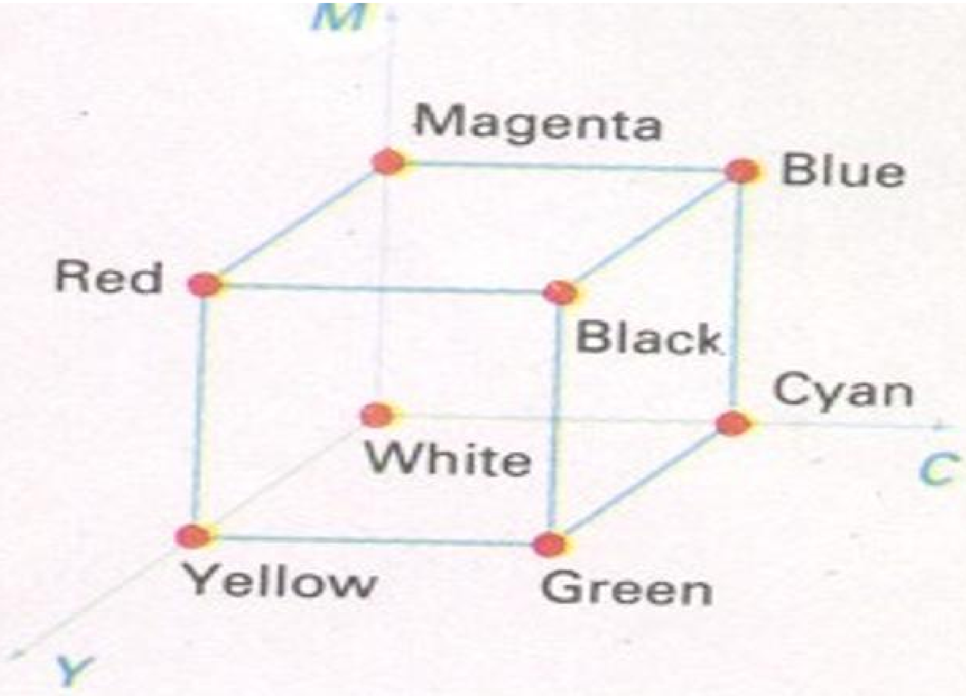


Figure 15-14
The CMY color model, defining colors with a subtractive process inside a unit cube.

In the CMY model point(1,1,1) represents black,because all components of the incident light are subtracted. The origin represents white light. Equal amounts of each of primary colors produce grays, along the main diagonal of the cube. A combination of cyan and magenta ink produces blue light, because the red and green components of the incident light are absorbed. Other color combinations are obtained by a similar subtractive process. The printing process often used with the CMY model generates a color point with a collection of four ink dots, somewhat as and RGB moniter uses a collection of 3 phosphor dots.

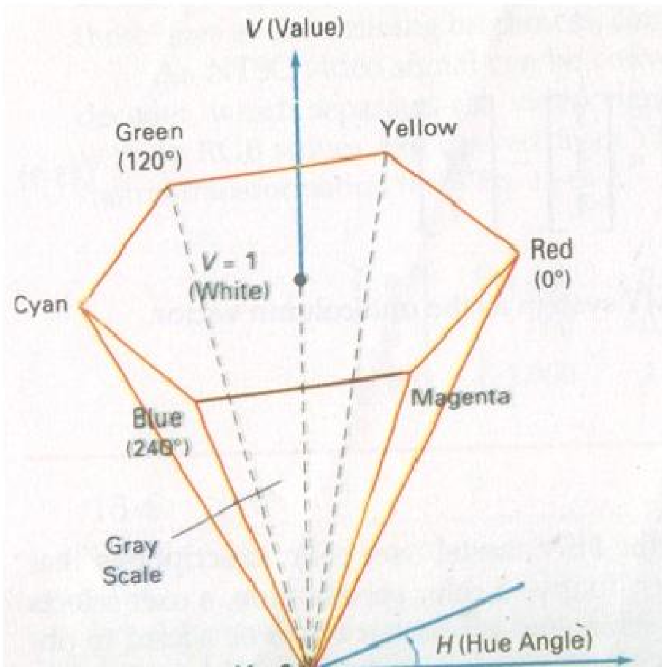
INTUTIVE COLOR CONCEPTS

- An artist creates a color painting by mixing color pigments with white and black pigments to form the various shades,tins and tones in the scene. Starting with the pigment for a 'pure color' the artist adds a black pigment to produce different shades of that color.The more black pigments, the darker the shade. Similarly different tints of color are obtained by adding a white pigment to the original color,making it lighter as more white is adding. Tones of the color are produced by adding both black and white pigments.

HSI COLOR MODEL

- To give a color specification, a user selects a spectral color and the amounts of white and black that are to be added to obtain different shades,tins and tones. Color parameters in this model are hue(H), saturation(S) and Intensity value (I).
- Hue is the term of dominant frequency used to describe combinations of light.
- The three dimension representation of the HSV model is derived from the RGB cube. We see an outline of the cube that has the hexagon shape as shown in the below figure.

The boundary of the hexagon represents the various hues, and it is used as the top of the HSV hexcone as shown in the below figure. In the hexcone the saturation is measured along a horizontal axis and value is along a vertical axis thru the center of hexcone.



Hue is represented as an angle about the vertical axis, ranging from 0° at red thru 360°. Vertices of the hexagon are separated by 60° intervals. Yellow is at 60° ,green at 120° and cyan opposite red at $H=180^\circ$. Complementary colors are 180° apart. Saturation S varies from 0 to 1. It is represented in this model as the ratio of the purity of a selected hue to its maximum purity at $s=1$. A selected hue is said to be one-quarter pure at the value $s=0.25$. Value V varies from 0 to the apex of the hexcone to 1 at the top.

Color concepts in terms of shades tins and tones is represented in a cross-sectional plane of HSV hexcone as shown below. Adding black to a pure hue decreases V down the side of the hexcone.

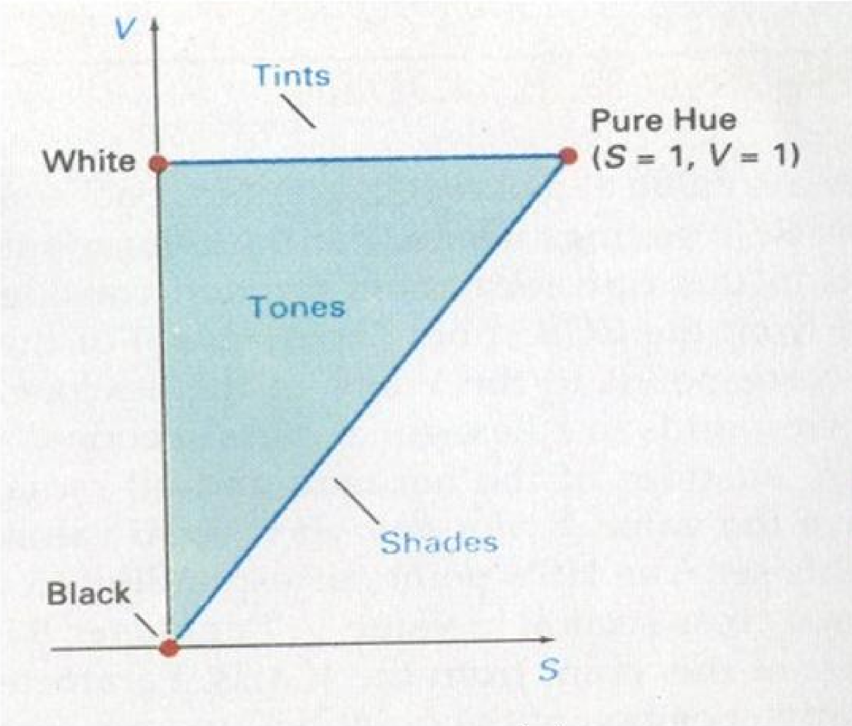


Figure 15-17
Cross section of th
showing regions fo
and tones.

With the range of parameters in the HSV color model 16,384 colors would be available to a user and the system would need 14 bit of color storage per pixel. Human eye can distinguish about 128 different hues and about 130 different tins.

Converting Colors from RGB to HSI

$$H = \begin{cases} \theta & \text{if } B \leq G \\ 360 - \theta & \text{if } B > G \end{cases}$$

with

$$\theta = \cos^{-1}\left\{ \frac{\frac{1}{2}\left[(R-G) + (R-B)\right]}{\left[(R-G)^2 + (R-B)(G-B)\right]^{1/2}} \right\}$$

The saturation component is given by

$$S = 1 - \frac{3}{(R+G+B)}\left[\min(R, G, B)\right].$$

Finally, the intensity component is given by

$$I = \frac{1}{3}(R+G+B).$$

Converting Colors from HIS to RGB

RG sector $(0^\circ \leq H < 120^\circ)$:

$$B = I(1 - S)$$

$$R = I\left[1 + \frac{S \cos H}{\cos(60^\circ - H)}\right]$$

$$G = 1 - (R + B).$$

Converting Colors from HIS to RGB

GB sector $(120° \leq H < 240°)$:

$$H = H - 120°.$$

Then the RGB components are

$$R = I(1 - S)$$

$$G = I\left[1 + \frac{S \cos H}{\cos(60° - H)}\right]$$

and

$$B = 1 - (R + G).$$

Converting Colors from HIS to RGB

BR sector $(240^\circ \le H \le 360^\circ)$:

$$H = H - 240^\circ.$$

Then the RGB components are

$$G = I(1 - S)$$

$$B = I\left[1 + \frac{S\cos H}{\cos(60^\circ - H)}\right]$$

and

$$R = 1 - (G + B).$$

Conversion of one Color model to other Color model is possible.

RGB ⟷ YIQ

RGB ⟷ YCbCr

RGB ⟷ CMY

RGB ⟷ HSI