Color Fundamentals

- When a beam of sunlight is passed through a glass prism, the emerging beam of light is not white but consists of a continuous spectrum of colors (Sir Isaac Newton, 1666).

- The color spectrum can be divided into six broad regions: violet, blue, green, yellow, orange, and red.

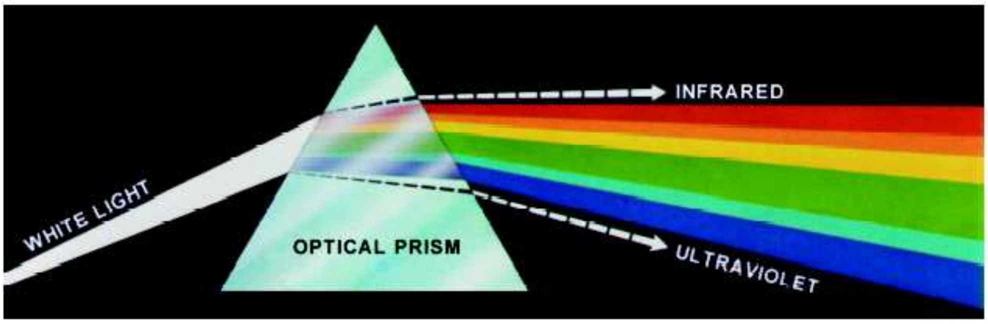


FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

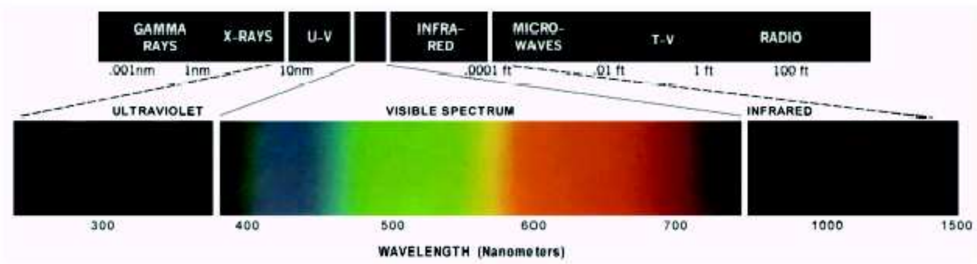


FIGURE 6.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

- The different colors in the spectrum do not end abruptly but each color blends smoothly into the next.

- Color perceived by the human eye depends on the nature of light reflected by an object. Light that is relatively balanced in all visible wavelengths is perceived as white. Objects that appear green reflect more light in the 500-570 nm range (absorbing other wavelengths of light).

- Characterization of light is important for the understanding of color.

- If the light is **achromatic** (devoid of color), its only attribute is its **intensity** (amount of light). This is what we have been dealing with so far. The term graylevel refers to the scalar measure of the intensity of light --- black to grays to white.

- **Chromatic** light spans the electromagnetic (EM) spectrum from approximately 400 nm to 700 nm.

- Three basic quantities are used to describe the quality of a chromatic source of light:

- **Radiance** is the total amount of light that flows from a light source (measured in Watts).
- **Luminance** gives a measure of the amount of energy an observer perceives from a light source (measured in lumens).
- **Brightness** is a subjective descriptor that is impossible to measure.

- Cones in the retina are responsible for color perception in the human eye.

- Six to seven million cones in the human eye can be divided into three categories: red light sensitive cones (65%), green light sensitive cones (33%) and blue light sensitive cones (2%). The latter cones are the most sensitive ones.

- Absorption of light by the three types of cones is illustrated in the figure below:

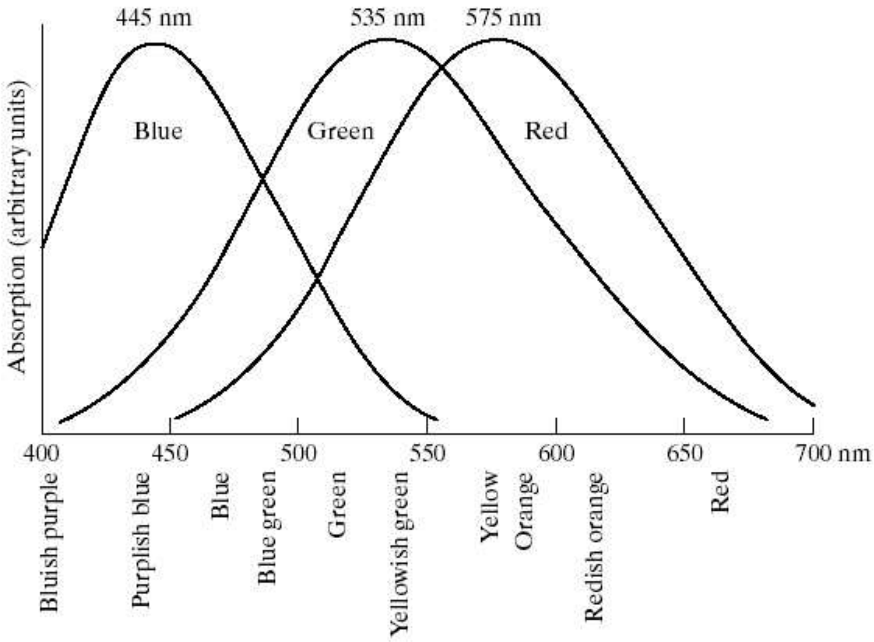
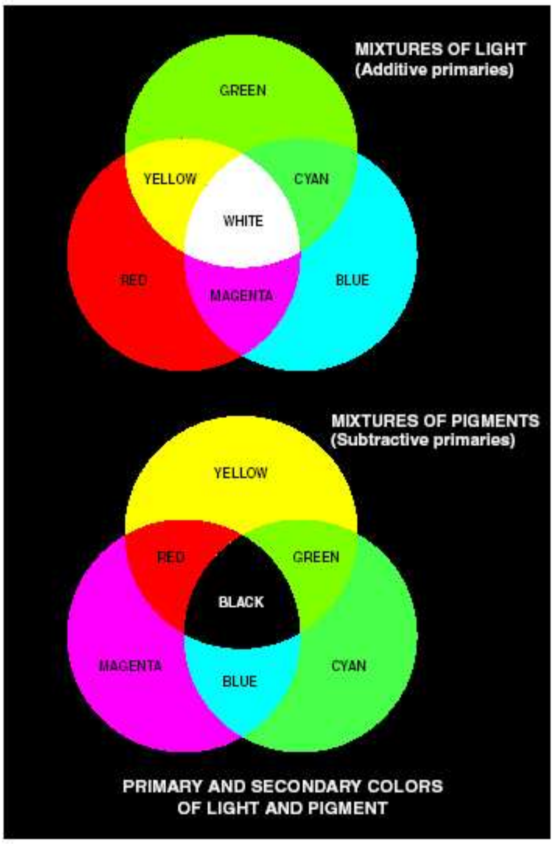


FIGURE 6.3 Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.

- Due to the absorption characteristics of the human eye, all colors perceived by the human can be considered as a variable combination of the so called three **primary colors**:
  - Red (R) (700 nm)
  - Green (G) (546.1 nm)
  - Blue (B) (435.8 nm)

- The wavelengths for the three primary colors are established by standardization by the CIE (International Commission on Illumination). They correspond to the experimental curve only approximately.

- Note that the specific color wavelengths are used mainly for standardization. It is not possible to produce all colors purely by combining these specific wavelengths.



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b

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

- Primary colors when added produce **secondary colors**:
  - Magenta (red + blue)
  - Cyan (green + blue)
  - Yellow (red + green)

- Mixing the three primaries, or a secondary with its opposite primary, in the right intensities produces white light.

- A primary color of pigment is defined as one that subtracts or absorbs a primary color of light and reflects or transmits the other two.

- Therefore, the primary colors of pigments are magenta, cyan, and yellow, and the secondary pigment colors are red, green, and blue.

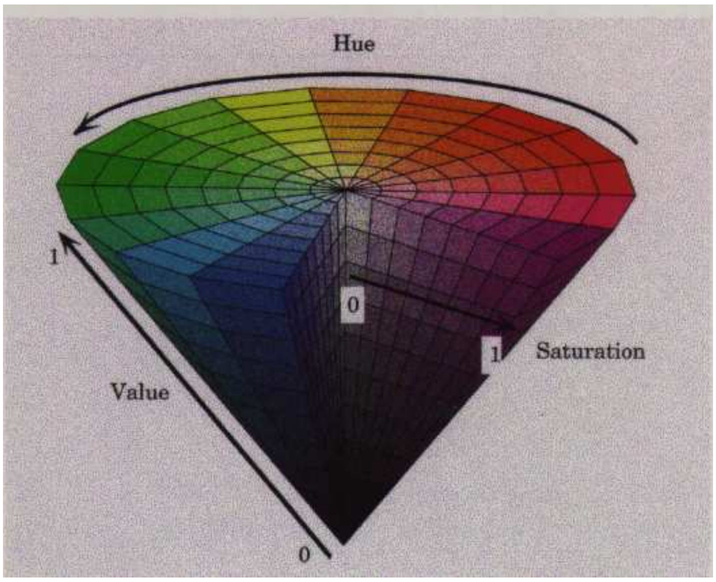
- Mixing the three pigment primaries, or a secondary with its opposite primary, in the right intensities produces black.

- Color television or a computer monitor is an example of additive nature of the color of light. The inside of the screen is coated with dots of phosphor, each being capable of producing one of the three primary colors. A combination of light of the three primary colors produces all the different colors we see.

- Printing is an example of the subtractive nature of color pigments. For example, a pigment of red color actually absorbs light of all wavelengths, except that corresponding to red color.

- The characteristics used to distinguish one color from another are:
  - **Brightness** (or value) embodies the chromatic notion of intensity.
  - **Hue** is an attribute associated with the dominant wavelength in a mixture of light waves. It represents the dominant color as perceived by an observer (ex. orange, red, violet).
  - **Saturation** refers to the relative purity or the amount of white light mixed with a hue. Pure colors are fully saturated. Colors such as pink (red + white) and lavendar (violet + white) are less saturated, with the saturation being inversely proportional to the amount of white light added.

- Hue and saturation together are called **chromaticity**. A color can be described in terms of its brightness and chromaticity.



Color Models

- The purpose of a color model (or color space or color system) is to facilitate the specification of color in some standard fashion.

- A color model is a specification of a 3-D coordinate system and a subspace within that system where each color is represented by a single point.

- Most color models in use today are either based on hardware (color camera, printer) or on applications involving color manipulation (computer graphics, animation).

- In image processing, the hardware based color models mainly used are: RGB, CMYK, and HSI.

- The RGB (red, green, blue) color system is used mainly in color monitors and video cameras.

- The CMYK (cyan, magenta, yellow, black) color system is used in printing devices.

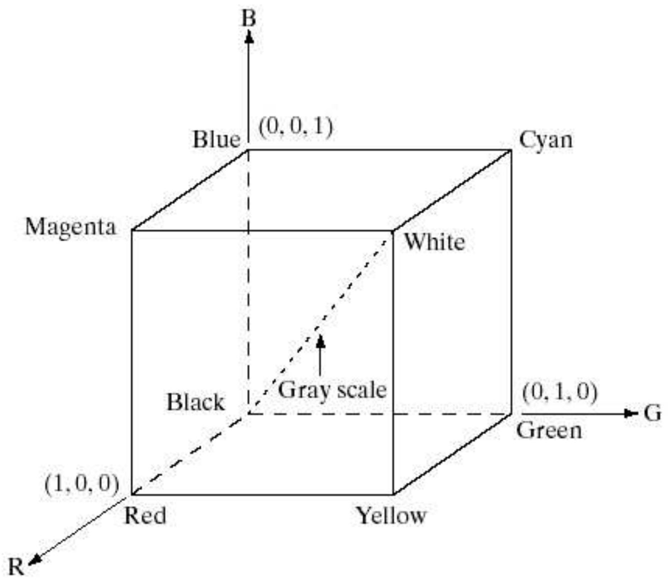
- The HSI (hue, saturation, intensity) is based on the way humans describe and interpret color. It also helps in separating the color and grayscale information in an image.

RGB Color model

- Each color appears in its primary spectral components of **red** (R), **green** (G), and **blue** (B).

- Mainly used for hardware such as color monitors and color video camera.

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).



- It is based on a Cartesian coordinate system. All color values are normalized so that the values of *R*, *G*, and *B* are in the range [0,1]. Thus, the color subspace of interest is the unit cube.

- The primary colors red, green, and blue correspond to three corners of the cube, whereas the secondary colors cyan, magenta, and yellow correspond to three other corners. Origin (0,0,0) represents black and (1,1,1) represents white.

- Grayscale (monochrome) is represented by the diagonal joining blak to white.

- Different points on or inside the cube correspond to different colors and can be represents as a vector or three values or coordinates. Each coordinate represents the amount of that primary color present in the given color.

- Images in the RGB model consist of three independent component images, one for each primary color.

- When fed to into an RGB monitor, these three images combine on the phosphor screen to produce a composite color image.

- The number of bits used to represent each pixel in RGB space is called **pixel depth**.

- For example, if eight bits are used to represent each of the primary components, each RGB color pixel would have a depth of 24 bits. This is usually referred to as a **full color** image.

- There are $2^{24} = 16{,}777{,}216$ unique colors possible in this system.

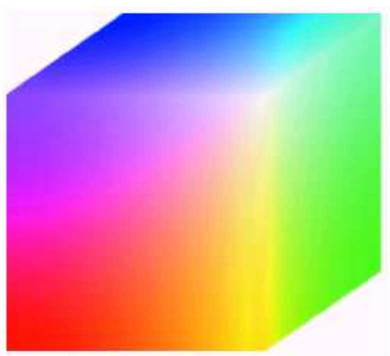
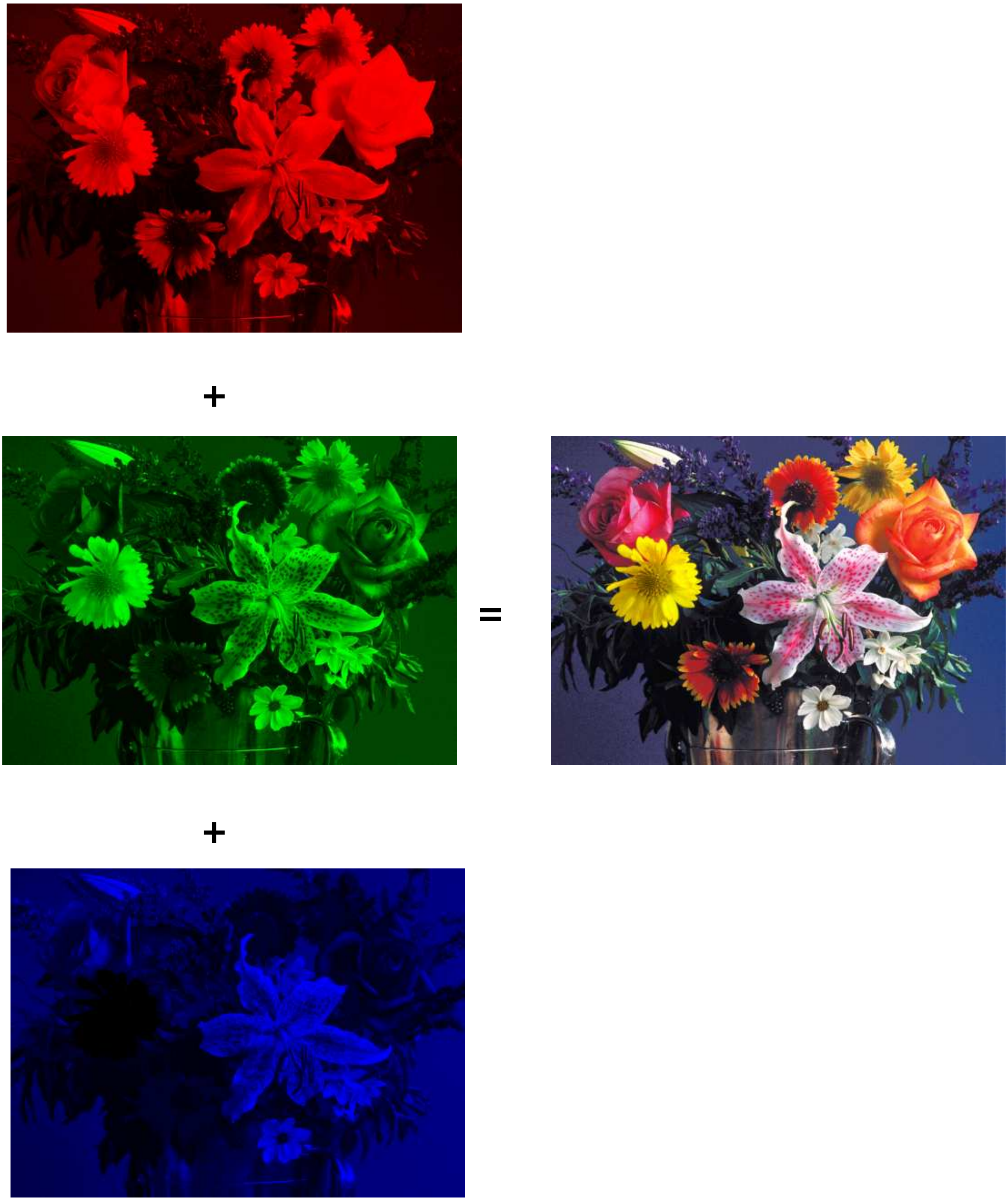


FIGURE 6.8 RGB 24-bit color cube.



- Although high-end monitors can display true 24-bit colors, more modest display devices are limited to smaller (typically 256) set of colors.

- Moreover, in many applications, it not useful to use more than a few (say 10-20) colors.

- Given the variety of display devices, it is useful to have a small subset of colors that are reproduced reliably and faithfully, independently of the display hardware specifics. This subset of colors is referred to as **safe RGB colors** or the set of **all-systems-safe colors**. They are also referred to as **safe web colors** or **safe browser colors** in internet applications.

- Assuming 256 distinct colors as the minimum capability of any color display device, a standard notation to refer to these "safe" colors is necessary.

- Forty of these 256 colors are known to be processed differently by various operating systems, leaving 216 colors that are common to most systems.

- These 216 colors are formed by a combination of RGB values, where each component is restricted to be one of possible six values in the set {0, 51, 102, 153, 204, 255} or using hexadecimal notation {00, 33, 66, 99, CC, FF}. Note that all the values are divisible by 3.

- These $2^6 = 216$ colors have become de facto standard for safe colors, especially in internet applications. They are commonly used, whenever it is desired that the colors viewed by most people appear the same.

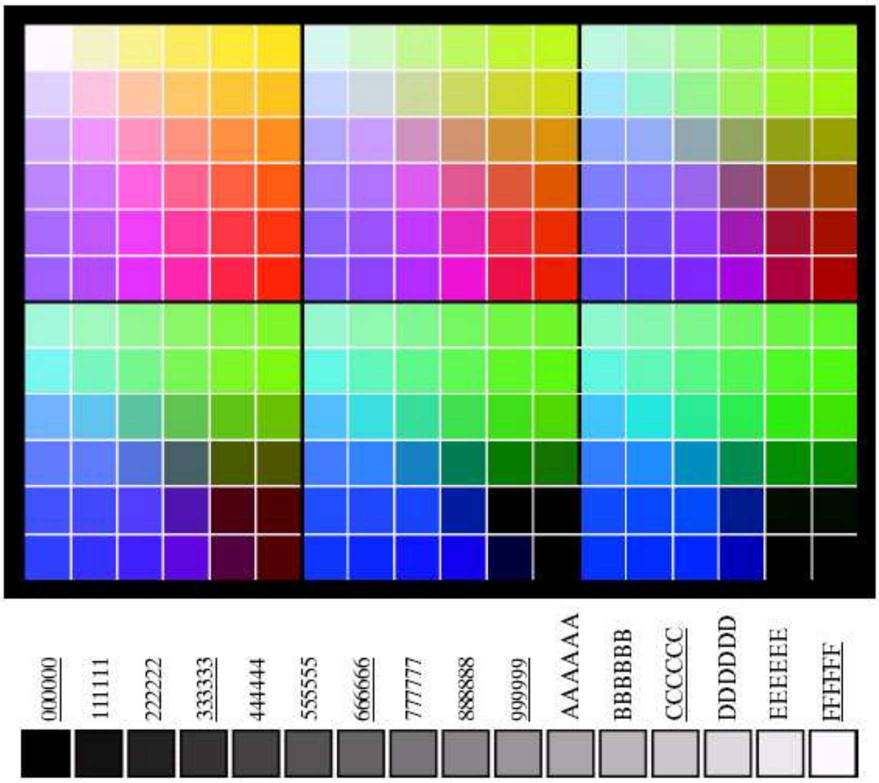


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FIGURE 6.10 (a) The 216 safe RGB colors. (b) All the grays in the 256-color RGB system (grays that are part of the safe color group are shown underlined).

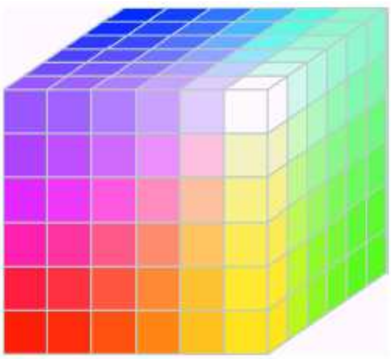

FIGURE 6.11 The RGB safe-color cube.