CSE4227 Digital Image Processing

Chapter 6 – **Colour Image Processing**

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Today's Contents

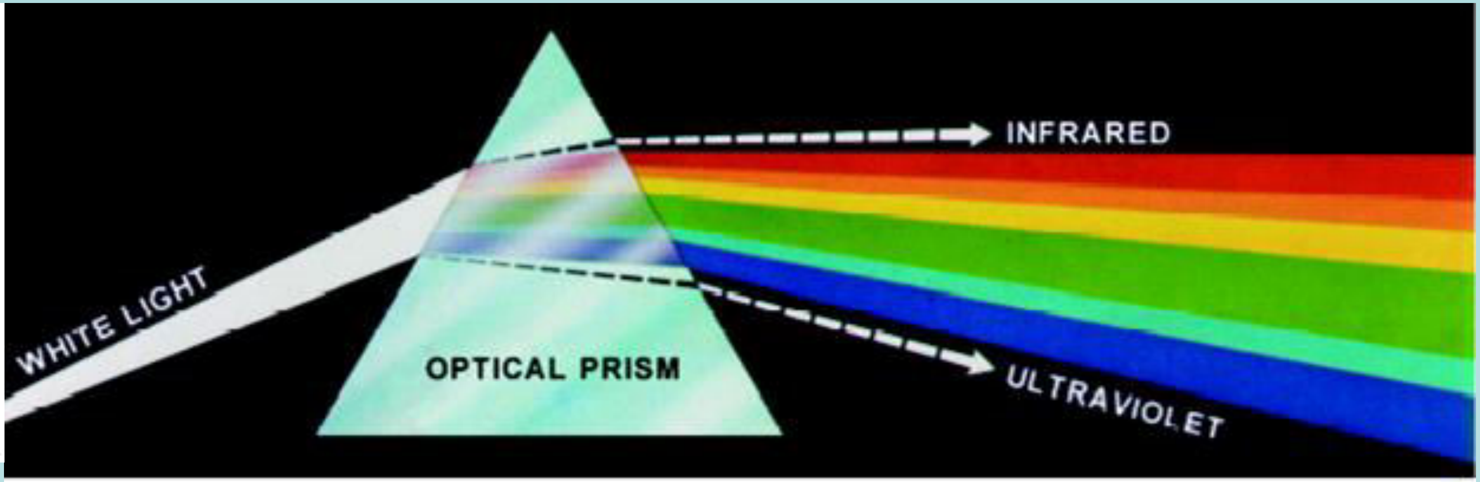
- Colour fundamentals
- Colour models:
  - RGB Colour Model
  - CMY and CMYK Colour Model
  - HSI Colour Model

• Chapter 6 from R.C. Gonzalez and R.E. Woods, Digital Image Processing (3rd Edition), Prentice Hall, 2008 [**Section 6.1, 6.2**]

Colour Fundamentals

- In 1666 **Sir Isaac Newton** discovered that **sunlight** passed through a prism splits into a **continuous spectrum of colors**.

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



- The colour spectrum of light may divided into six regions:

  Violet – Blue – Green – Yellow – Orange – Red

- No colour in the spectrum ends abruptly, but rather **blends smoothly into the next**.

Light And The Electromagnetic Spectrum

- The electromagnetic spectrum is split up according to the wavelengths of different forms of energy.

- Light is just a particular part of the electromagnetic spectrum (approximately 400 to 700 nm) that can be sensed by the human eye.

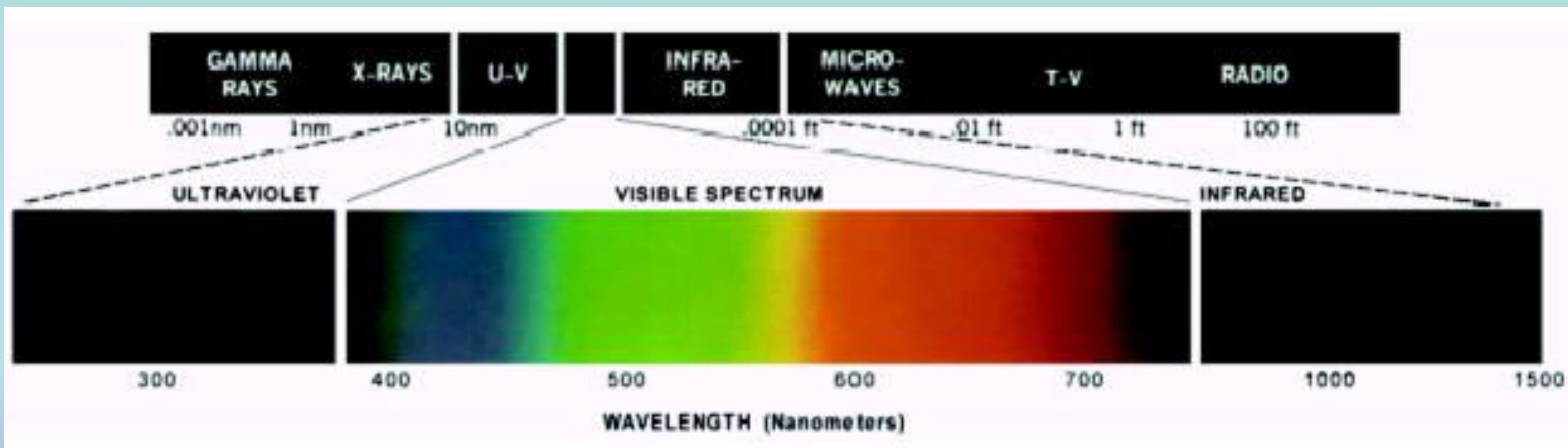
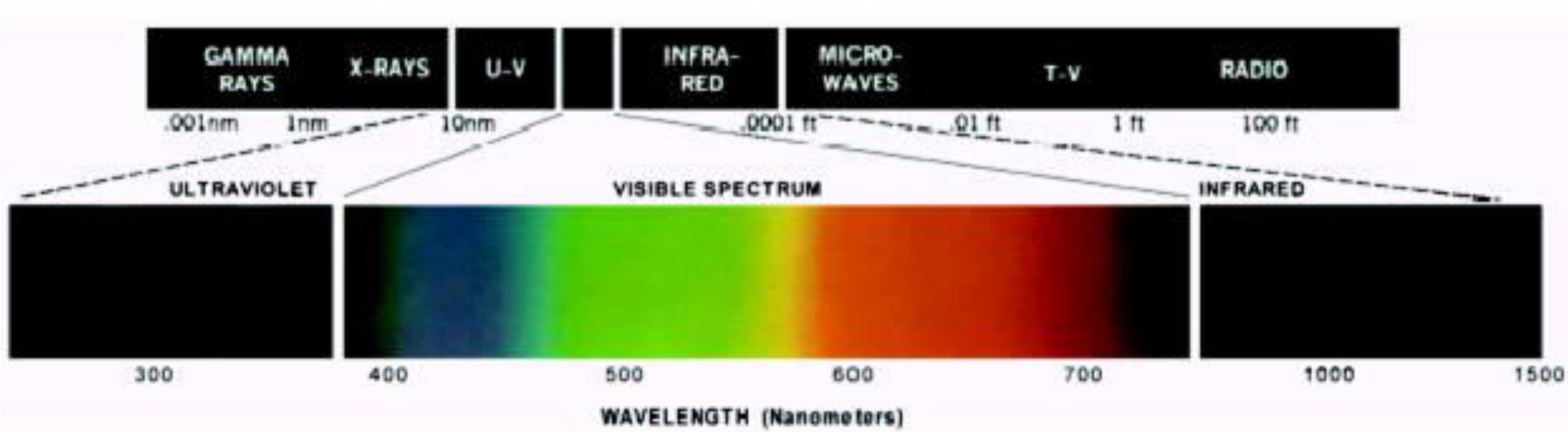


FIGURE 6.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

Color Fundamentals

- Visible light as a narrow band of frequencies in EM
- A body that reflects light that is balanced in all visible wavelengths appears white
- However, a body that favors reflectance in a limited range of the visible spectrum exhibits some shades of color
- Green objects reflect wavelength in the 500 nm to 570 nm range while absorbing most of the energy at other wavelengths



Color Models

- **Color Model**
  - A mathematical system for representing color
- The human eye combines 3 primary colors (using the 3 different types of cones) to discern all possible colors.
- Colors are just different light frequencies
  - red – 700nm wavelength
  - green – 546.1 nm wavelength
  - blue – 435.8 nm wavelength
- Higher frequencies are **cooler** colors

Human eye is sensitive to light with wavelengths from about 700 nm, which we see as **red**, to about 400 nm, which we see as **violet**.

Human Colour Vision

- ❑ Retina contains two types of photoreceptors
  - Cones (color sensitive)
  - Rods (more numerous, insensitive to color)

- ❑ 6 to 7 million cones in each eye are responsible for colour vision. Approximately:
  - ❖ 65% of these are sensitive to Red light,
  - ❖ 33% to **Green light** and
  - ❖ 2% to Blue light (blue cones are the most sensitive)

Absorption curves for the different cones

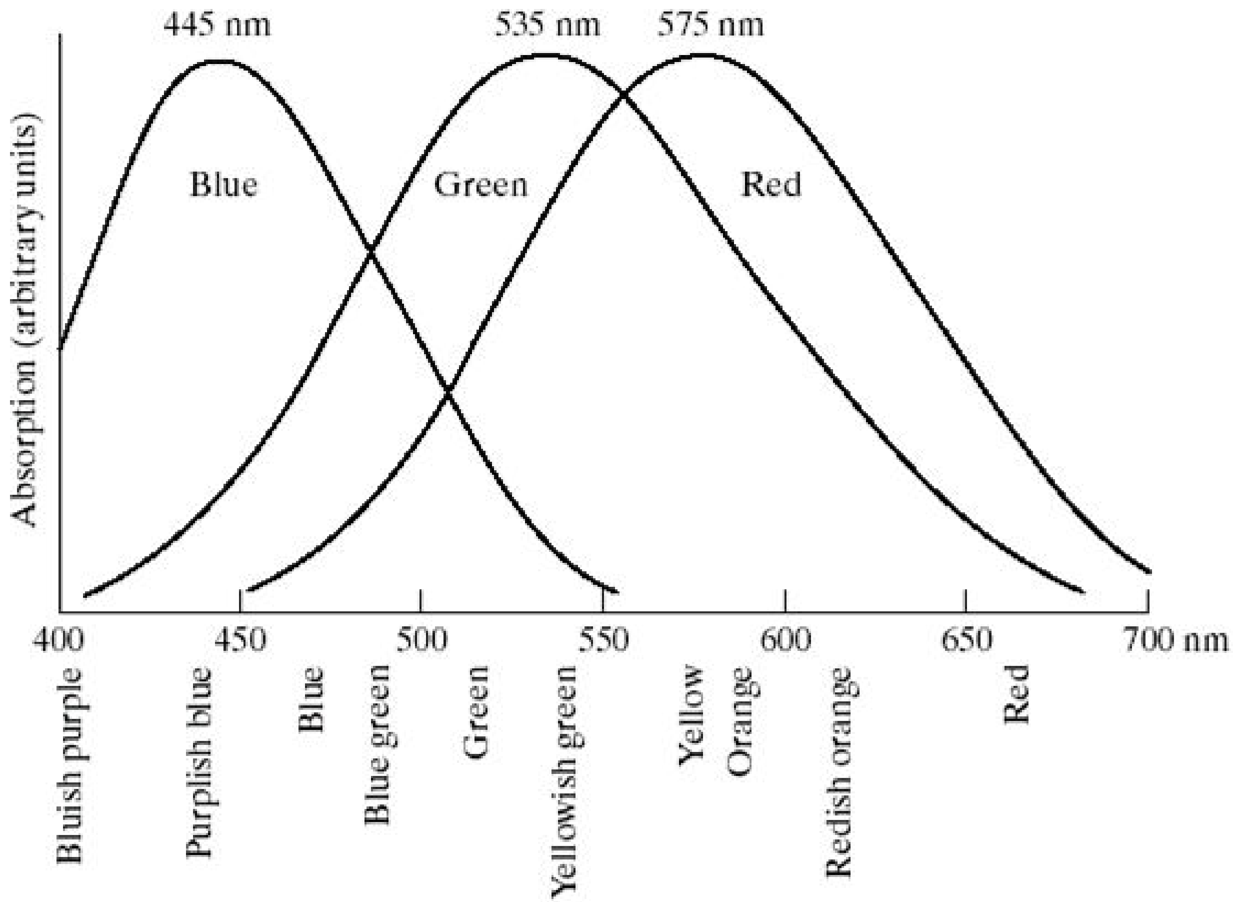
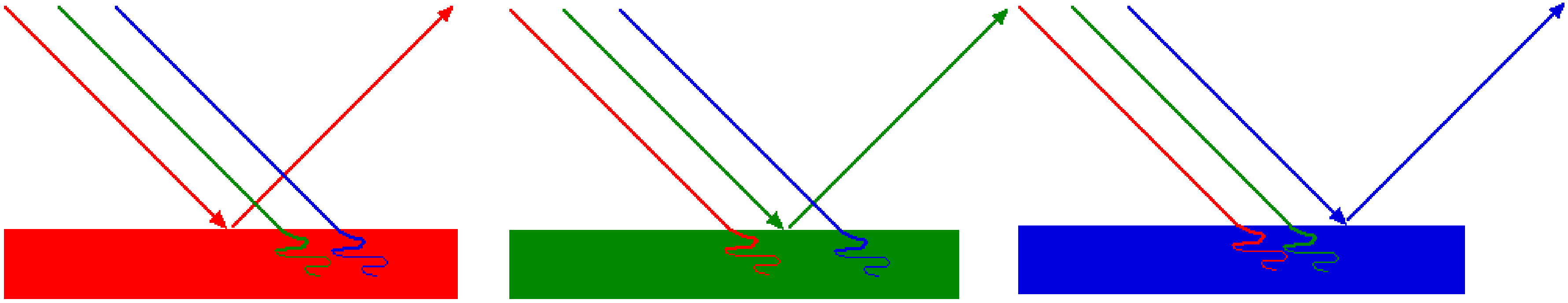


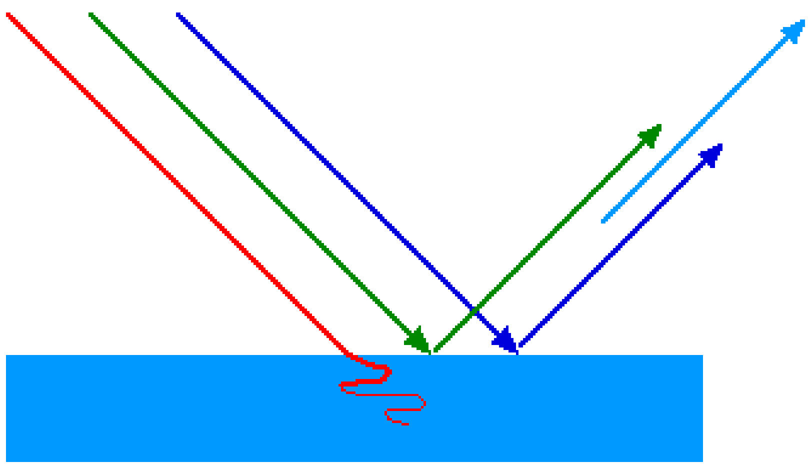
FIGURE 6.3 Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.

Color Vision

- We see the color of an object by the light that it reflects.
- White light/Sunlight shines on an object that means it is illuminated with light of all wavelengths.
- If Red light is reflected while light of other colors is absorbed, we will see the object as Red as shown on the left below:

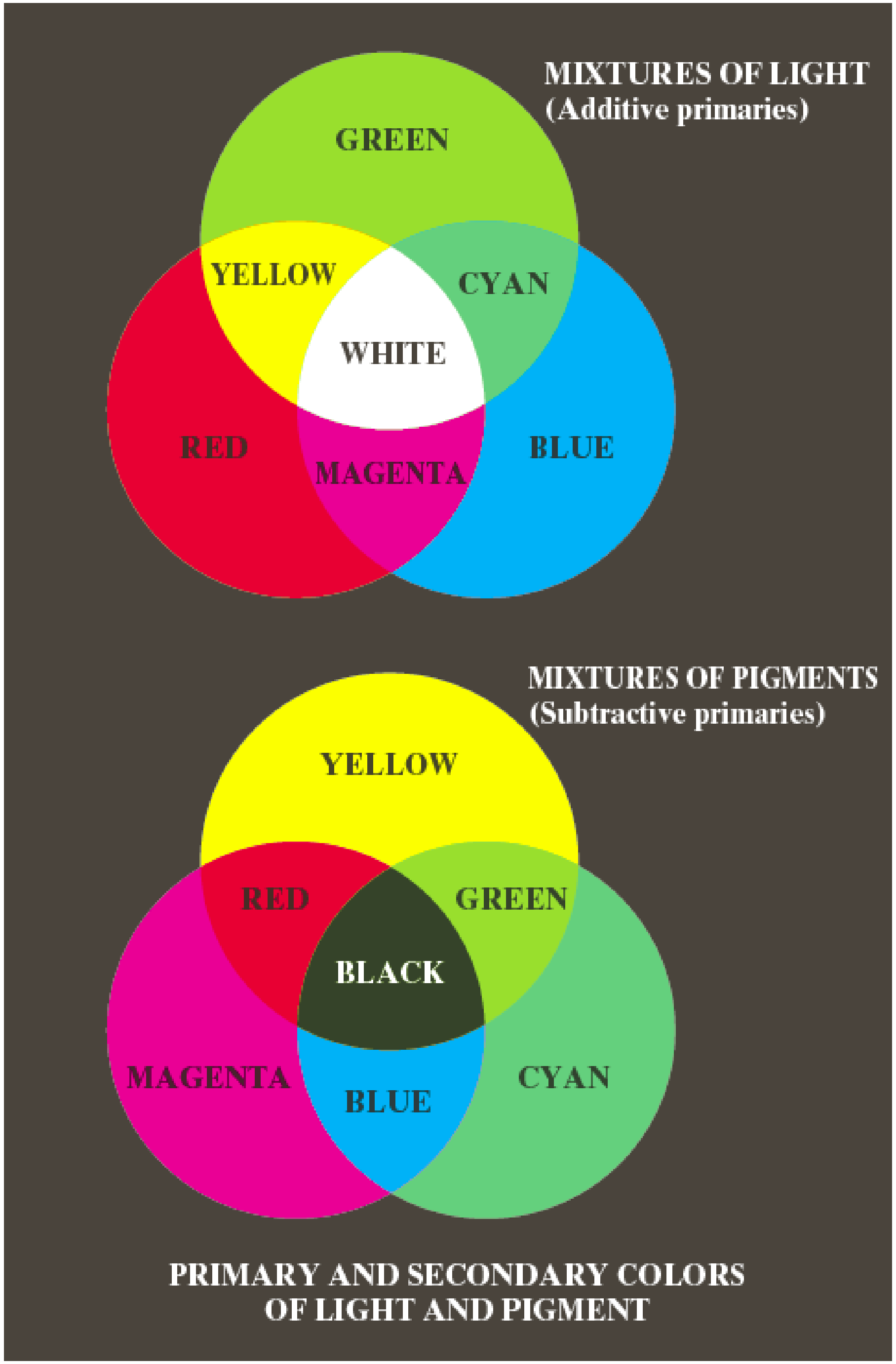


Color-sensitive **cones** in our retinas are **sensitive over a fairly wide range of wavelengths** or colors. And very few objects **absorb or reflect light** over a very **short range of wavelengths**. Below is a sketch which illustrates what we see when **white light shines** on something that **absorbs** light from the **red** end of the spectrum while the **rest of the light is reflected**. White light **without its reds and oranges** will be bluish-green or aqua-colored or turquoise; we call this color **cyan**.



Primary Colors

- Primary colors of light are additive
  - Primary colors are red, green, and blue
  - Combining red + green + blue yields white
- Primary colors of pigment are subtractive
  - Primary colors are cyan, magenta, and yellow
  - Combining cyan + magenta + yellow yields black



a
b

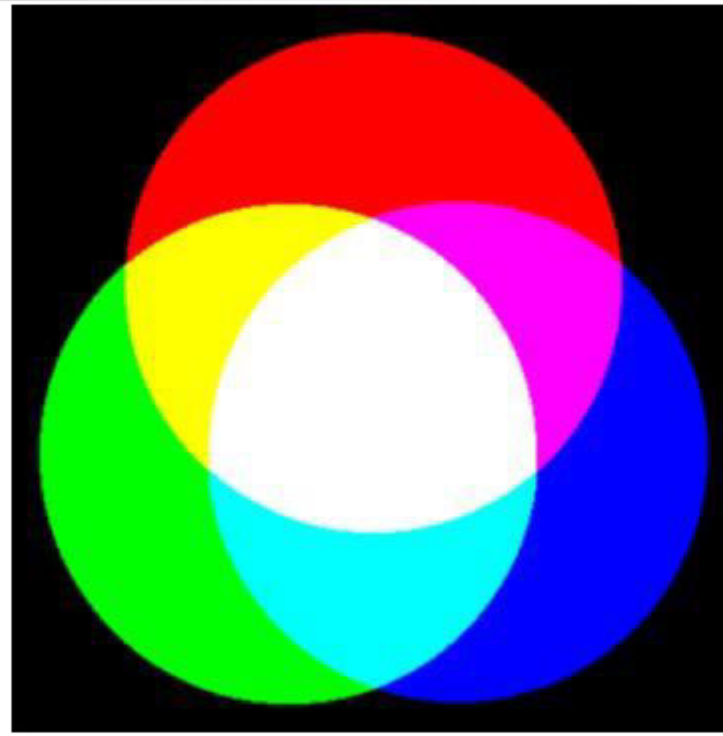
FIGURE 6.4 Primary and secondary colors of light and pigments. (Courtesy of the General Electric Co., Lamp Business Division.)

Primary and Secondary Colors

Additive Primaries of Light	**Subtractive primaries of Pigments**
Red + Green + Blue = White	Cyan + Magenta + Yellow = Black
Red + Green = Yellow	Cyan = White - Red
Green + Blue = Cyan	Magenta = White - Green
Blue + Red = Magenta	Yellow = White - Blue

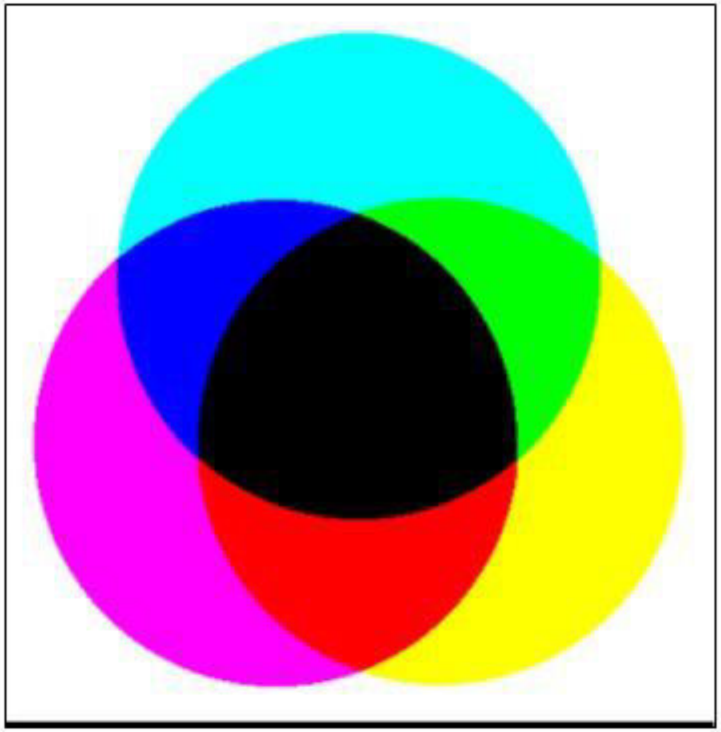
RGB Color model

Source: www.mitsubishi.com



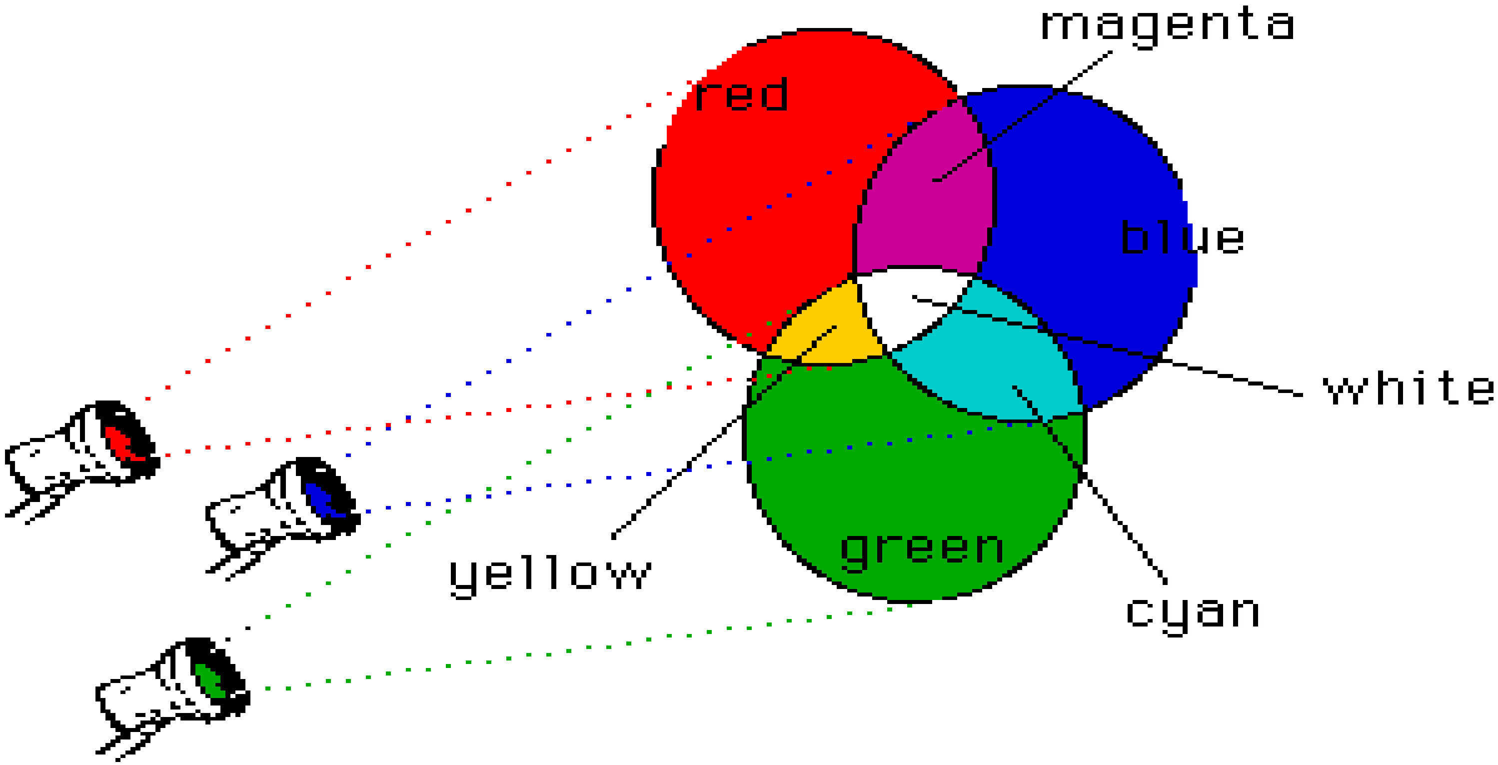
Active displays, such as computer monitors and television sets, emit combinations of red, green and blue light. This is an **additive** color model

CMY Color model

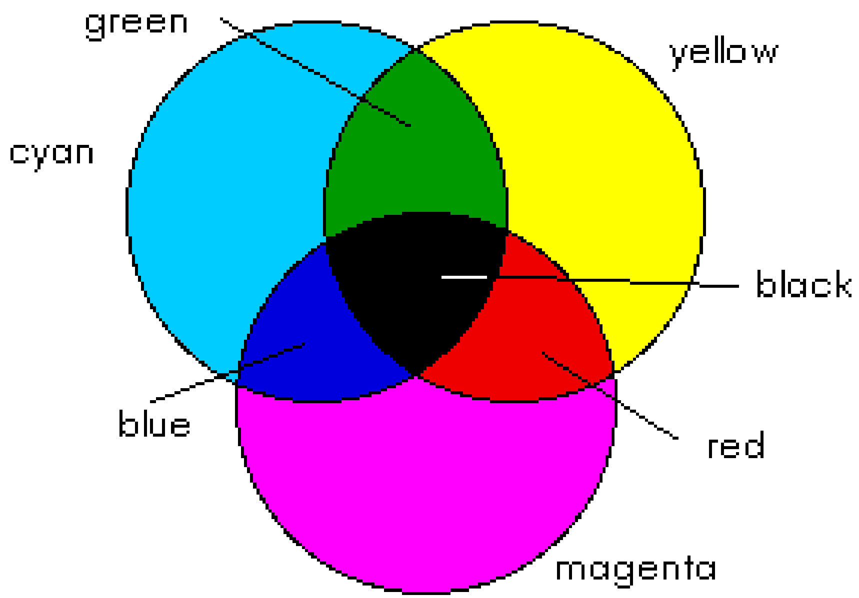


Passive displays, such as color inkjet printers, **absorb** light instead of emitting it. Combinations of **cyan**, **magenta** and **yellow** inks are used. This is a **subtractive** color model.

Color Addition: mixtures of light



- ❖ Overlapping filters of the subtractive primary colors Cyan, Yellow and Magenta allow the additive primary colors Red, Green, and Blue -- to pass through where two of the filters overlap.
- ❖ Where all three filters overlap, no light passes through and the area is black



Color subtraction is the basis for all color **printing**. Pigments of cyan, yellow, and magenta are used to produce a myriad of colors. A **fourth** printing of **black** is used to make colors and shadows darker.

Summary

- Additive color mixing involves multiple sources of light with different colors in each source.
- Subtractive color mixing involves a single source of light with different colors absorbing various wavelengths of the color spectrum.
- Additive color systems use colored light passing through the image elements to reconstruct the full colors on the screen.
- Subtractive systems use multi-layered colored dyes to reconstruct the spectrum on the film and then white light projects through the image onto the screen.

Color Models

- Also known as *color space* or *color system*
- Purpose is to facilitate the specification of colors in some standard, generally accepted way
- Oriented either toward hardware (such as monitors and printers) or toward applications (color graphics for animation)
- Hardware oriented models most commonly used in practices are the RGB model for color monitors or color video cameras, CMY and CMYK models for color printing, and the HSI model, which corresponds closely with the way humans describe and interpret color.
- HSI model also has the advantage that it decouples the color and gray-scale information in an image

The RGB Color Model

- ❑Each colour appears in its primary spectral components of red, green and blue
- ❑The model is based on a Cartesian coordinate system
  - RGB values are at 3 corners
  - Cyan magenta and yellow are at three other corners
  - Black is at the origin
  - White is the corner furthest from the origin
  - Different colours are points on or inside the cube represented by RGB vectors

RGB Color Model

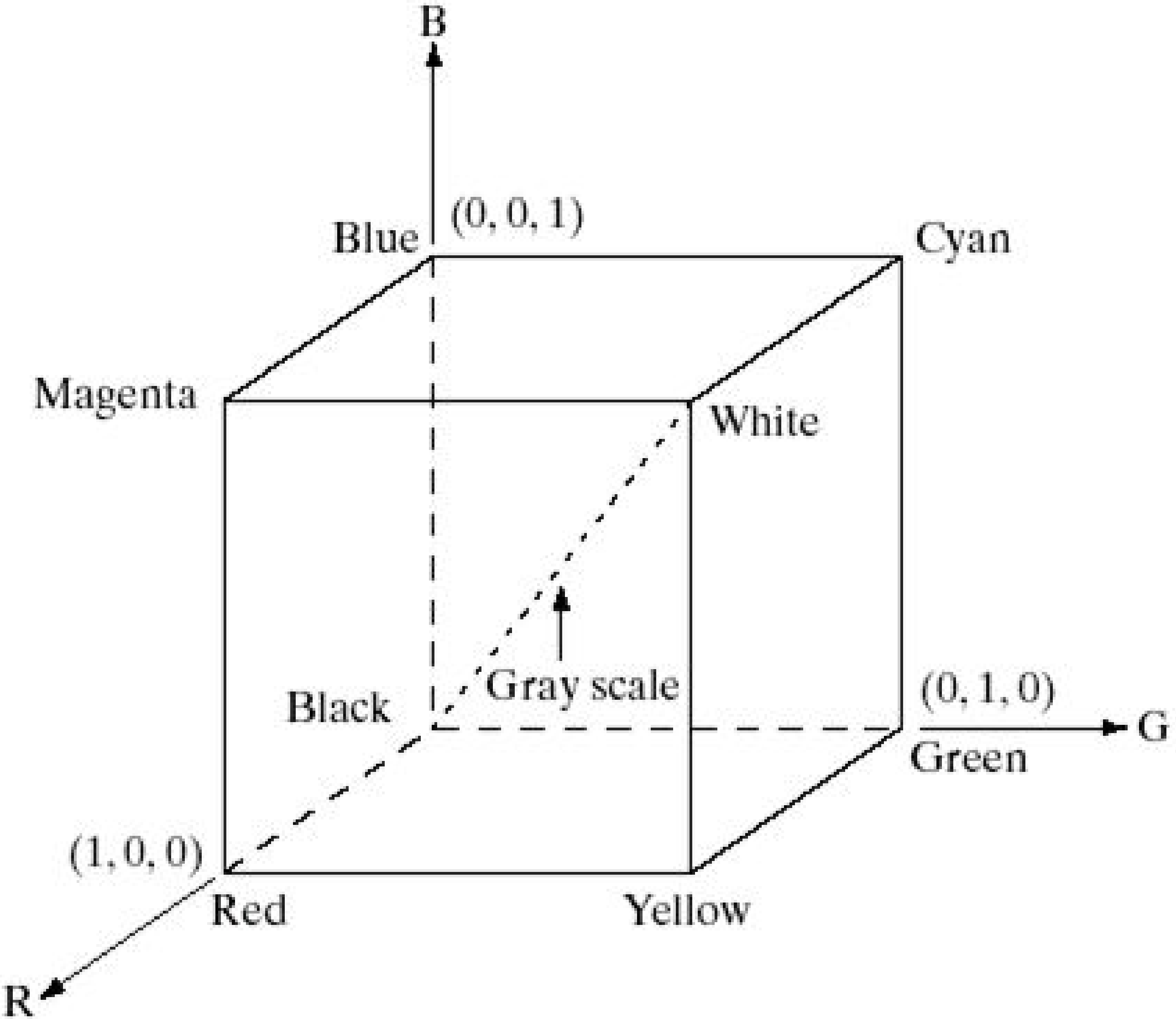
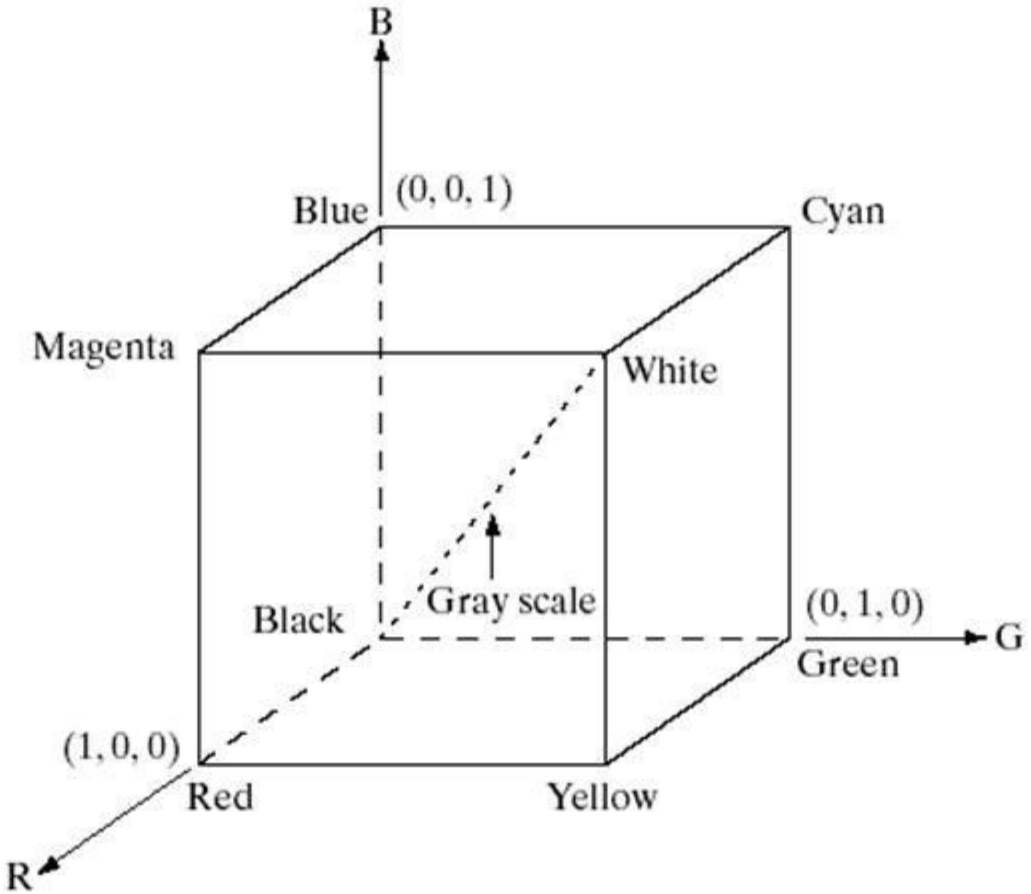
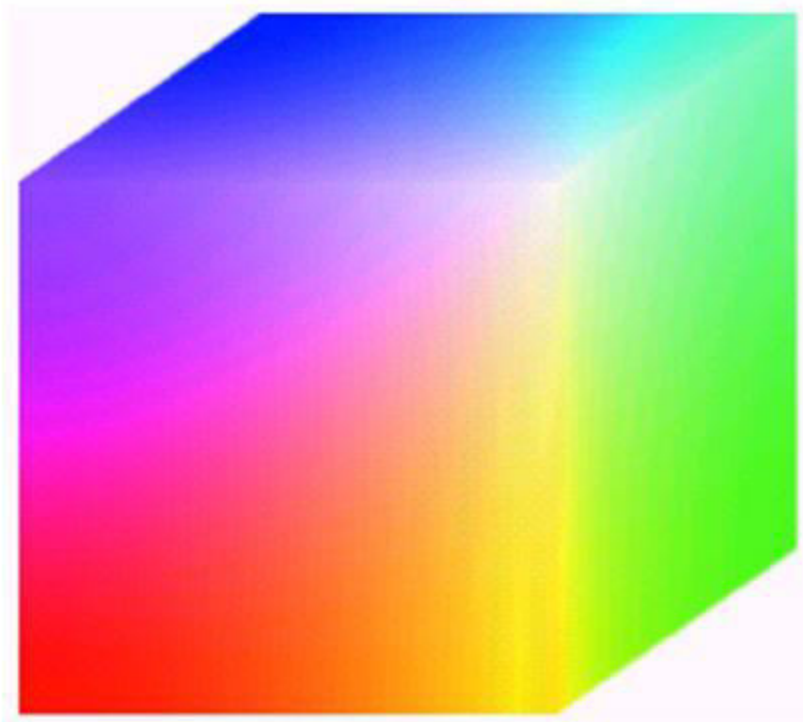


FIGURE 6.7 Schematic of the RGB color cube. Points along the main diagonal have gray values, from black at the origin to white at point (1, 1, 1).

RGB color cube





RGB 24-bit color cube

RGB Color Model

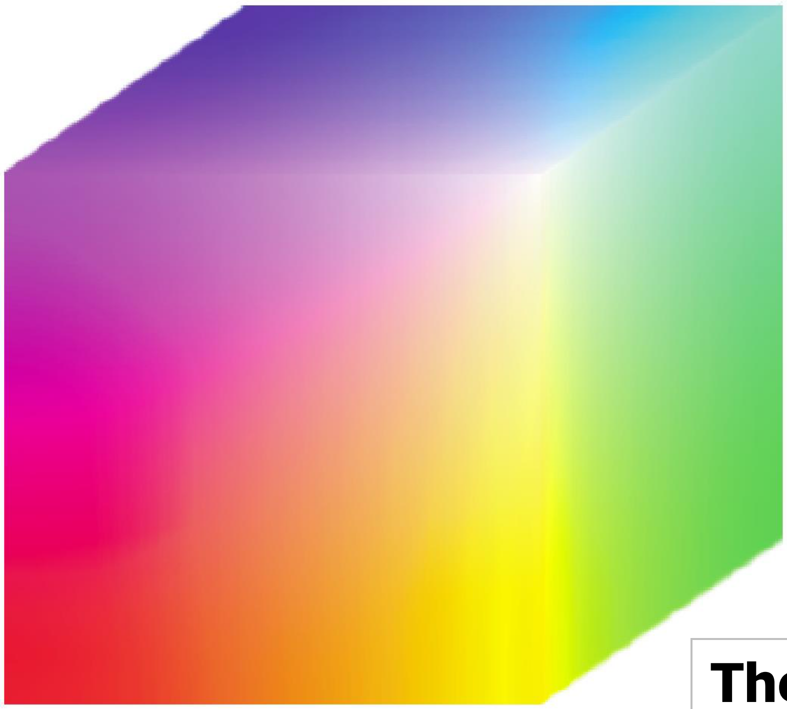


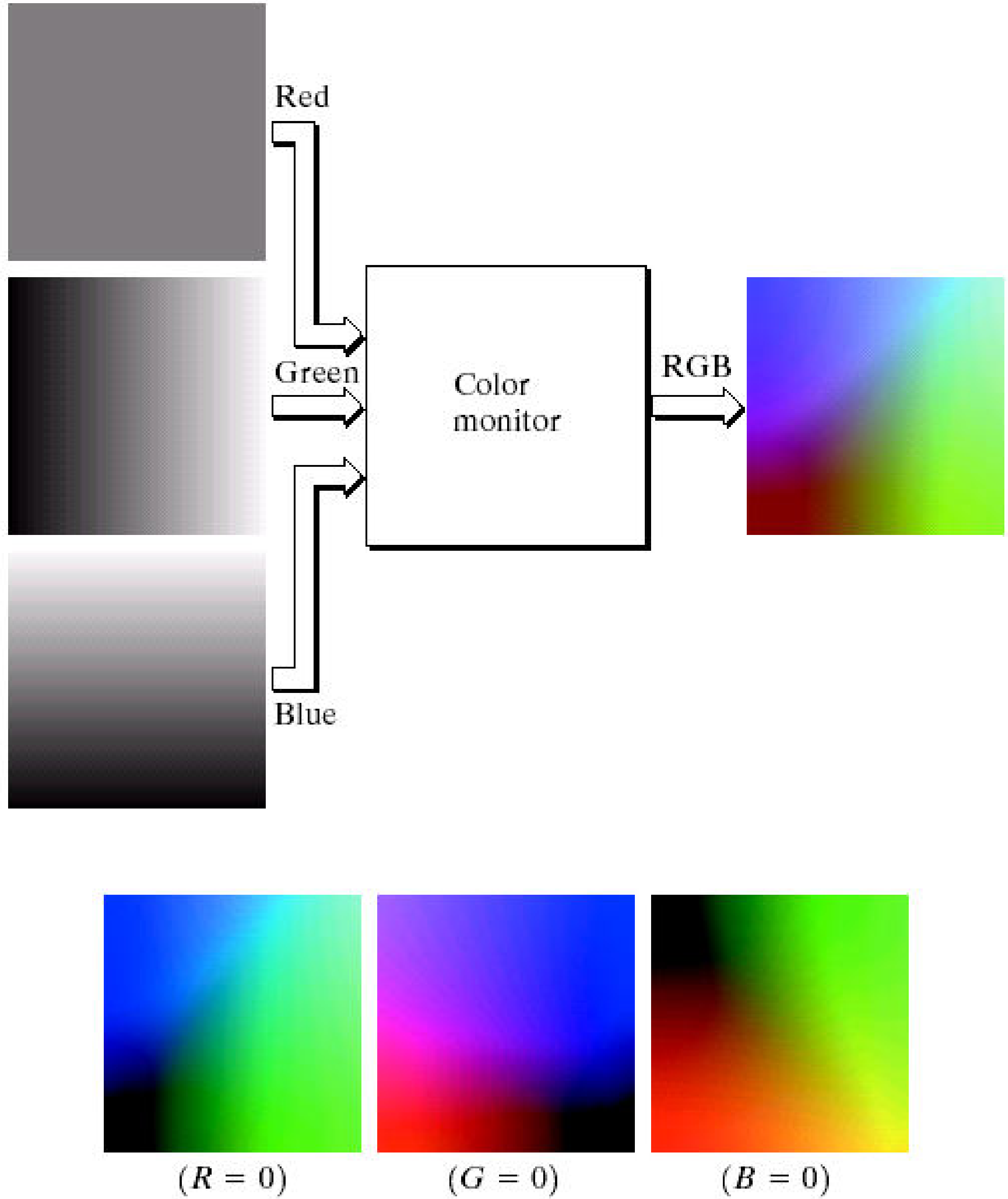
FIGURE 6.8 RGB 24-bit color cube.

Pixel depth = 24 bits
(8 bit per plane)

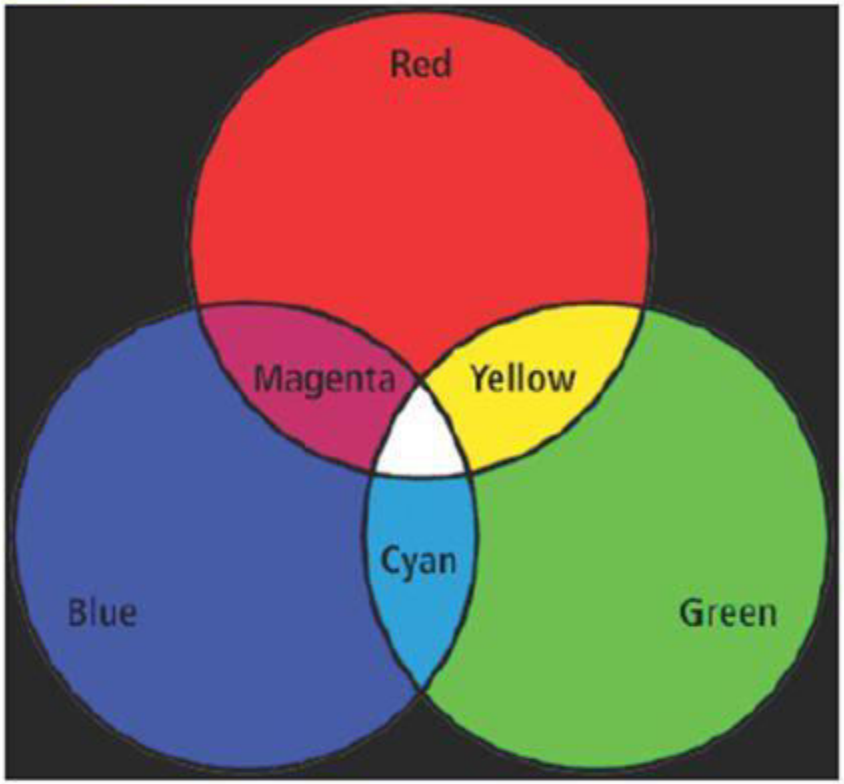
The total number of colors in a 24-bit RGB image is
$(2^8)^3$ = 16,777,216

a
b

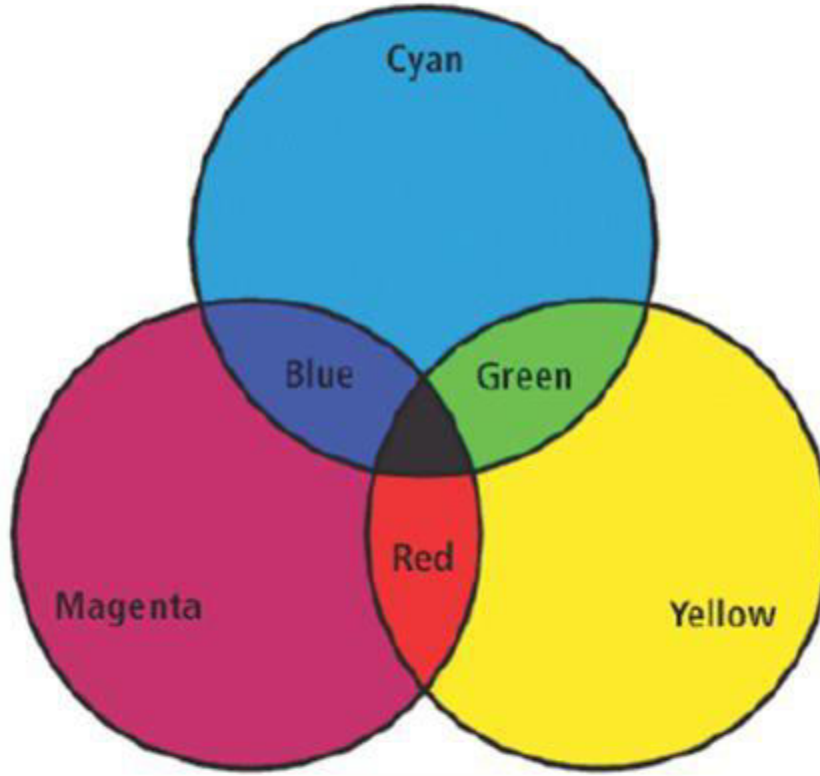
FIGURE 6.9
(a) Generating the RGB image of the cross-sectional color plane $(127, G, B)$.
(b) The three hidden surface planes in the color cube of Fig. 6.8.



RGB vs CMY



Magenta = Red + Blue
Cyan = Blue + Green
Yellow = Green + Red



Magenta = White - Green
Cyan = White - Red
Yellow = White - Blue

The CMY and CMYK Color Models

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

Equal amounts of the pigment primaries, cyan, magenta, and yellow should produce black. In practice, combining these colors for printing produces a muddy-looking black.

To produce true black, the predominant color in printing, the fourth color, black, is added, giving rise to the CMYK color model.

RGB Example

Original Red Band Green Band Blue Band

RGB Example

Original | No Red | No Green | No Blue

RGB Example

Red

Green

Blue

Example of Color Quantization

24 bits -> 8 bits

Adaptive (non-uniform) quantization
(vector quantization)

Uniform quantization
(3 bits for R,G, 2 bits for B)

Light Intensity

- Note that intensity is a weighted function of the r, g, b values.
- The human eye doesn't weight each component identically!

```
intensity = 0.299*Red + 0.587*Green + 0.144*Blue
```

- Assume three light sources have the same **actual** intensity but are colored red, green, and blue

The **green** light will appear brightest followed by **red** and **blue**

The HSI Colour Model

- RGB is useful for hardware implementations and is serendipitously related to the way in which the human visual system works.

- However, RGB is not a particularly intuitive way to describe colours rather describe colours to use **hue**, **saturation** and **brightness.**

- RGB is great for colour generation, but HSI is great for colour description.

The HSI Colour Model (cont…)

The HSI model uses three measures to describe colours:

– **Hue:** A colour attribute that describes a pure colour (pure yellow, orange or red)

– **Saturation:** Gives a measure of how much a pure colour is diluted with white light

– **Brightness:** Brightness is nearly impossible to measure because it is so subjective. Instead we use **intensity**.

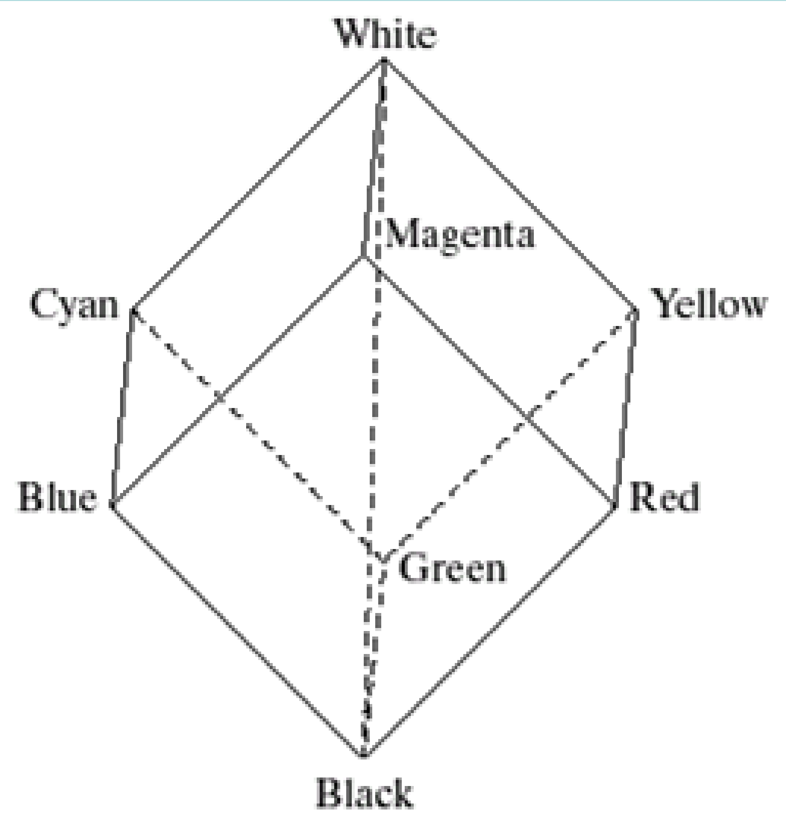
Intensity: is the same achromatic notion that we have seen in grey level images.

HSI, Intensity & RGB

- Intensity can be extracted from RGB images which is not surprising if we stop to think about it
- Remember the diagonal on the RGB colour cube that we saw previously ran from black to white
- Now consider if we stand this cube on the black vertex and position the white vertex directly above it

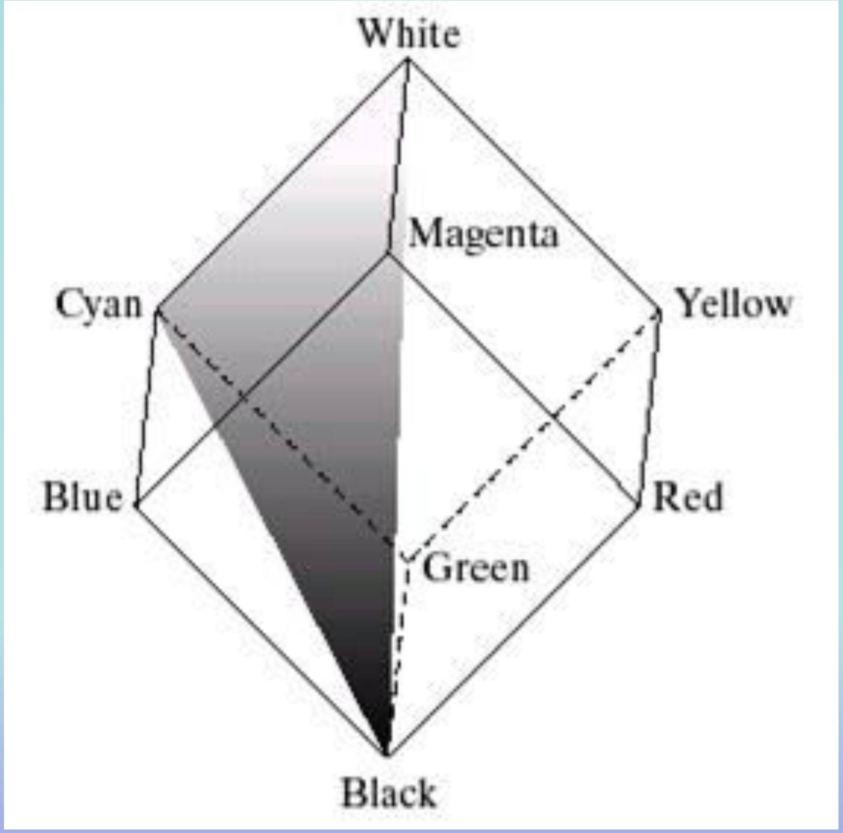
HSI, Intensity & RGB (cont…)

- Now the intensity component of any colour can be determined by passing a plane *perpendicular* to the intensity axis and containing the colour point
- The intersection of the plane with the intensity axis gives us the intensity component of the colour



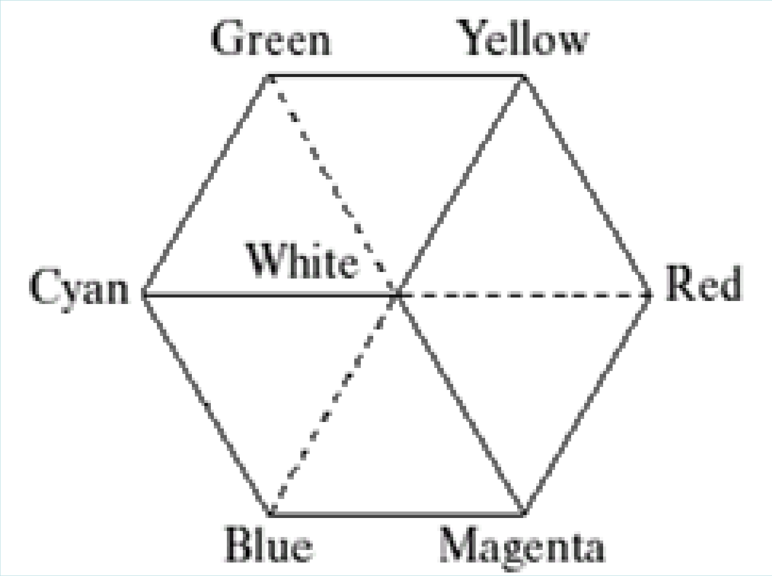
HSI, Hue & RGB

- In a similar way we can extract the hue from the RGB colour cube
- Consider a plane defined by the three points cyan, black and white
- All points contained in this plane must have the same hue (cyan) as black and white cannot contribute hue information to a colour



The HSI Colour Model

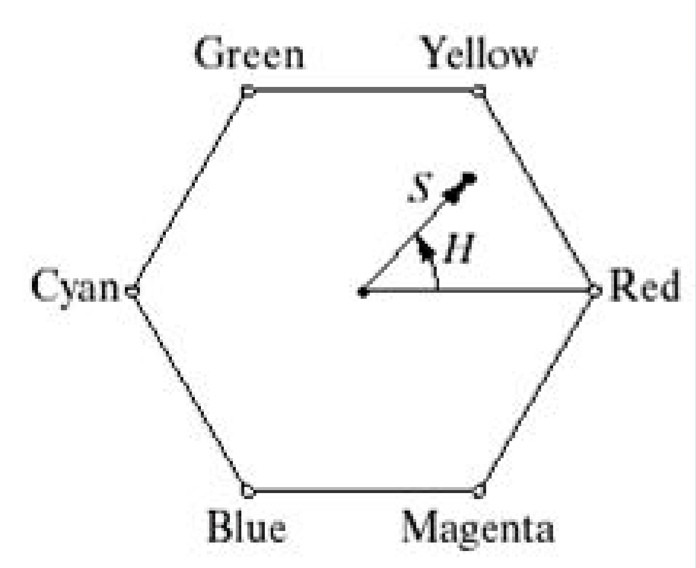
- Consider if we look straight down at the RGB cube as it was arranged previously
- We would see a hexagonal shape with each primary colour separated by 120° and secondary colours at 60°from the primaries



- So the HSI model is composed of a vertical intensity axis and the locus of colour points that lie on planes perpendicular to that axis

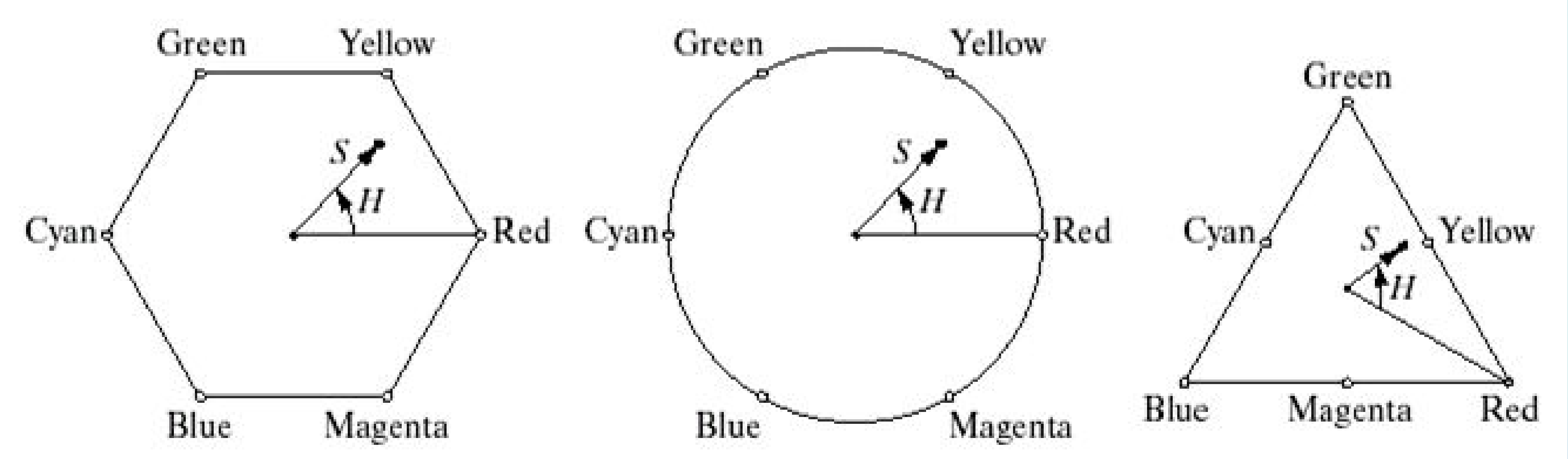
The HSI Colour Model (cont…)

- To the right we see a hexagonal shape and an arbitrary colour point
  - The hue is determined by an angle from a reference point, usually red
  - The saturation is the distance from the origin to the point
  - The intensity is determined by how far up the vertical intensity axis this hexagonal plane sits (not apparent from this diagram

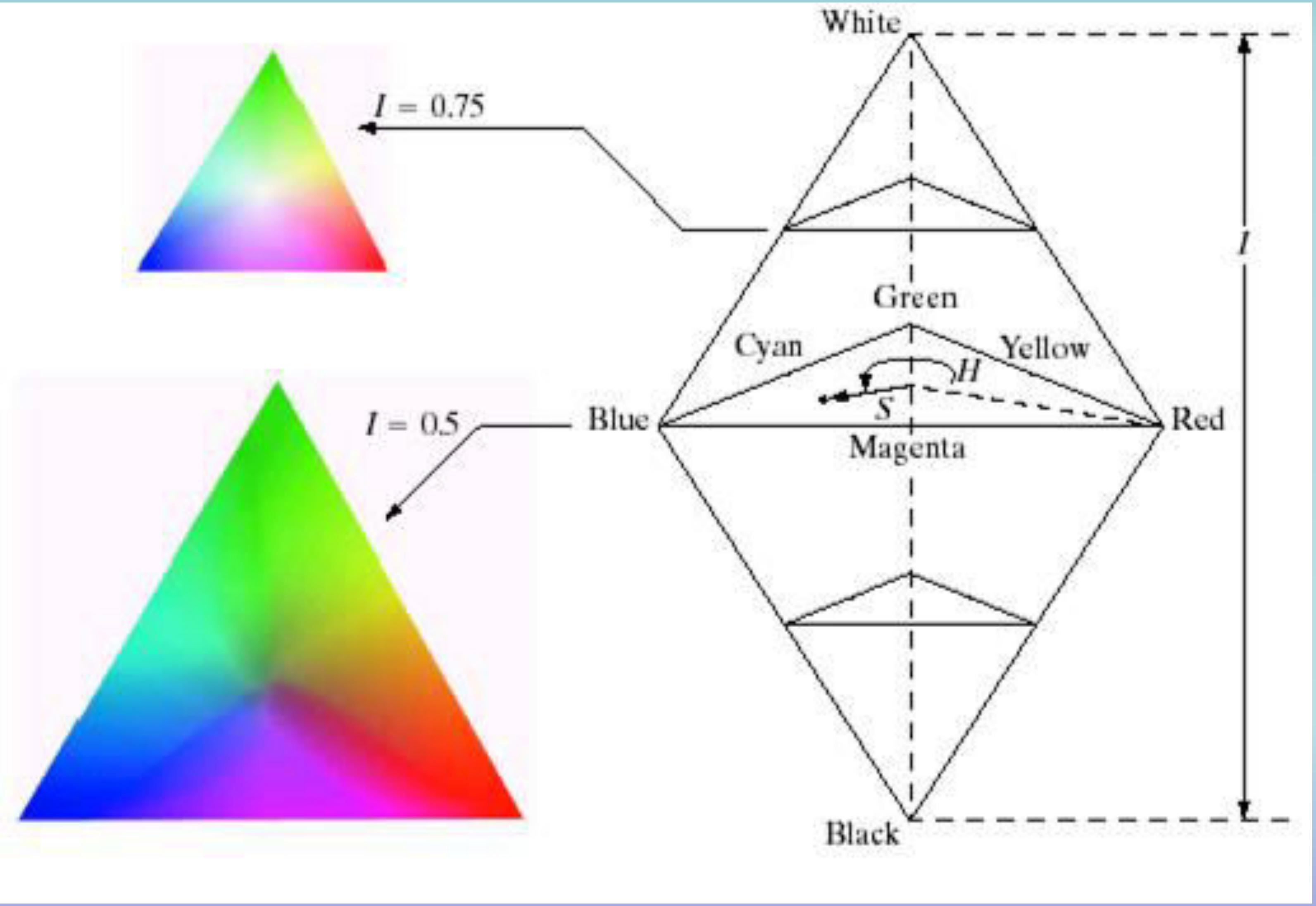


The HSI Colour Model (cont…)

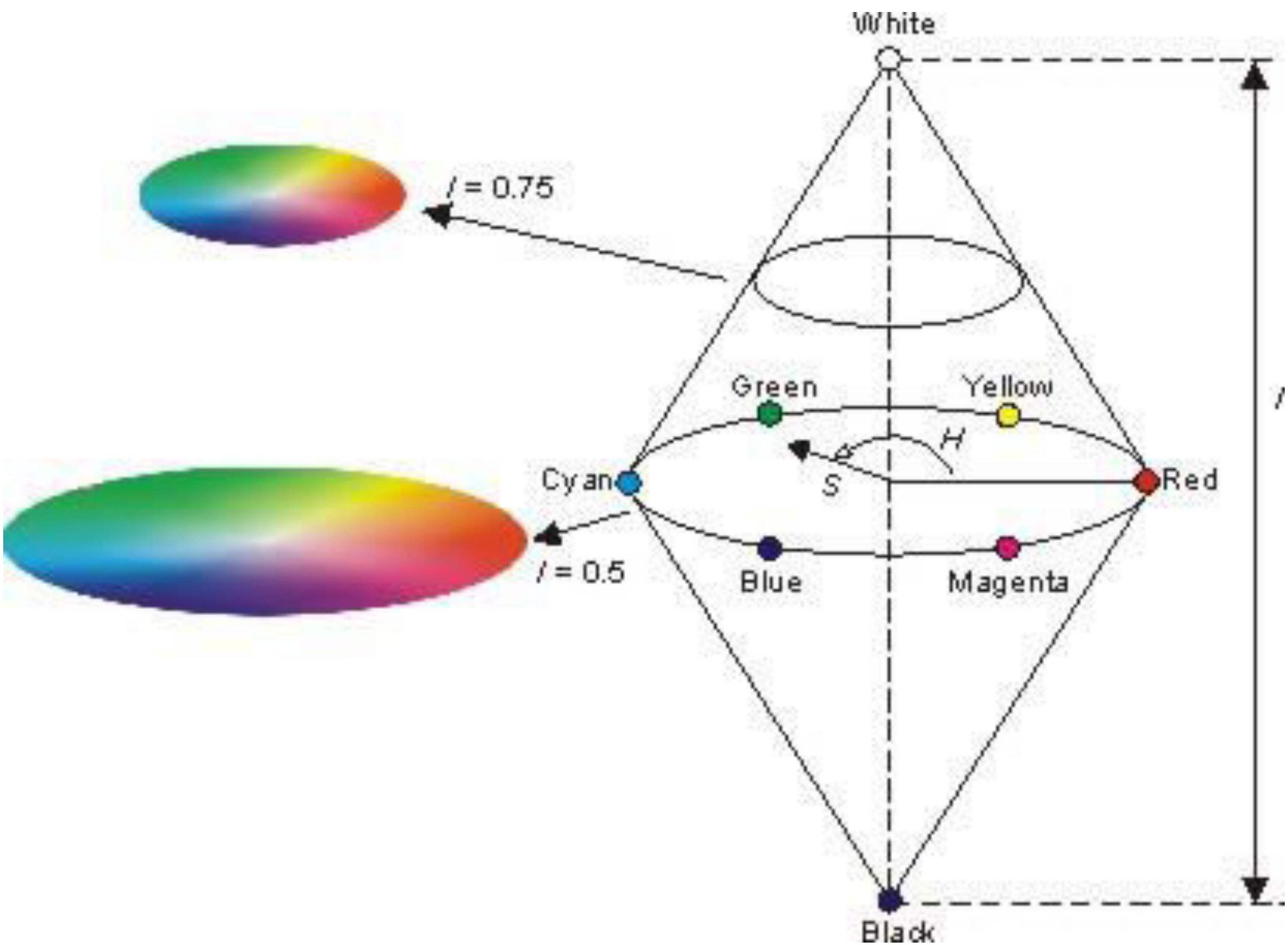
- Because the only important things are the angle and the length of the saturation vector this plane is also often represented as a circle or a triangle



HSI Model Examples



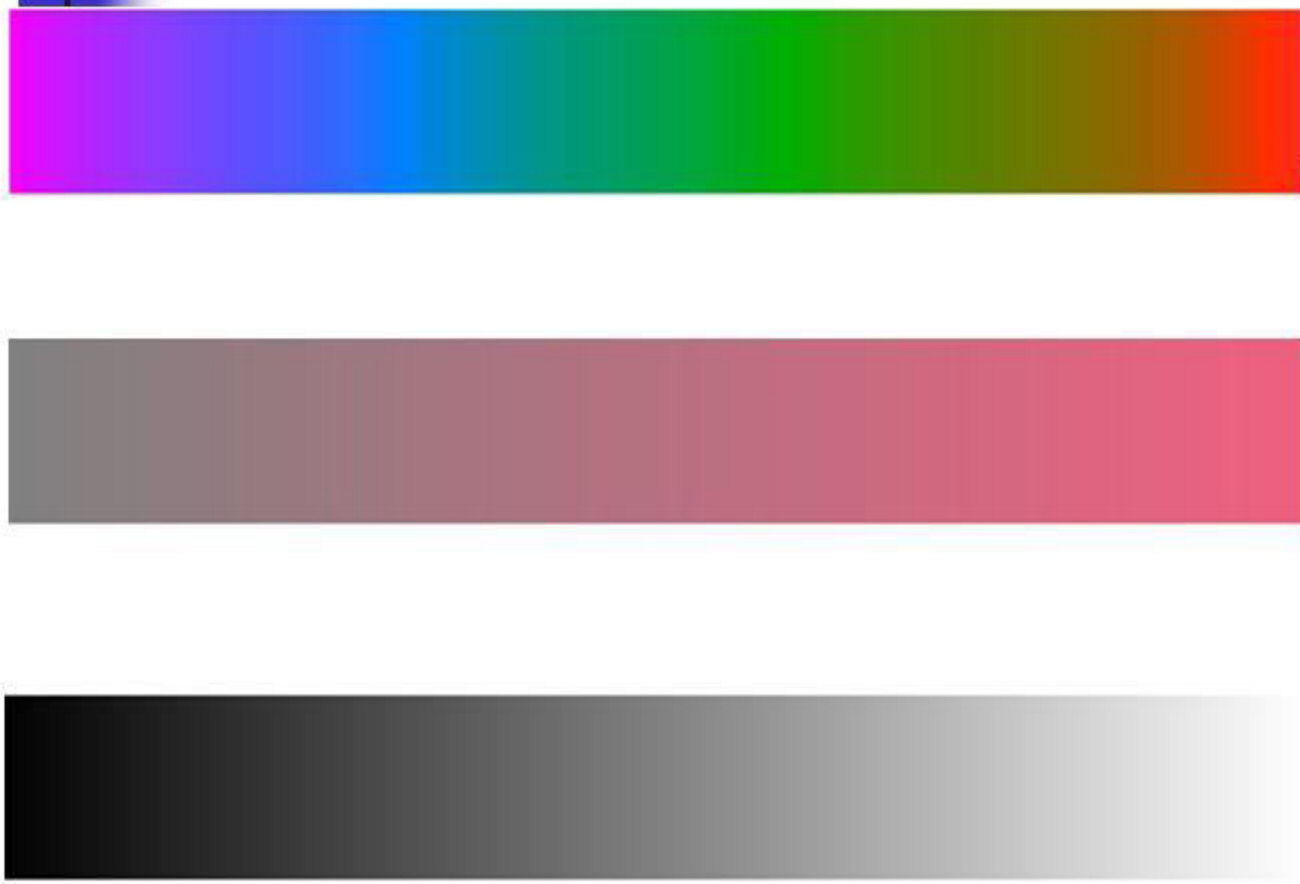
HSI Model Examples



HSI Color Model

- Based on human perception of colors. **Color** is "decoupled" from **intensity**.
  - HUE
    - A subjective measure of color
    - Average human eye can perceive ~200 different colors
  - Saturation
    - Relative purity of the color. Mixing more "white" with a color reduces its saturation.
    - Pink has the same **hue** as **red** but less **saturation**
  - Intensity
    - The brightness or darkness of an object

HSI Color Model



H
dominant wavelength

S
purity
% white

I
Intensity

Source: http://www.cs.cornell.edu/courses/cs631/1999sp/

HSI Color Model

- Hue is defined as an angle
  - 0 degrees is RED
  - 120 degrees is GREEN
  - 240 degrees is BLUE
- Saturation is defined as the percentage of distance from the center of the HSI triangle to the pyramid surface.
  - Values range from 0 to 1.
- Intensity is denoted as the distance "up" the axis from black.
  - Values range from 0 to 1

Conversion Between RGB and HSI

- Converting color from RGB to HSI

$$H = \begin{cases} \theta & \text{if } B \le G \\ 360-\theta & \text{if } B > G \end{cases} \quad \text{with } \theta = \cos^{-1}\left\{ \frac{\frac{1}{2}[(R-G)+(R-B)]}{\left[(R-G)^2+(R-B)(G-B)\right]^{\frac{1}{2}}} \right\}$$

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

$$I = \frac{1}{3}[R+G+B]$$

- Converting color from HSI to RGB

RG sector (0≤H<120)

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

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

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

GB sector (120≤H<240)

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

$$G = I\left[1 + \frac{S\cos(H-120)}{\cos(60-(H-120))}\right]$$

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

BR sector (240≤H<360)

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

$$B = I\left[1 + \frac{S\cos(H-240)}{\cos(60-(H-240))}\right]$$

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

Criteria for Choosing the Color Coordinates

- The type of representation depends on the applications at hand.
  - For display or printing, choose primary colors so that more colors can be produced. E.g. RGB for displaying and CMY for printing.
- For analytical analysis of color differences, HSI is more suitable.
- For transmission or storage, choose a less redundant representation, eg. YIQ or YUV or YCbCr

Thank

You

Color Fundamentals

- If the light is **achromatic** (void of color), its only attribute is its intensity, or amount
- **Chromatic** light spans EM from 380 to 780 nm
- Three basic quantities to describe the quality:
- 1) **Radiance** is the total amount of energy that flows from the light source, and it is usually measured in watts (W)
- 2) **Luminance,** measured in lumens (lm), gives a measure of the amount of energy an observer perceives from a light source
- For example, light emitted from a source operating in the far infrared region of the spectrum could have significant energy (radiance), but an observer would hardly perceive it; its luminance would be almost zero

Color Fundamentals

- 3) **Brightness** is a subjective descriptor that is practically impossible to measure. It embodies the achromatic notion of intensity and is one of the key factors in describing color sensation

Color Fundamentals

- To distinguish one color from another are **brightness, hue,** and **saturation**
- **Brightness** embodies the achromatic notion of intensity
- **Hue** is an attribute associated with the dominant wavelength in a mixture of light waves. Hue represents dominant color as perceived by an observer. Thus, when we call an object red, orange, or yellow, we are referring to its hue
- **Saturation** refers to the relative purity or the amount of white light mixed with a hue. The pure spectrum colors are fully saturated. Colors such as pink and lavender are less saturated, with the degree of saturation being inversely proportional to the amount of white light added

Color Fundamentals

- Hue and saturation taken together are called **Chromaticity**
- Therefore a color may be characterized by its brightness and chromaticity
- The amounts of red, green, and blue needed to form any particular color are called the **Tristimulus** values and are denoted, X, Y, and Z, respectively
- **Tri-chromatic coefficients**

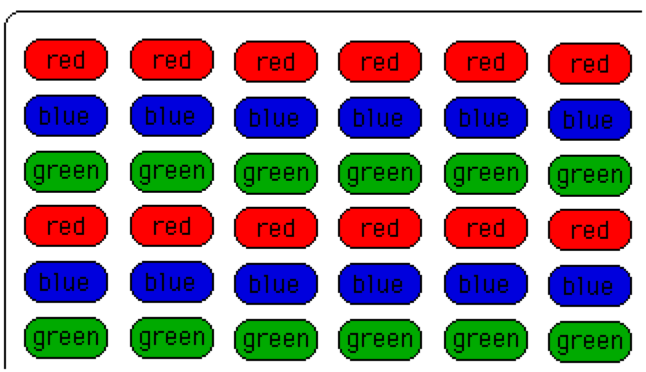
$$x = \frac{X}{X+Y+Z} \qquad y = \frac{Y}{X+Y+Z} \qquad z = \frac{Z}{X+Y+Z}$$

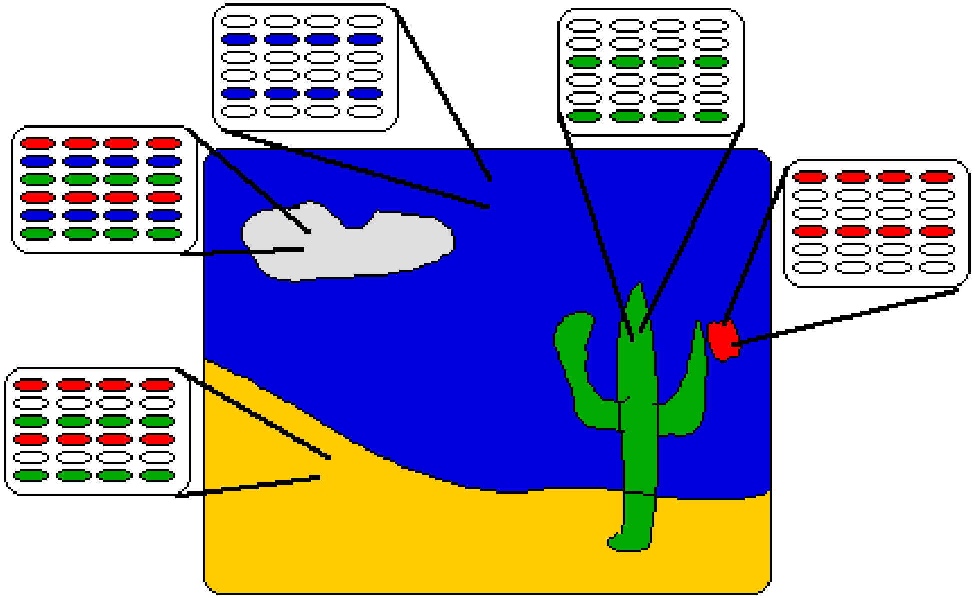
$$x + y + z = 1$$

Color Fundamentals

- Color Image Processing is divided into two major areas:
- 1) Full-color processing
  - Images are acquired with a full-color sensor, such as a color TV camera or color scanner
  - Used in publishing, visualization, and the Internet
- 2) Pseudo color processing
  - Assigning a color to a particular monochrome intensity or range of intensities

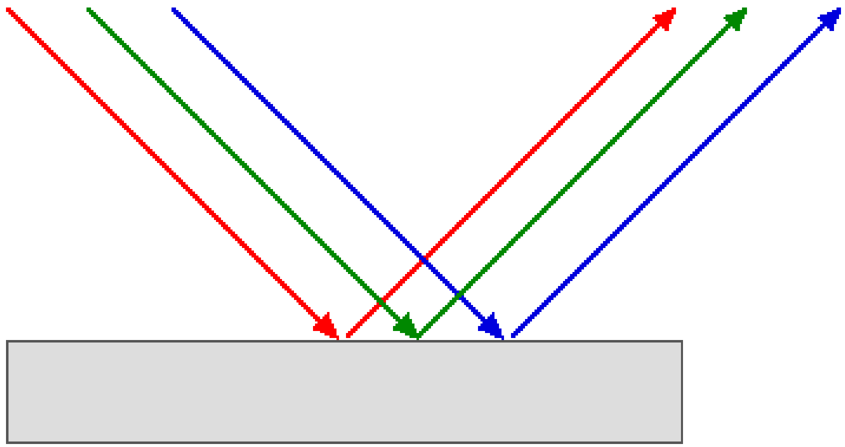
- A color screen or monitor is made up of thousands of tiny dots called phosphors which glow red, green, or blue when excited by an electron beam.
- All the colors that we see on a screen are made of differing intensities and combinations of red, green, and blue.





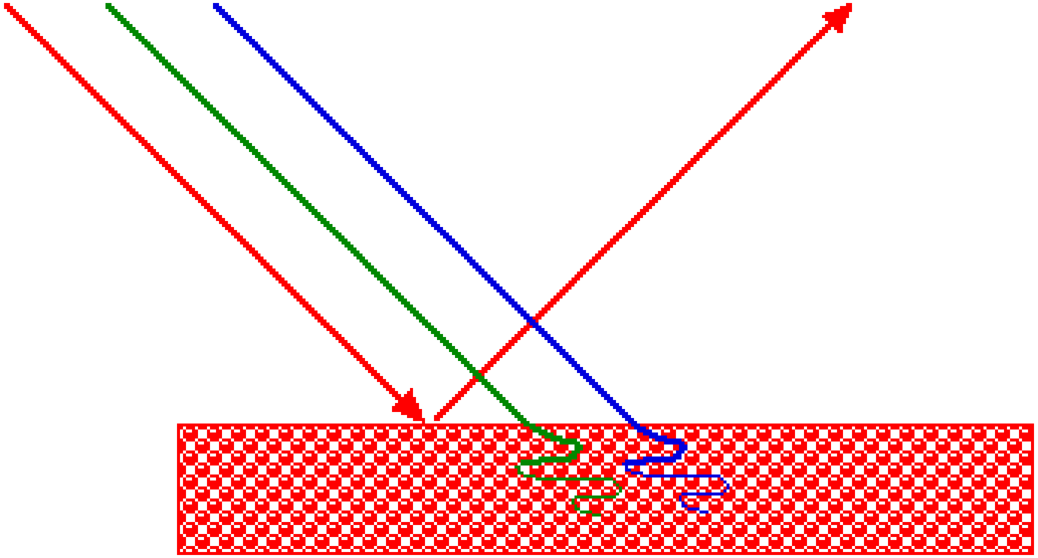
Color Subtraction: mixtures of pigments

- When red, green, and blue spotlights are "mixed" together, they produce white light.
- But you already know that mixing red, green, and blue paint together does not produce white -- it produces a murky grey or muddy brown.
- What is the difference? When we mix paint -- or ink or crayons or chalk -- we are mixing pigments.

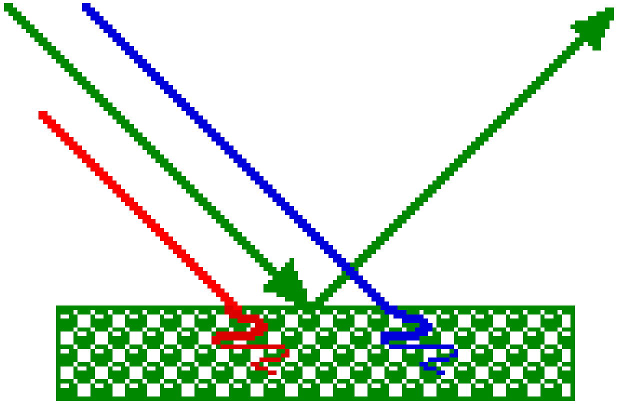


White paint reflects all colors.

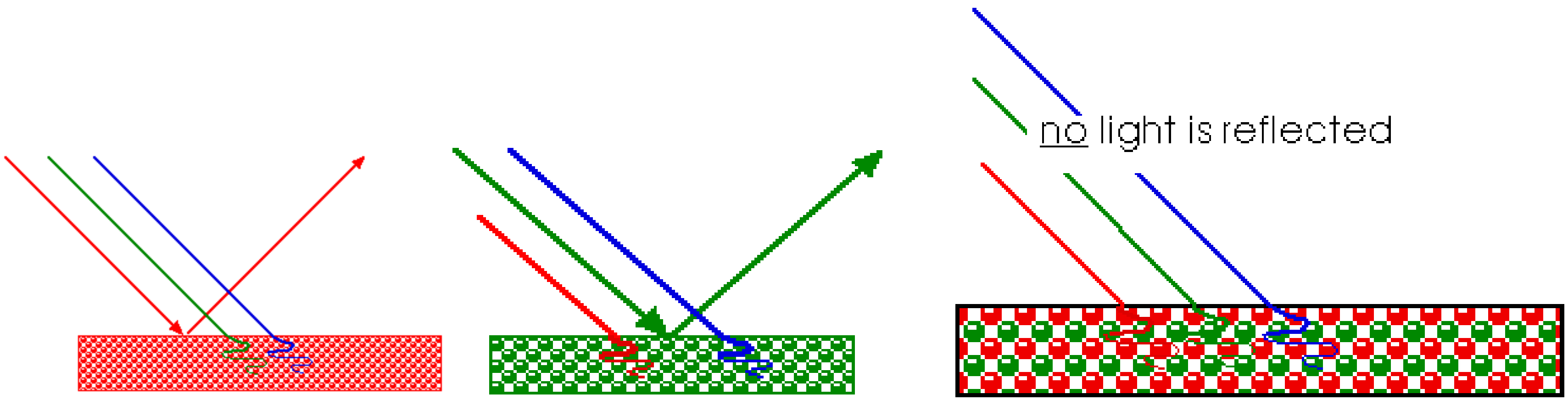
To make the paint red,
we mix in **red** pigment -
- small particles that
reflect **red** light
and **absorb** other colors
of light.



The green pigment will absorb the
red and blue light.
To make the paint green, we mix
in **green** pigment.

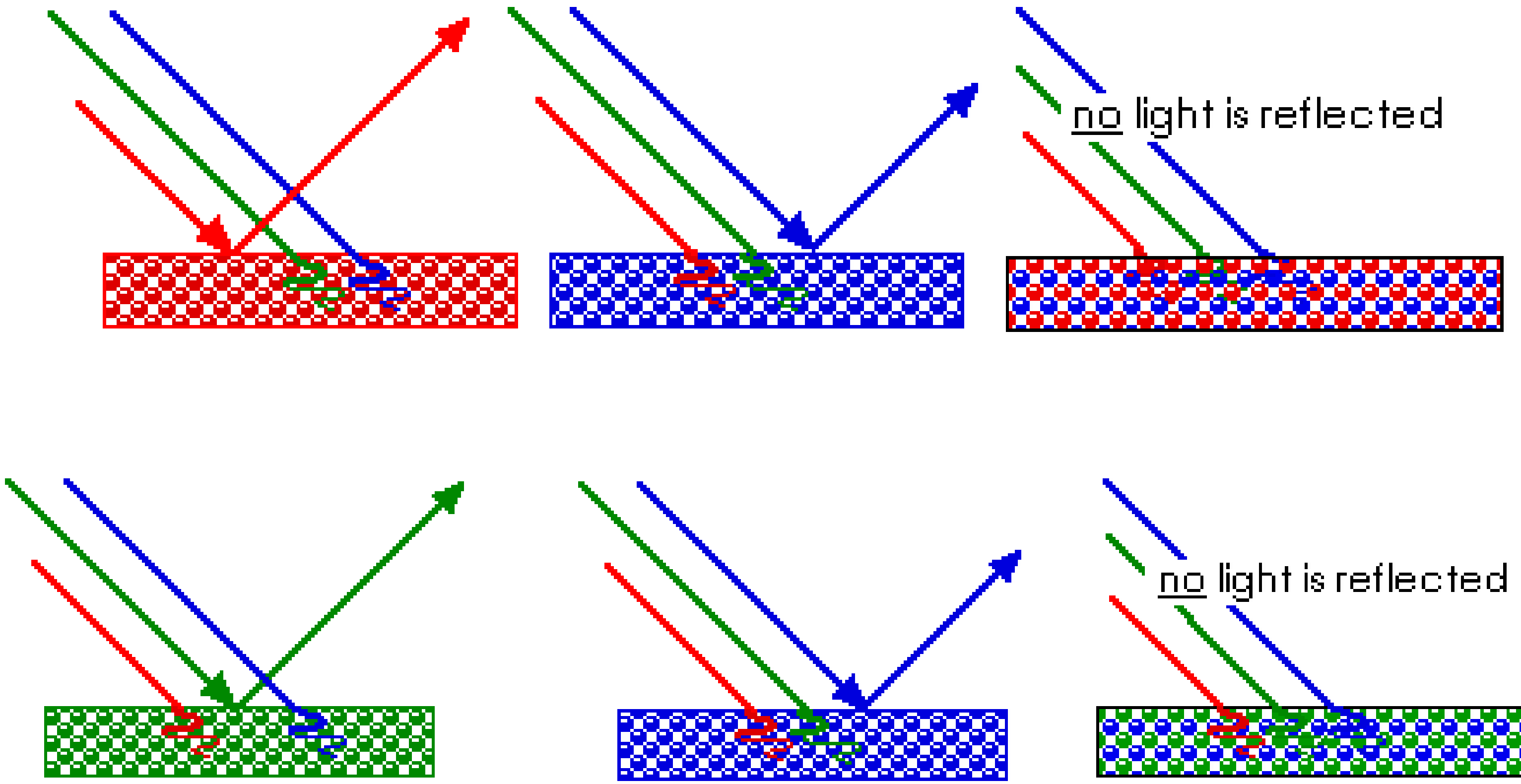


If we mix red and green pigment in white paint, the red pigment will absorb the green and blue light while the green pigment will absorb the red and blue light. The end result of this will be that **no light** is reflected at all, as illustrated below.



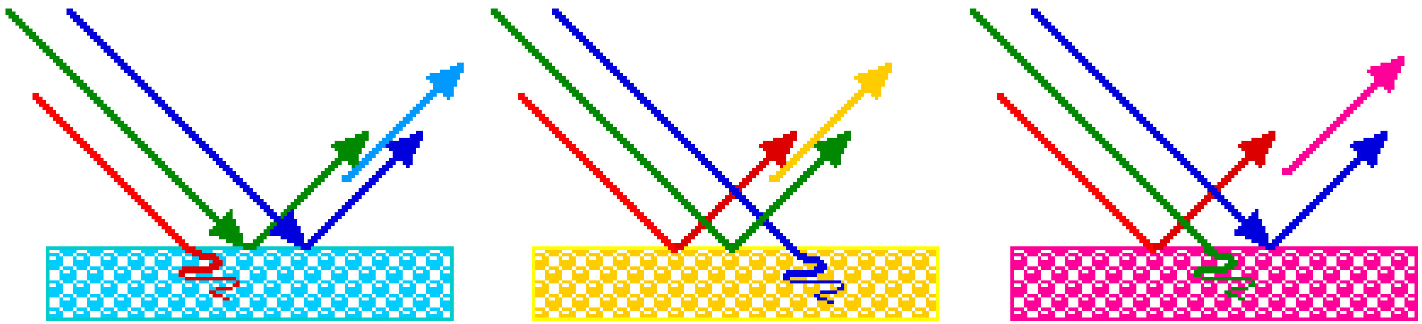
We will get black by mixing red and green pigment as illustrated above

We will also get BLACK as illustated bellow:



Pigment reflects what it does not absorb but its active role is absorbing. When paints are mixed together the result is the sum of their absorption characteristics. That is why this is known as **color subtraction.**

Cyan is light with a wavelength between green and blue or a combination of green and blue light.

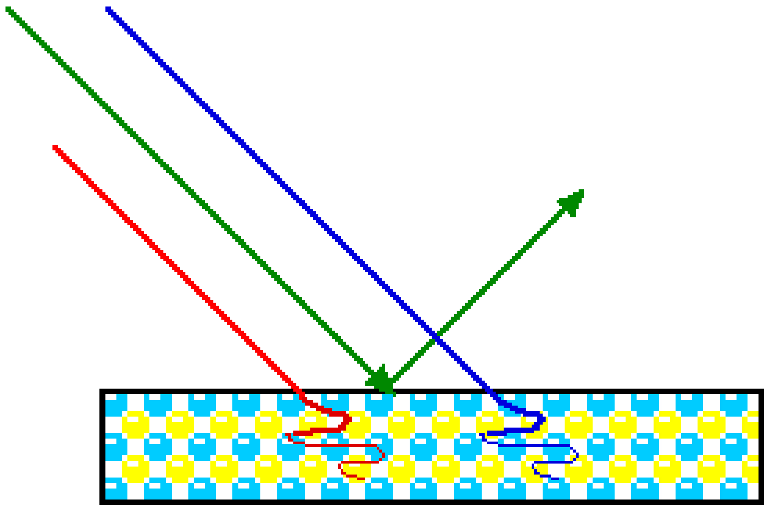


- Cyan pigment will absorb the red and reflect green and blue or cyan colored light.

- Yellow is seen when red and green light are combined.

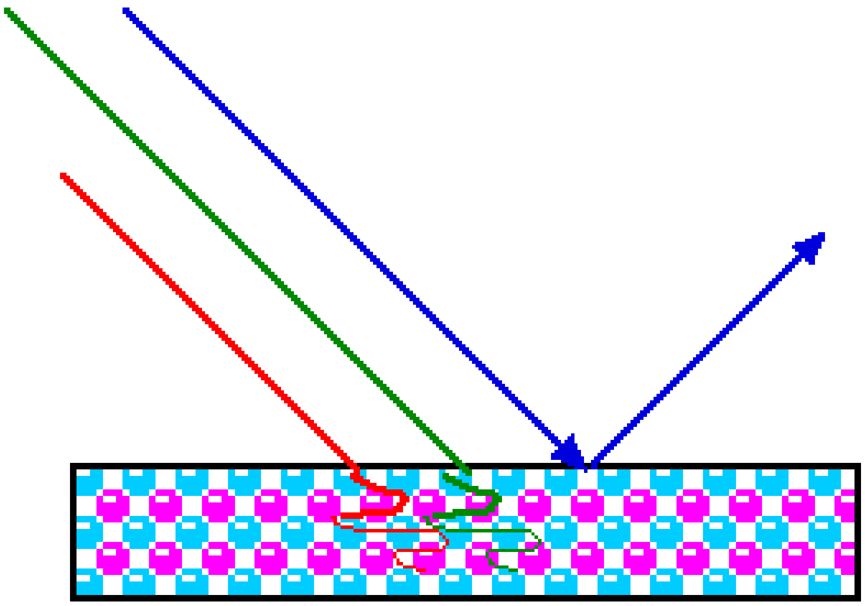
- Magenta is a combination of red and blue, without any green.

- We have already seen what happens when we mix various combinations of red, green, and blue paint.
- Now we shall do the same with cyan, yellow, and magenta.



cyan and yellow paint mixed together. The cyan pigment absorbs red while the yellow pigment absorbs blue. Only the green is reflected.

Here we show the mixing of cyan paint and magenta paint. Cyan absorbs red while magenta absorbs green. Only the blue remains.



Remember, when mixing pigments, it is the colors that are absorbed or taken out or subtracted that compound or accumulate.

Pigments in filters selectively absorb different colors and the remaining colors pass through the filters just as the remaining colors are reflected from paint.