Computer Graphics

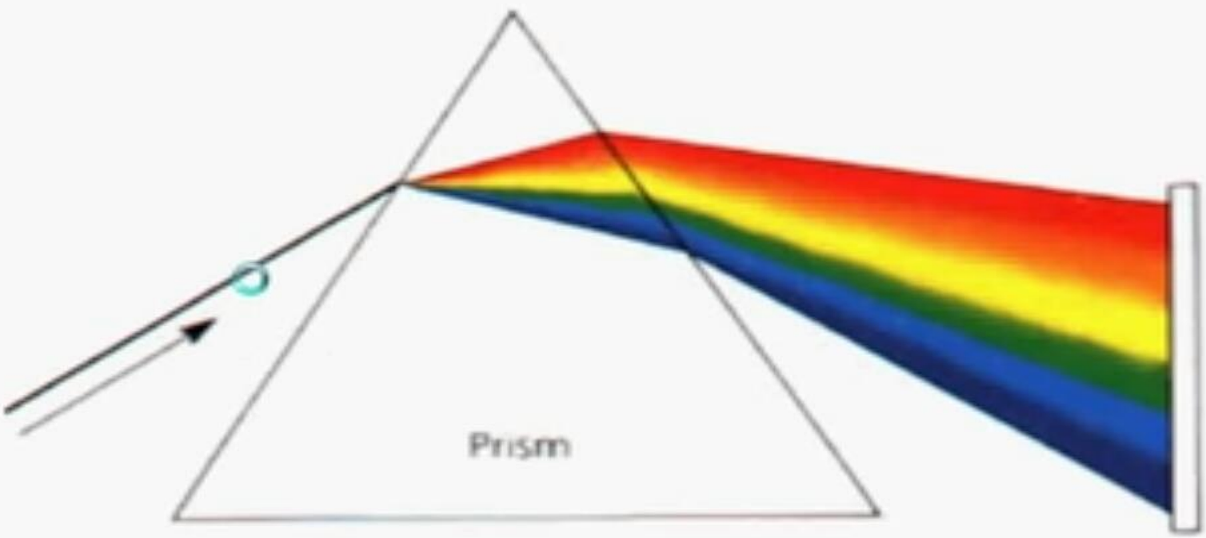
Unit 3 – Part 4

–By Manjula. S

Physical properties of light

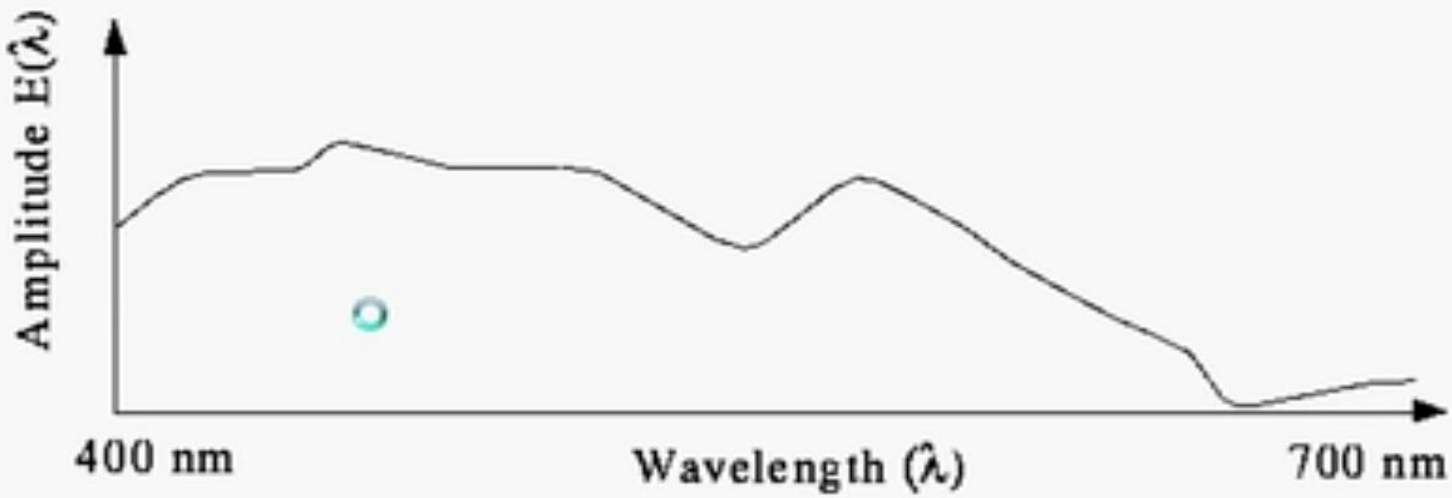
White light consists of a spectrum of all visible colors.

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



Cont...

Most light we see is not just a single wavelength, but a combination of many wavelengths like below. This profile is often referred to as a spectrum, or spectral power distribution.



Color Models and Color Applications

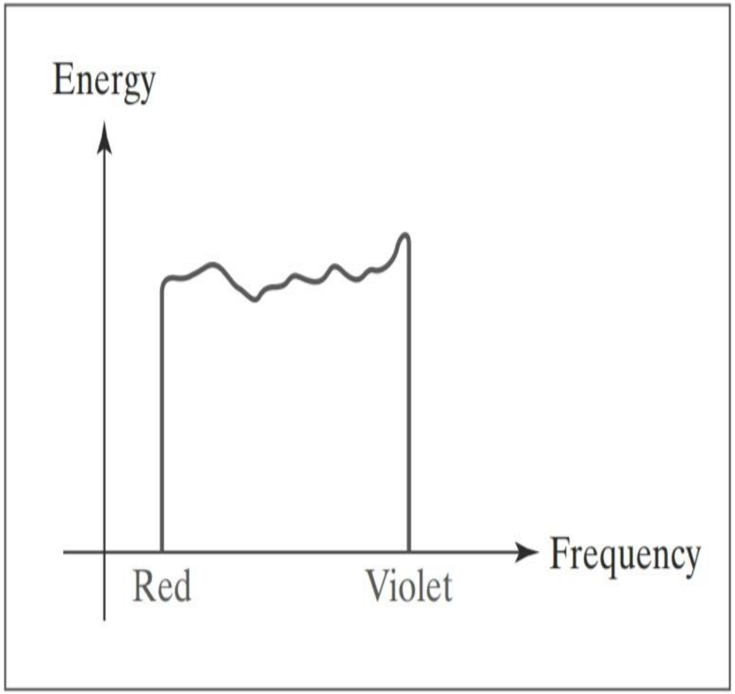


FIGURE 3
Energy distribution for a white light source.

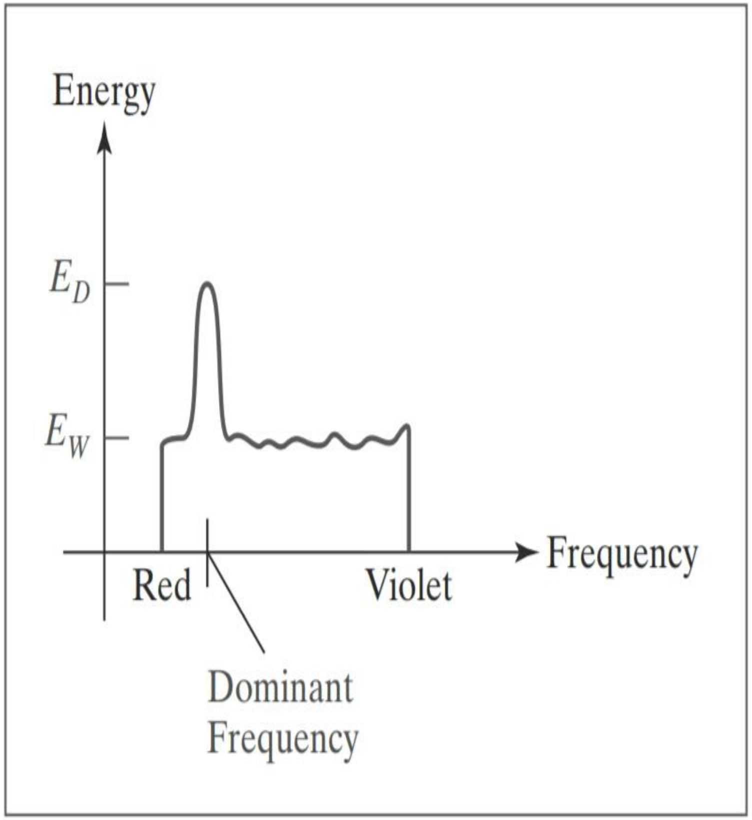


FIGURE 4
Energy distribution for a light source with a dominant frequency near the red end of the frequency range.

Electro magnetic spectrum

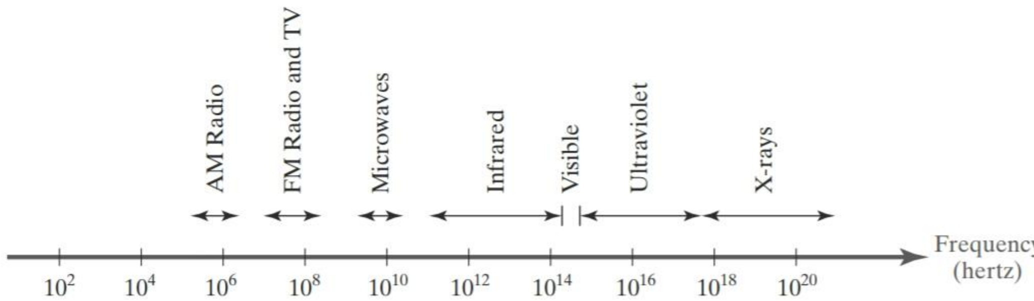


FIGURE 1
Electromagnetic spectrum.

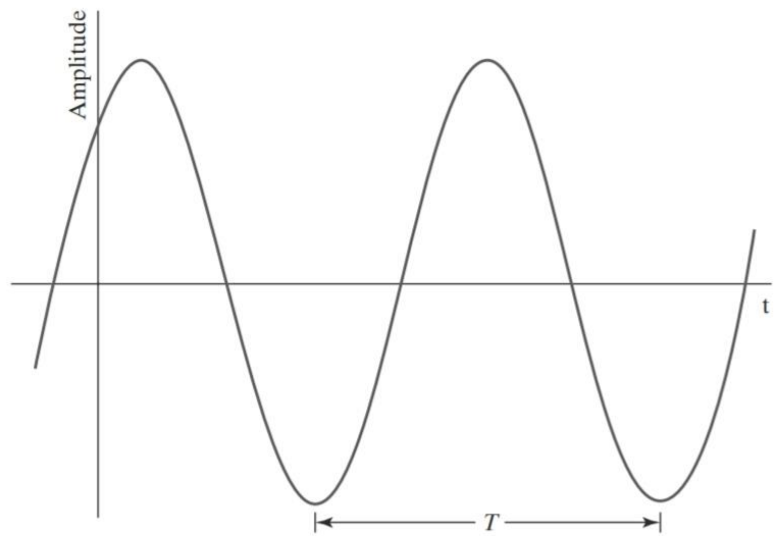


FIGURE 2
Time variations for the amplitude of the electric field for one frequency component of a plane-polarized electromagnetic wave. The time between two consecutive amplitude peaks or two consecutive amplitude minimums is called the period of the wave.

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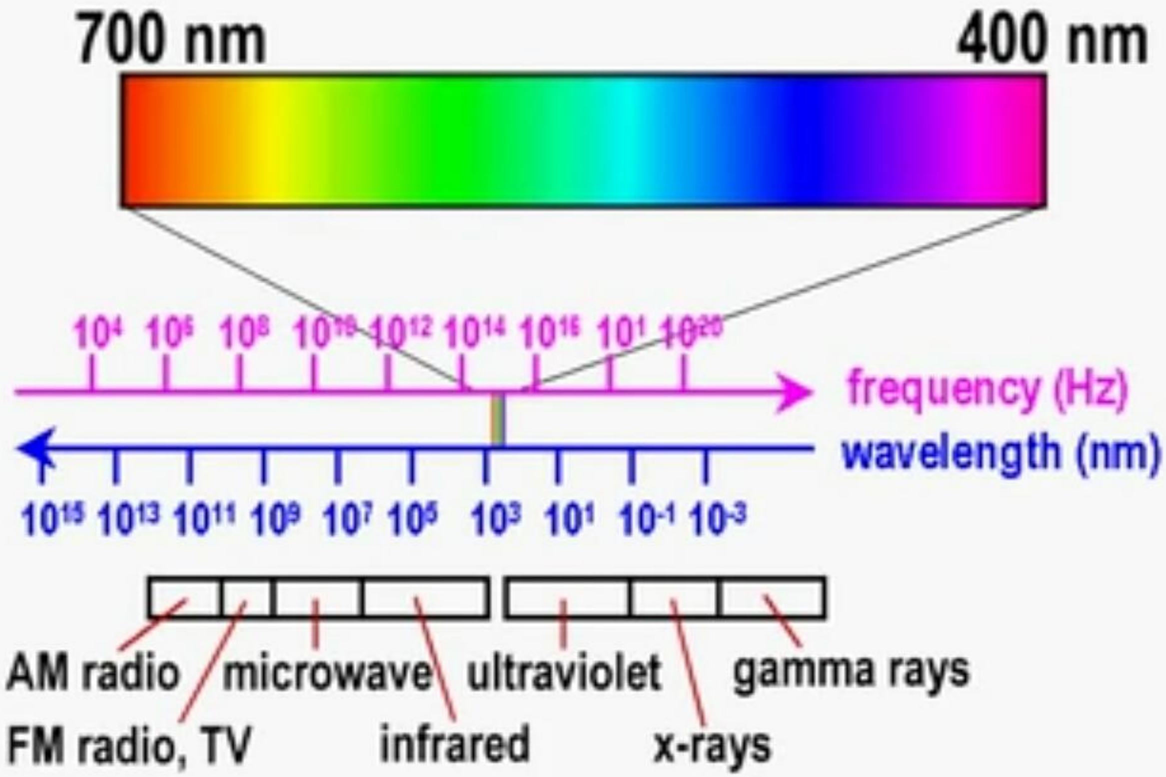
Cont…

Frequency:

- Red: 3.8×10^{14} hertz
- Violet: 7.9×10^{14} hertz

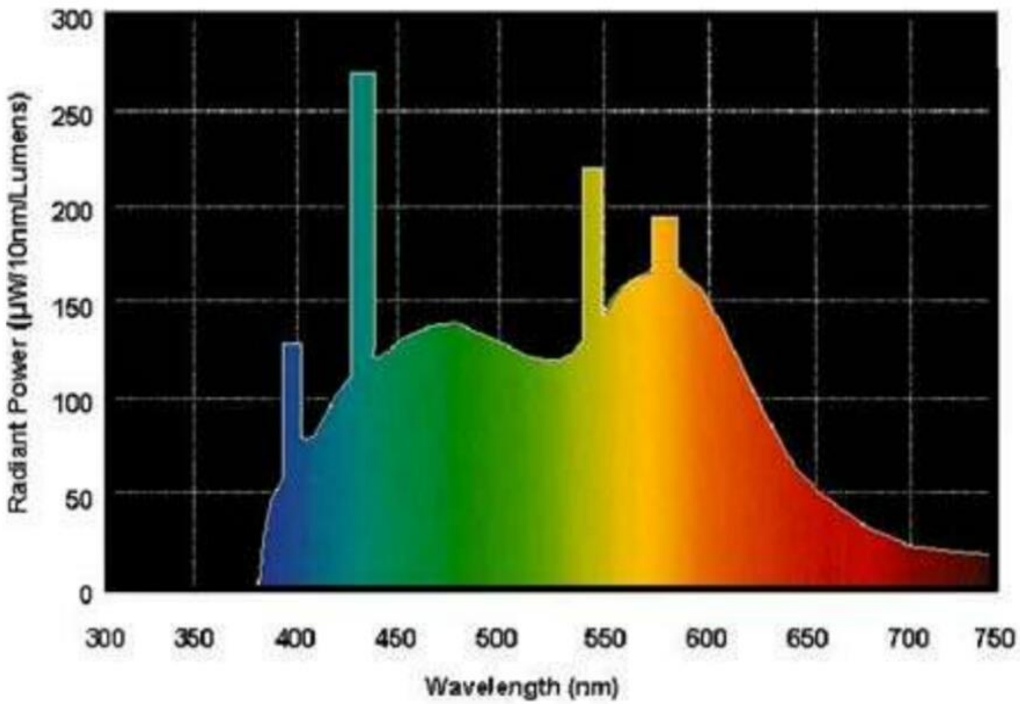
Wavelength:

- Red: 700 nm
- Violet: 400 nm



Color

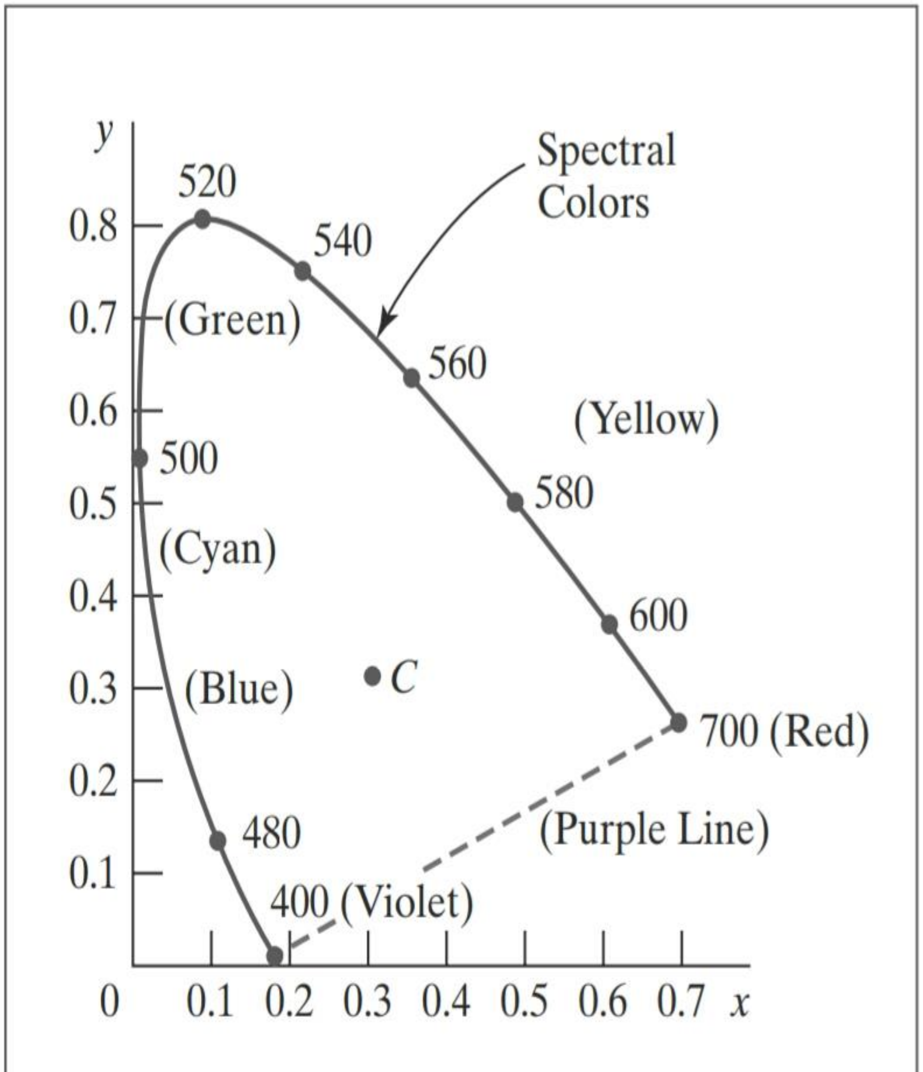
- It is the most important attribute of any geometric primitive.
- A visible color can be characterized by function C(X) that occupies wavelengths from about 350 nm to 780 nm.

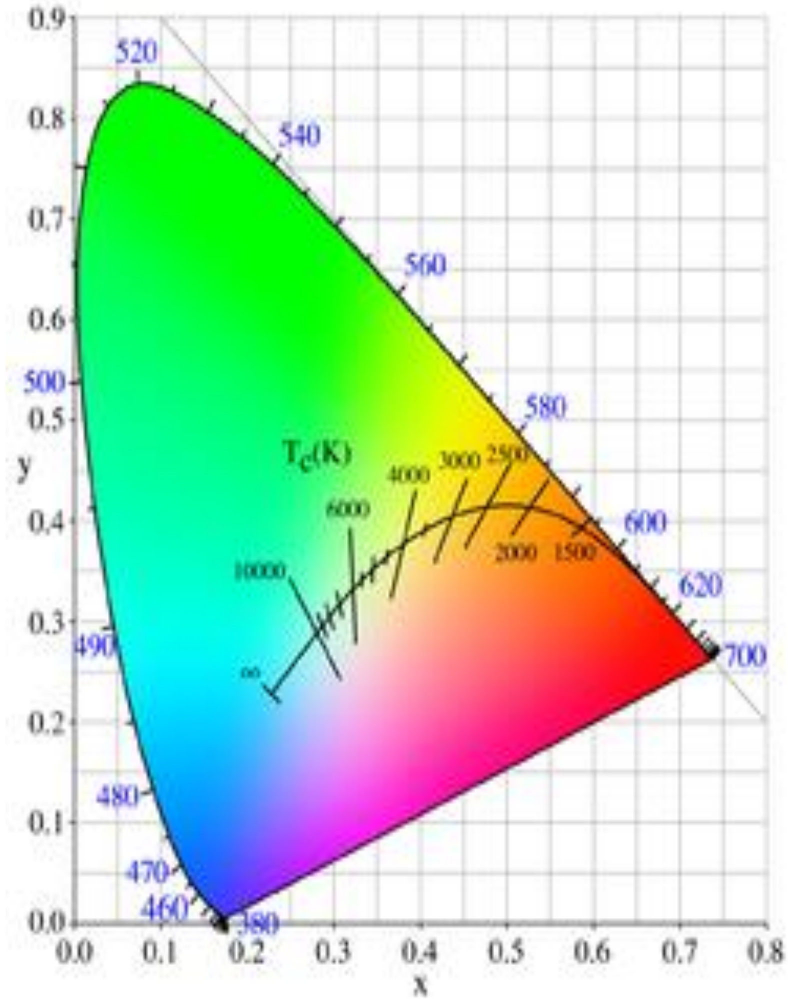


Chromaticity

Chromaticity is an objective specification of the quality of a color regardless of its luminance. Chromaticity consists of two independent parameters, often specified as hue (h) and colorfulness (s), where the latter is alternatively called saturation, chroma, intensity or excitation purity.

Color Models and Color Applications





CIE chromaticity diagram for the spectral colors from 400 nm to 700 nm.

Color

- It is the most important attribute of any geometric primitive.
- A visible color can be characterized by function C(X) that occupies wavelengths from about 350 nm to 780 nm.

Color

- The human visual system has 3 types of cones responsible for color vision.
- Hence our brains do not receive the entire distribution for the given color but 3 values – **tristimulus values –** that are responses of the **3 types of cones to the color.**
- This reduction of a color to 3 values leads to the basic tent of three-color theory.
- If two colors produce same tristimulus values, then they are visually indistinguishable.

Tristimulus Values

- Any color which can be produced by three primary colors - blue, green, and red and can be written as:

$$C = rR + gG + bB$$

- Where **R,G,B** can be considered to be "unit values" for blue, green, and red.
- r,g,b are the magnitudes or relative intensities of those primaries and are called "tristimulus values".

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The XYZ Color Model

The set of CIE primaries is generally referred to as the XYZ color model, where parameters X, Y, and Z represent the amount of each CIE primary needed to produce a selected color. Thus, a color is described with the XYZ model in the same way that we described a color using the RGB model.

In the three-dimensional XYZ color space, we represent any color $C(\lambda)$ as

$$C(\lambda) = (X,\ Y,\ Z) \tag{2}$$

where X, Y, and Z are calculated from the color-matching functions (Figure 6):

$$\begin{aligned} X &= k \int_{\text{visible}\,\lambda} f_X(\lambda)\, I(\lambda)\, d\lambda \\ Y &= k \int_{\text{visible}\,\lambda} f_Y(\lambda)\, I(\lambda)\, d\lambda \\ Z &= k \int_{\text{visible}\,\lambda} f_Z(\lambda)\, I(\lambda)\, d\lambda \end{aligned} \tag{3}$$

Parameter k in these calculations has the value 683 lumens/watt, where lumen is a unit of measure for light radiation per unit solid angle from a "standard" point light source (once called a *candle*). The function $I(\lambda)$ represents the spectral radiance, which is the selected light intensity in a particular direction, and the color-matching function f_Y is chosen so that parameter Y is the luminance for that color. Luminance values are normally adjusted to the range from 0 to 100.0, where 100.0 represents the luminance of white light.

Any color can be represented in the XYZ color space as an additive combination of the primaries using unit vectors **X**, **Y**, **Z**. Thus, we can write Equation 2 as

$$C(\lambda) = X\mathbf{X} + Y\mathbf{X} + Z\mathbf{X} \tag{4}$$

Color Models and Color Applications

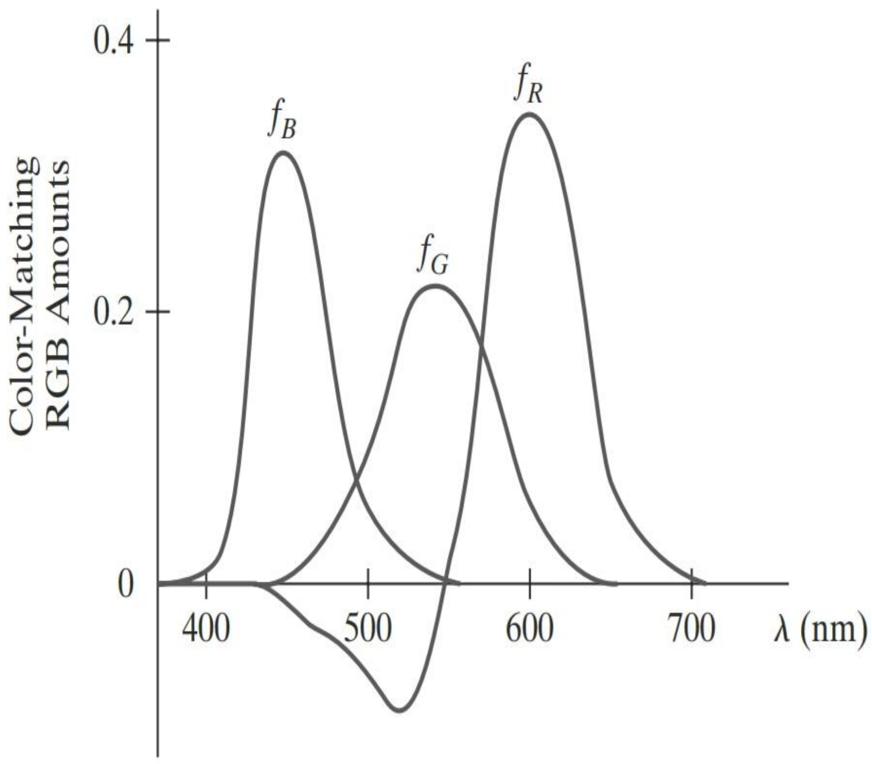

FIGURE 5
Three color-matching functions for displaying spectral frequencies within the approximate range from 400 nm to 700 nm.

Normalized XYZ Values

In discussing color properties, it is convenient to normalize the amounts in Equation 3 against the sum $X + Y + Z$, which represents the total light energy. Normalized amounts are thus calculated as

$$x = \frac{X}{X+Y+Z}, \qquad y = \frac{Y}{X+Y+Z}, \qquad z = \frac{Z}{X+Y+Z} \tag{5}$$

Because $x+y+z=1$, any color can be represented with just the x and y amounts. Also, we have normalized against total energy, so parameters x and y depend only on hue and purity and are called the **chromaticity values.** However, the x and y values alone do not allow us to describe all properties of the color completely, and we cannot obtain the amounts X, Y, and Z. Therefore, a complete description of a color is typically given with three values: x, y, and the luminance Y. The remaining CIE amounts are then calculated as

$$X = \frac{x}{y}Y, \qquad Z = \frac{z}{y}Y \tag{6}$$

where $z = 1 - x - y$. Using chromaticity coordinates (x, y), we can represent all colors on a two-dimensional diagram.

Color Matching functions

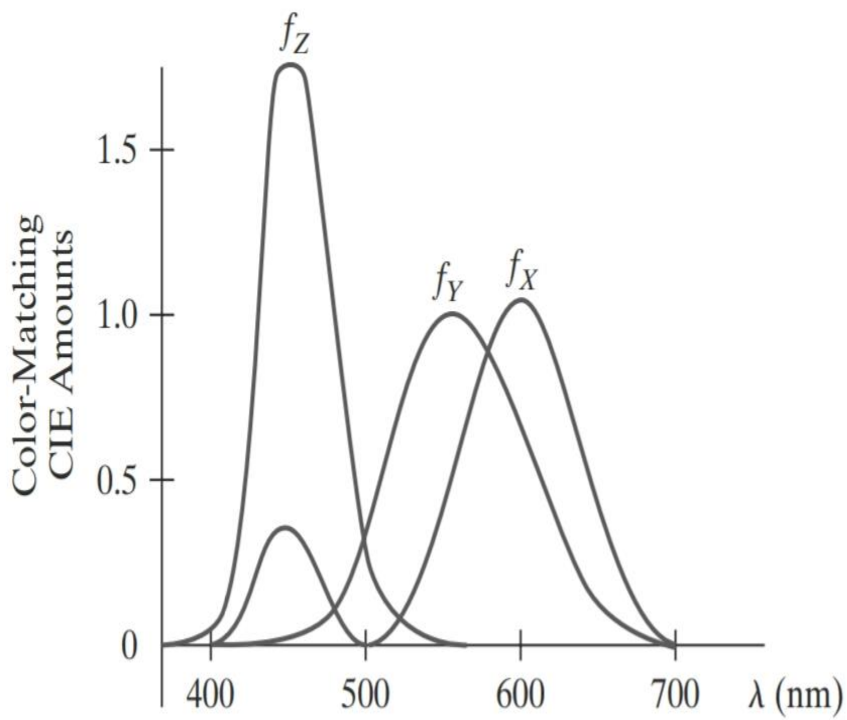

FIGURE 6
The three color-matching functions for the CIE primaries.

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TABLE 1

RGB (*x*, *y*) Chromaticity Coordinates

	NTSC Standard	CIE Model	Approx. Color Monitor Values
R	(0.670, 0.330)	(0.735, 0.265)	(0.628, 0.346)
G	(0.210, 0.710)	(0.274, 0.717)	(0.268, 0.588)
B	(0.140, 0.080)	(0.167, 0.009)	(0.150, 0.070)

Color Cube

- **We can view color as a point in a color solid**
- **The vertices of a cube correspond to:**

  black(no primaries on)

  red, **green**, **blue**(one primary fully on)

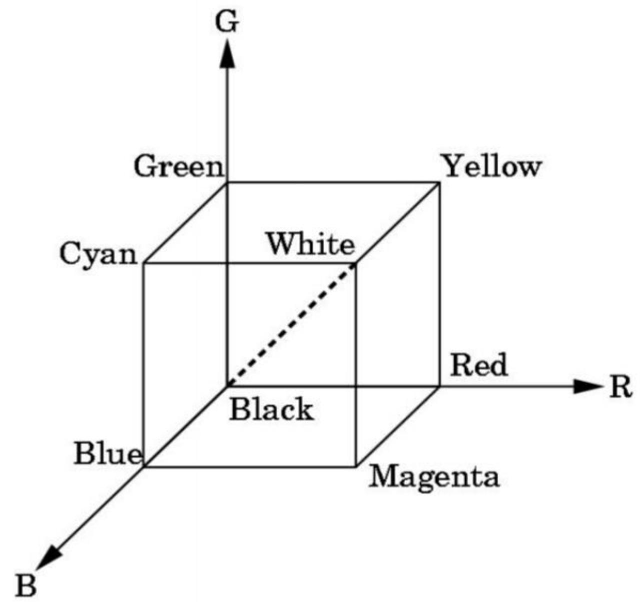
  cyan(green and blue fully on)

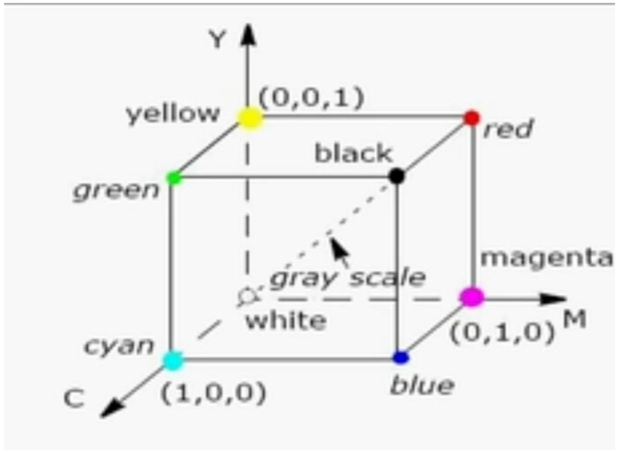
  magenta(red and blue fully on)

  yellow(red and green fully on)

  white(all primaries fully on)

- **All colors along principal diagonal line have equal tristimulus values and appear as shades of gray.**





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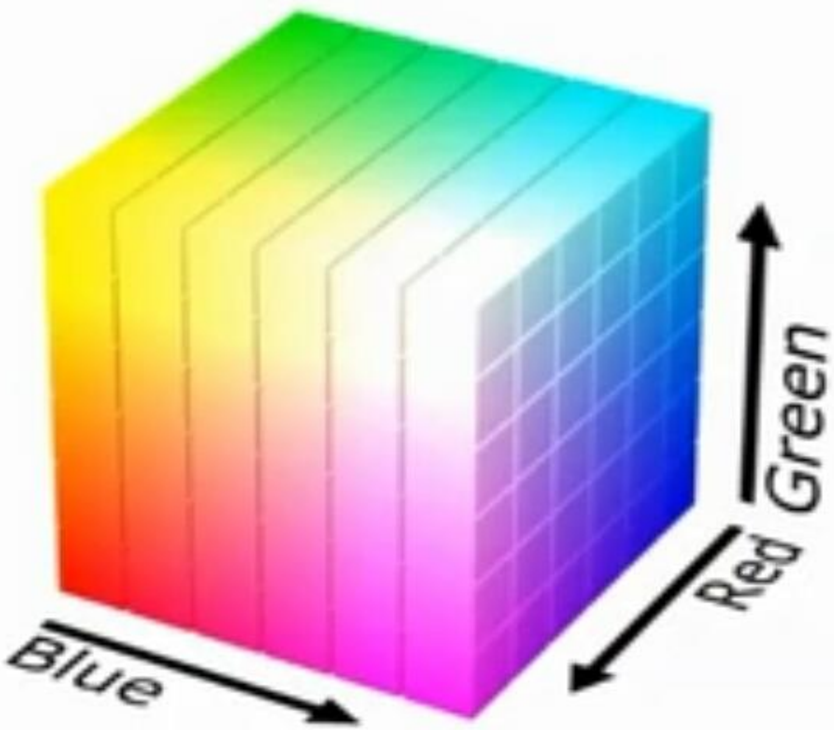
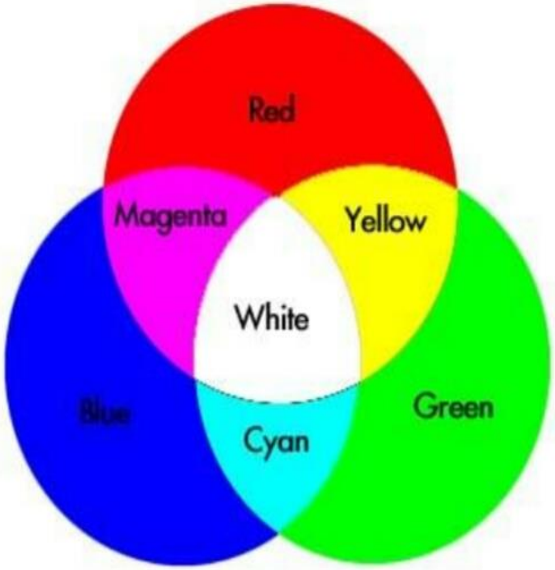
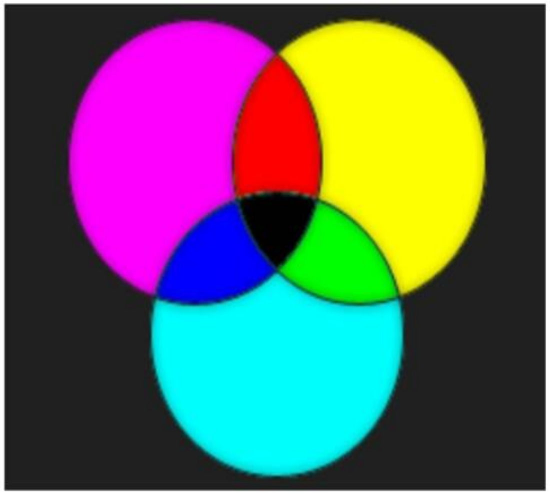
RGB Color Model



Color modes

- **Additive color**
- **Subtractive color**





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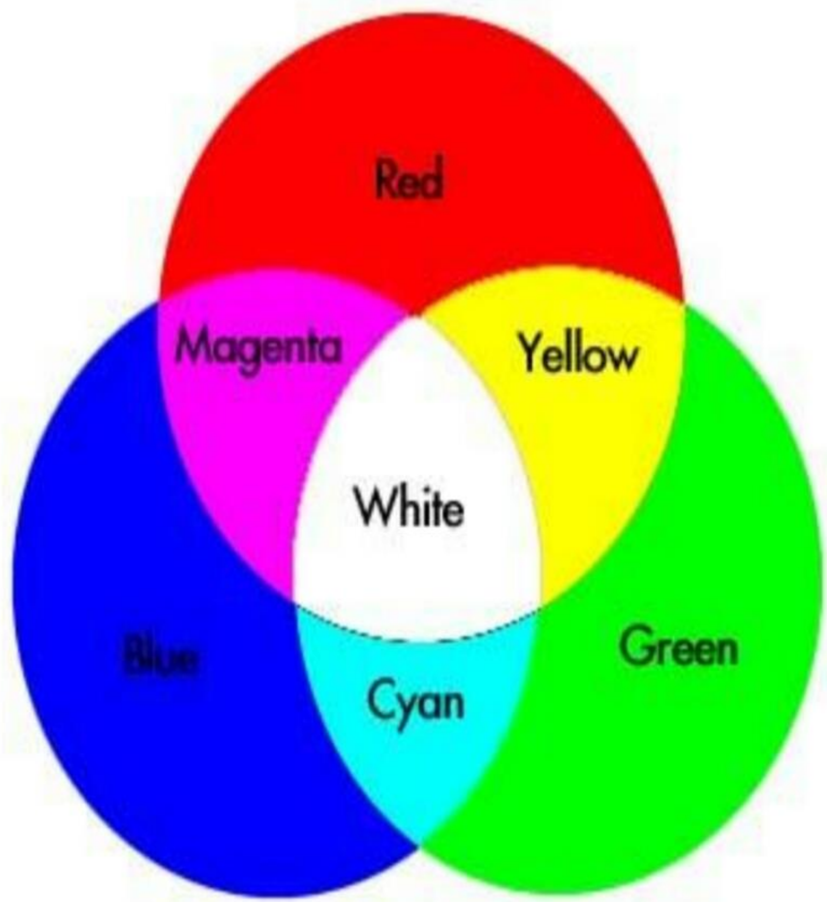
Additive Color

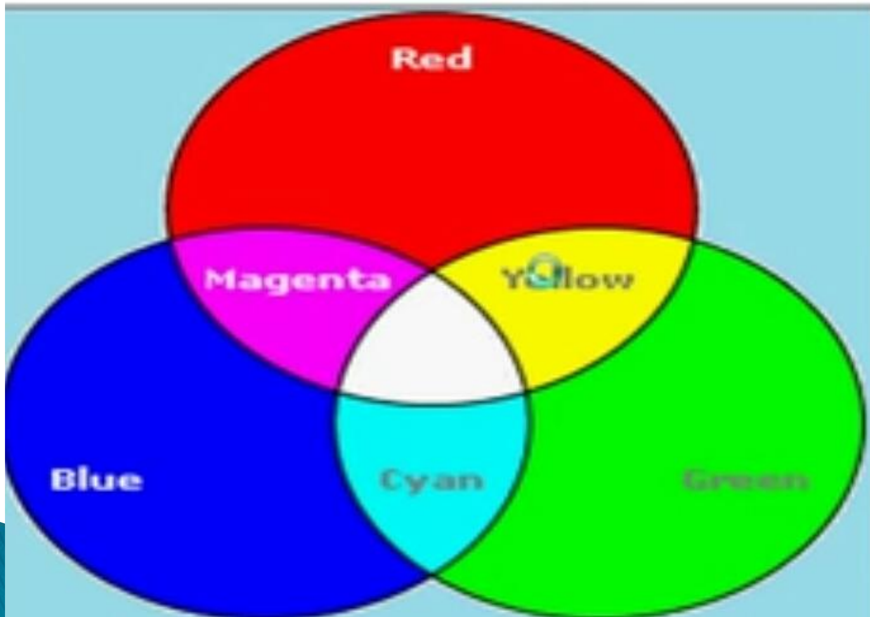
- **Primary** colors used (RGB)
  - Red
  - Green
  - Blue.
- CRT is an example of **additive color** where primary colors are added together to give the perceived color.

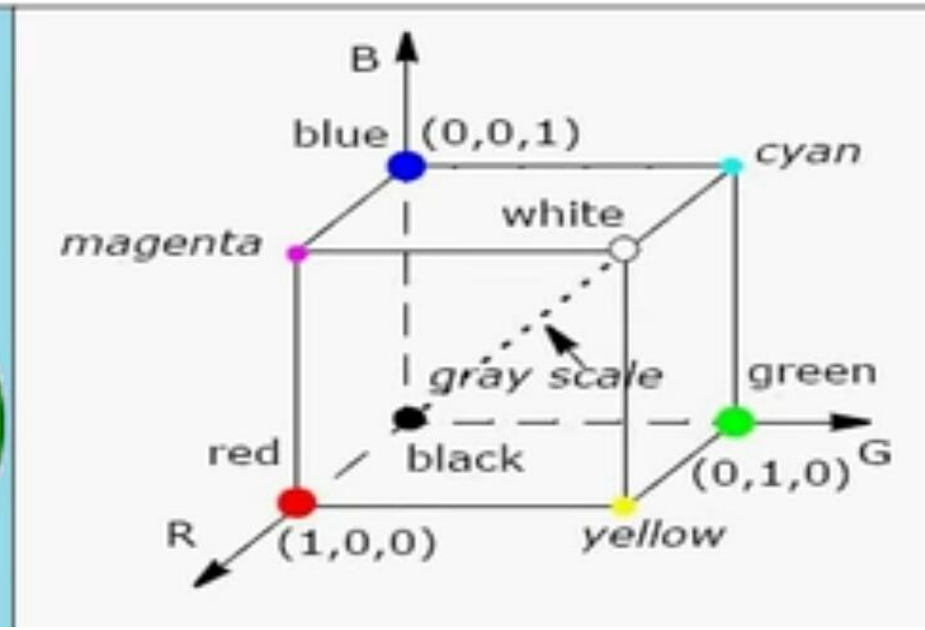


RGB (Red,Green,Blue) color model

The RGB color model used in color CRT monitors.

In this model,
Red,Green and Blue are added together to get the resultant color WHITE.





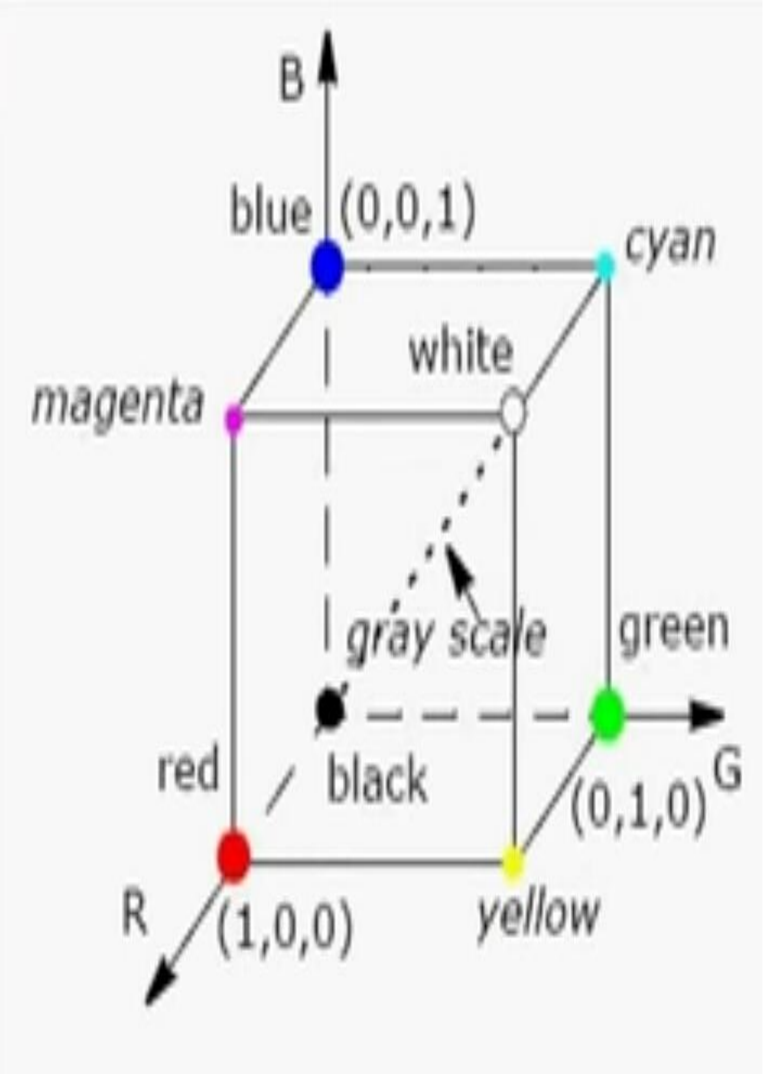
RGB Color Model

Each color point within the bounds of the cube is represented as the triple (R,G,B).where value for R,G,B are assigned in the range from 0 to 1.

Here RGB color place together at 120 degree.

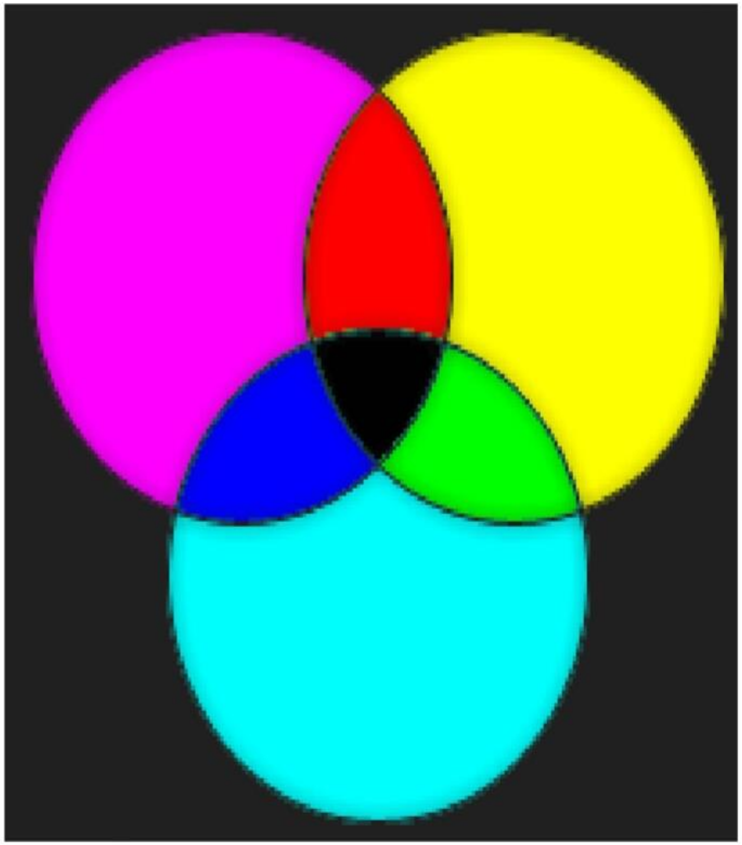
RED + GREEN + BLUE = WHITE(contribute)

All other colors are generated from these three primary colors.



Subtractive Color

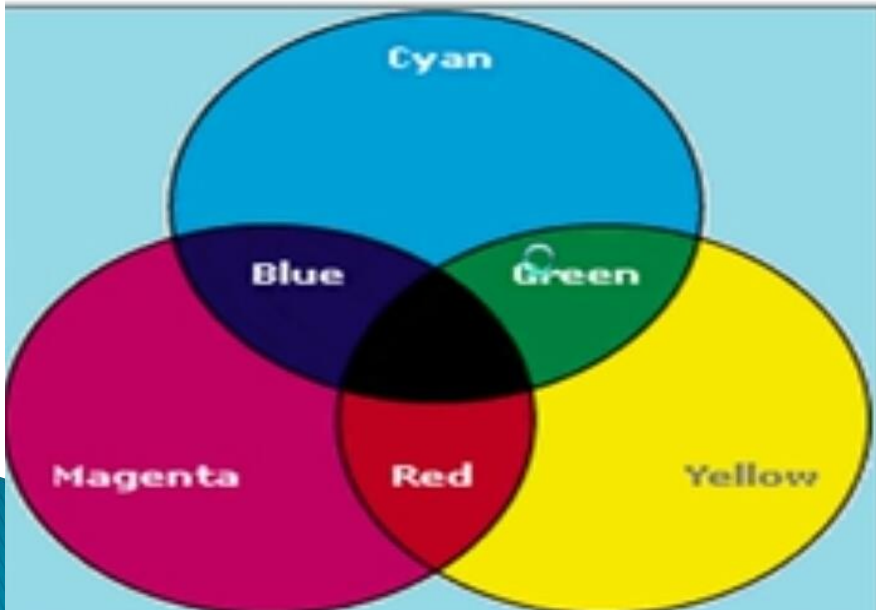
- It suits for processes such as **commercial printing and painting** as white surface is used as background.
- The primaries are usually the complementary colors (CMY)
  - Cyan
  - Magenta
  - yellow

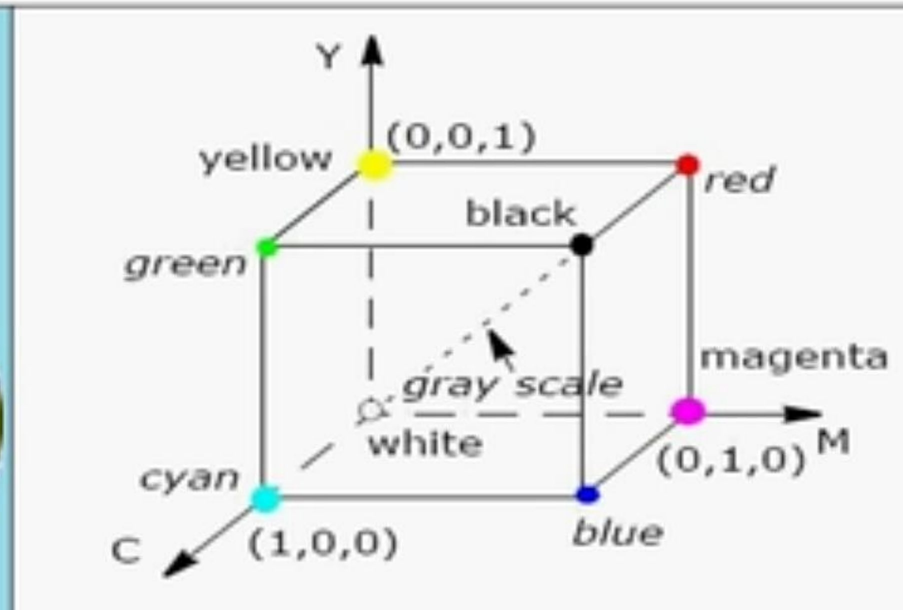


CMY (Cyan,Magenta,Yellow) color model

The CMY color model used in color printing devices.

In this model,
Cyan,Magenta and Yellow are added together to get the resultant color BLACK.





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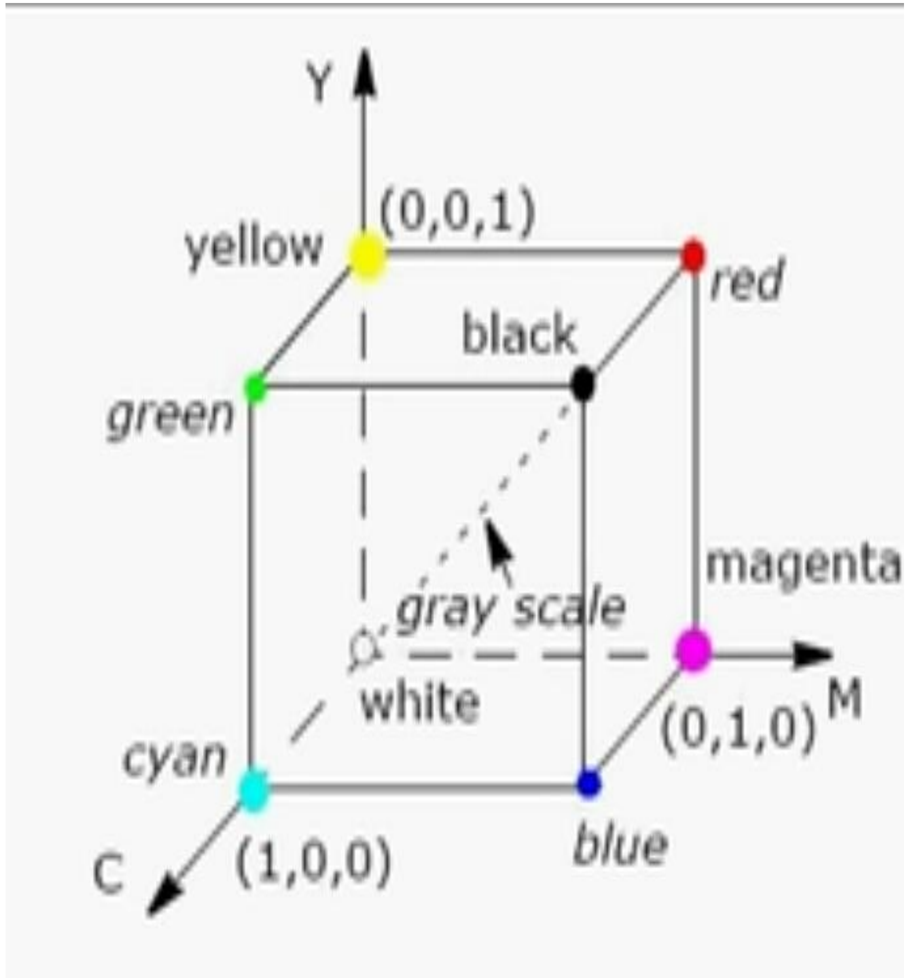
CMY color Model

Each color point within the bounds of the cube is represented as the triple (C,M,Y).where value for C,M,Y are also assigned in the range from 0 to 1.

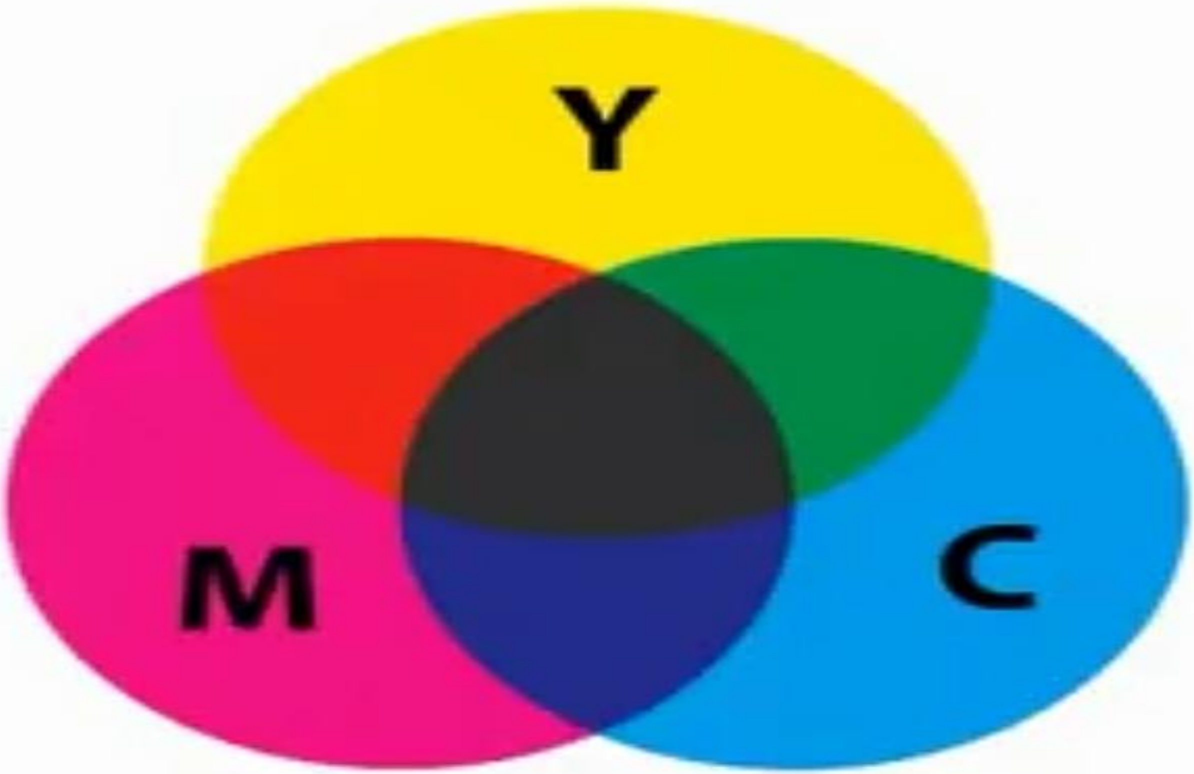
Here CMY color also place together at 120 degree.

CYAN+MAGENTA + YELLO = BLACK(contribute)

All other colors are generated from these three primary colors.



CMYK Color model



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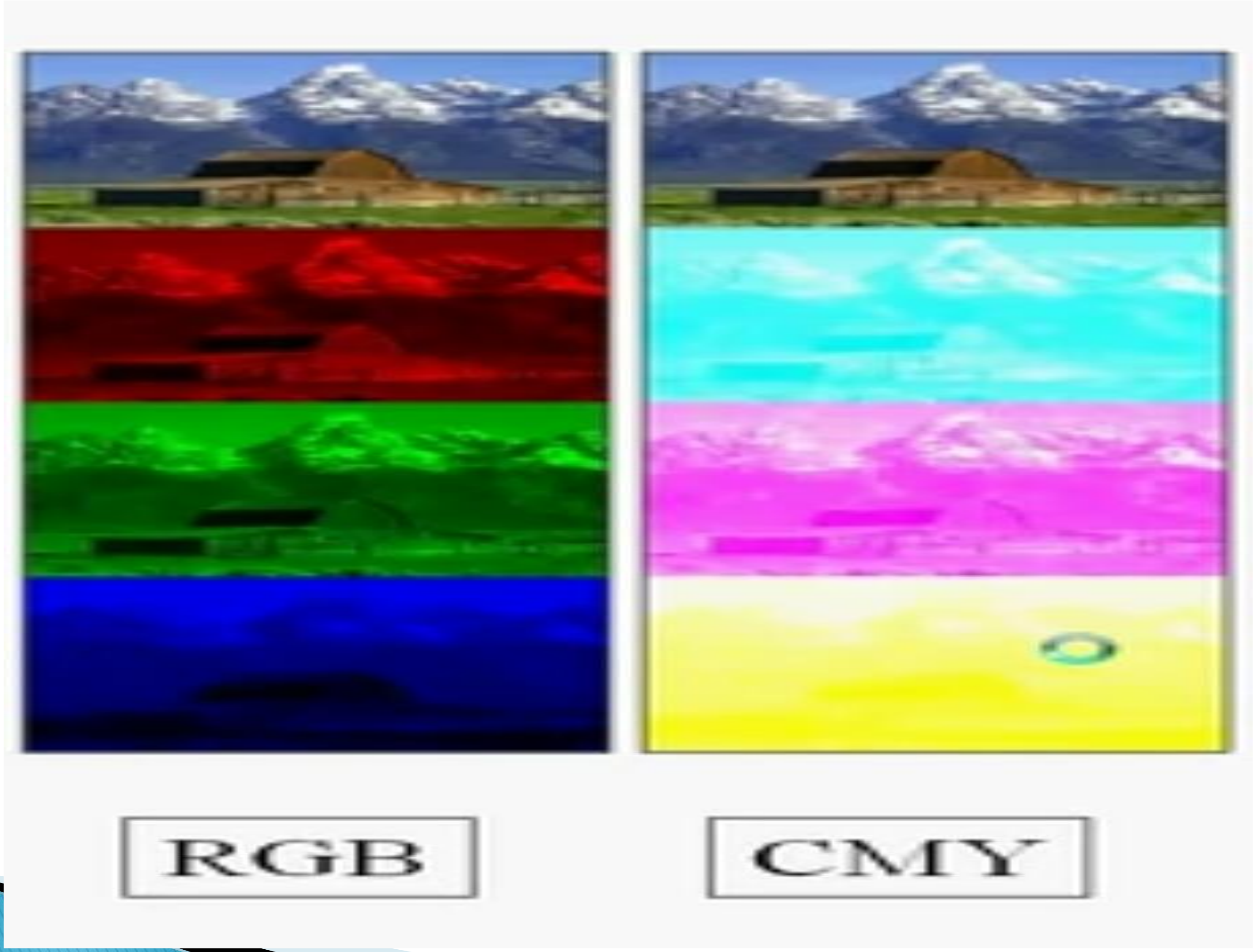
Comparison between RGB & CMY



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Color Models

There are 2 color models

1. RGB color model

2. Index color model

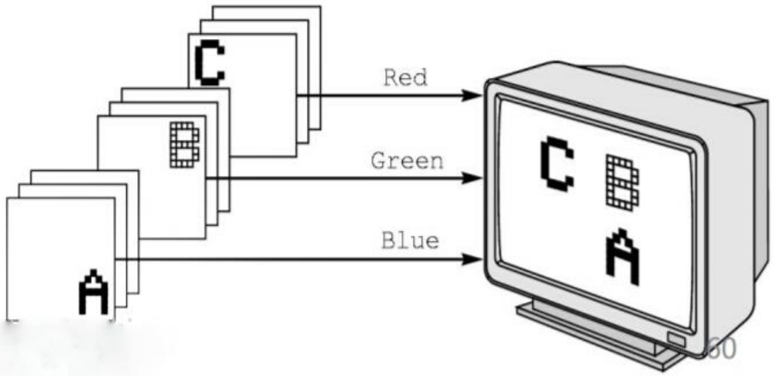
RGB Color

- In **additive color** RGB system, there are **separate buffers** for Red, Green and Blue images.
- Each pixel has separate R, G, and B components that corresponds to location in memory.
- **Ex : 24 bits for each pixel will be divided into**

  8 bits + 8 bits + 8 bits = 24 bits

  R G B
- Using 24 bit format, a total of 2^{24} different colors are possible.
- In OpenGL, color wrt RGB is represented as

  void glColor3f(GLfloat R, GLfloat G, Glfloat B);



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RGB Color

- In OpenGL, the color attribute can be specified as a number between 0.0 and 1.0
- Ex : to draw in red, the following function call is used:

  glColor3f(1.0, 0.0, 0.0);

  Default value of each one is 0.
- The execution of this function will set the present drawing color to red. Because the color is part of the state, draw in **red is continued until the color is changed.**
- The "**3f**" is used in a manner similar to the **glVertex** function: It conveys that, a three-color (RGB) model is used, and that the values of the components are given as floats in C.

RGBA Color

- Four color model namely RGBA system.
- A(alpha) – used for creating ***fog effects***(combining the images).

  0.0 – transparent (passes all kinds of light)

  1.0 – opaque(does not pass any light)

glClearColor(1.0,1.0,1.0,1.0)

would set the background color of the window to white and opaque.

Indexed Color

- Commonly used color model.
- It is used when **frame buffer has limited depth.**
- ***Example :***

If the frame buffer has 1280 x 1024 array of pixels but with each pixel consisting of only 8 bits, then color index model is used.

Input		Red	Green	Blue
0		0	0	0
1		$2^m - 1$	0	0
.		0	$2^m - 1$	0
.		.	.	.
.		.	.	.
$2^k - 1$		.	.	.

m bits | m bits | m bits

Indexed Color

Input		Red	Green	Blue
0		0	0	0
1		$2^m - 1$	0	0
.		0	$2^m - 1$	0
.		.	.	.
.		.	.	.
$2^k - 1$		.	.	.
		m bits	m bits	m bits

- In the model, suppose there are 'k' bits per pixel, then each pixel value is an integer between 0 to $2^k - 1$.
- We can display colors with a precision of m bits.
- We can choose from 2^m reds, 2^m greens and 2^m blues.
- Hence we can produce any of 2^{3m} colors on the display but the frame buffer can specify only 2^k of them.

Indexed Color

Advantages

- We can operate with such systems where the **number of bits per pixel is less.**
- The programmer can change the lookup table according to his requirements and hence has the flexibility to enjoy the usage of all possible colors.

Disadvantages

- All possible colors would not be available for usage simultaneously.

Setting of Color attributes

glClearColor(1.0,1.0,1.0,1.0);

Background color is set to white.

glColor3f(0.0, 1.0, 0.0);

Rendering color for the points is set to Red.

glPointSize(2.0);

The size of rendered points is set to 2 pixels wide.

Thank You

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