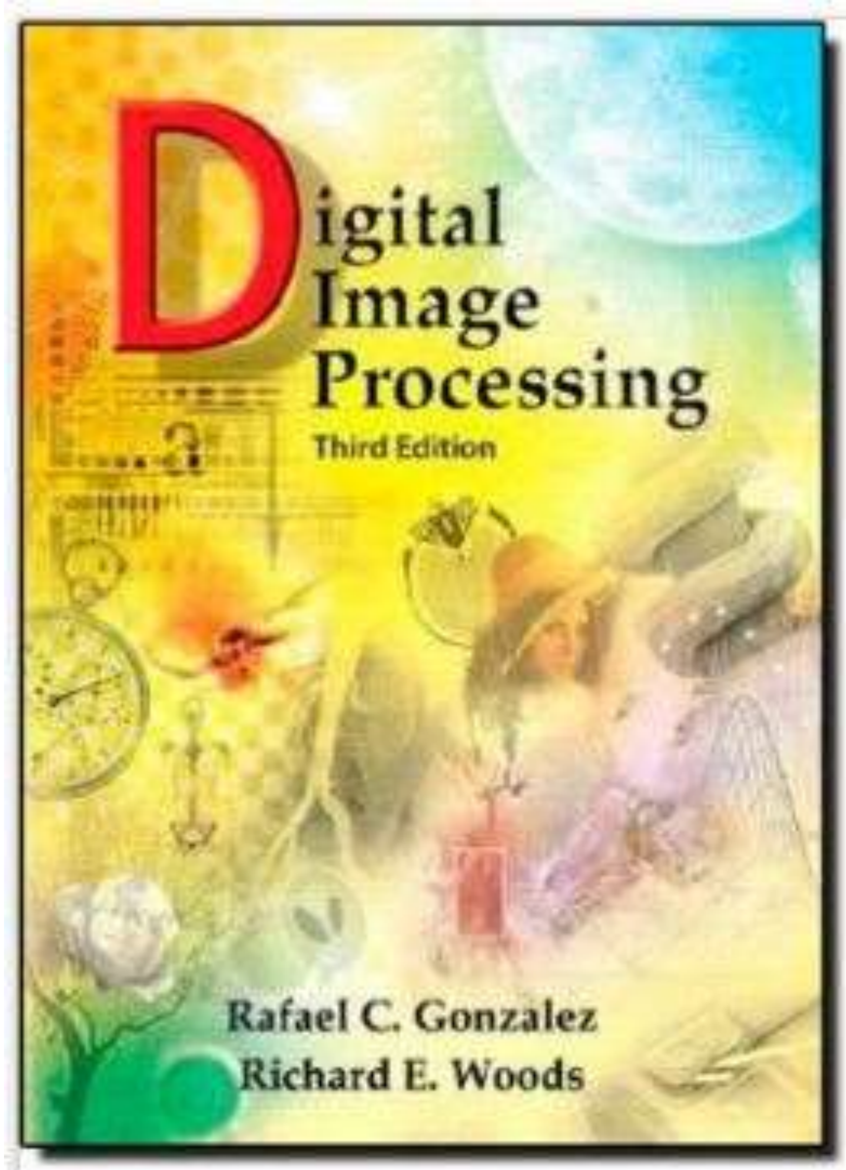
Color Image Processing

Subject: FIP (181102)
Prof. Asodariya Bhavesh
ECD,SSASIT, Surat

Digital Image Processing, 3rd edition by Gonzalez and Woods



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

Color Fundamentals

- In 1666, Sir Isaac Newton discovered that when a beam of sunlight passes through a glass prism, the emerging beam of light is split into a spectrum of colors ranging from violet at one end to red at the other

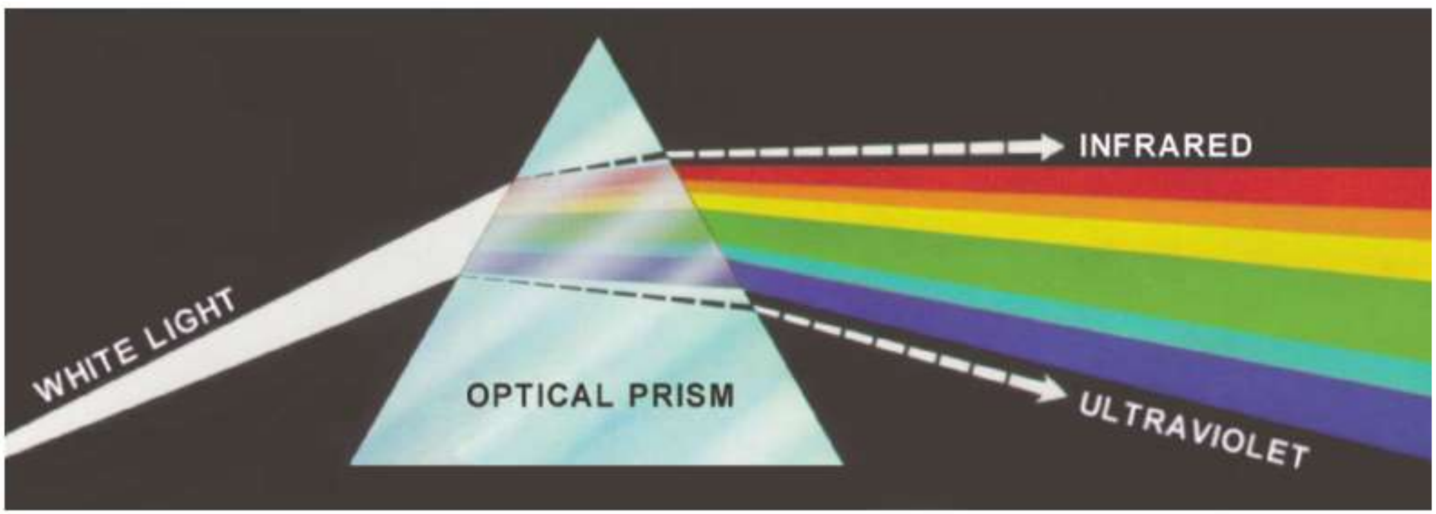
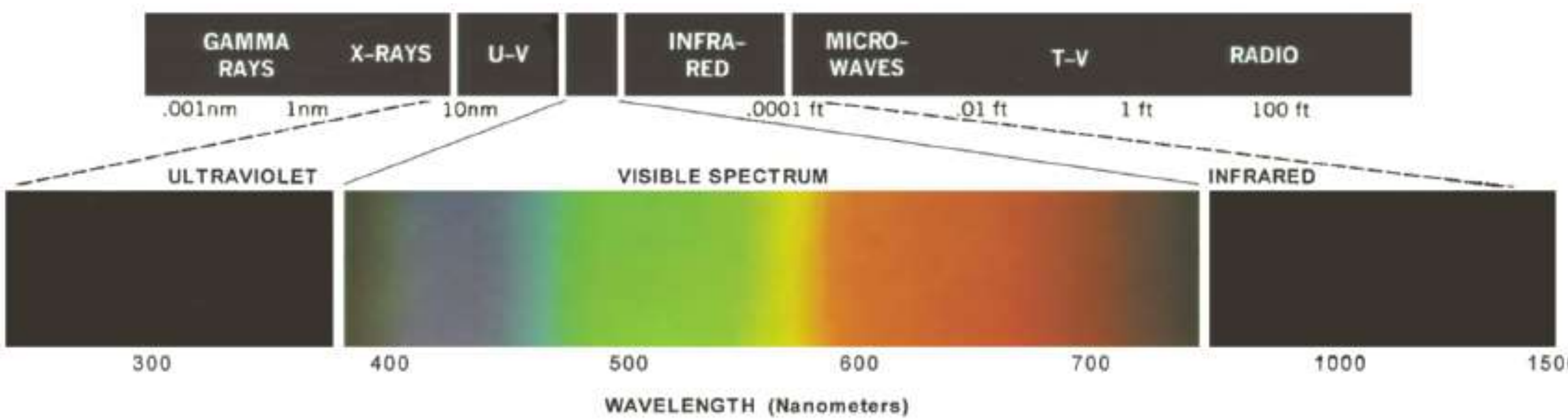


FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

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 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

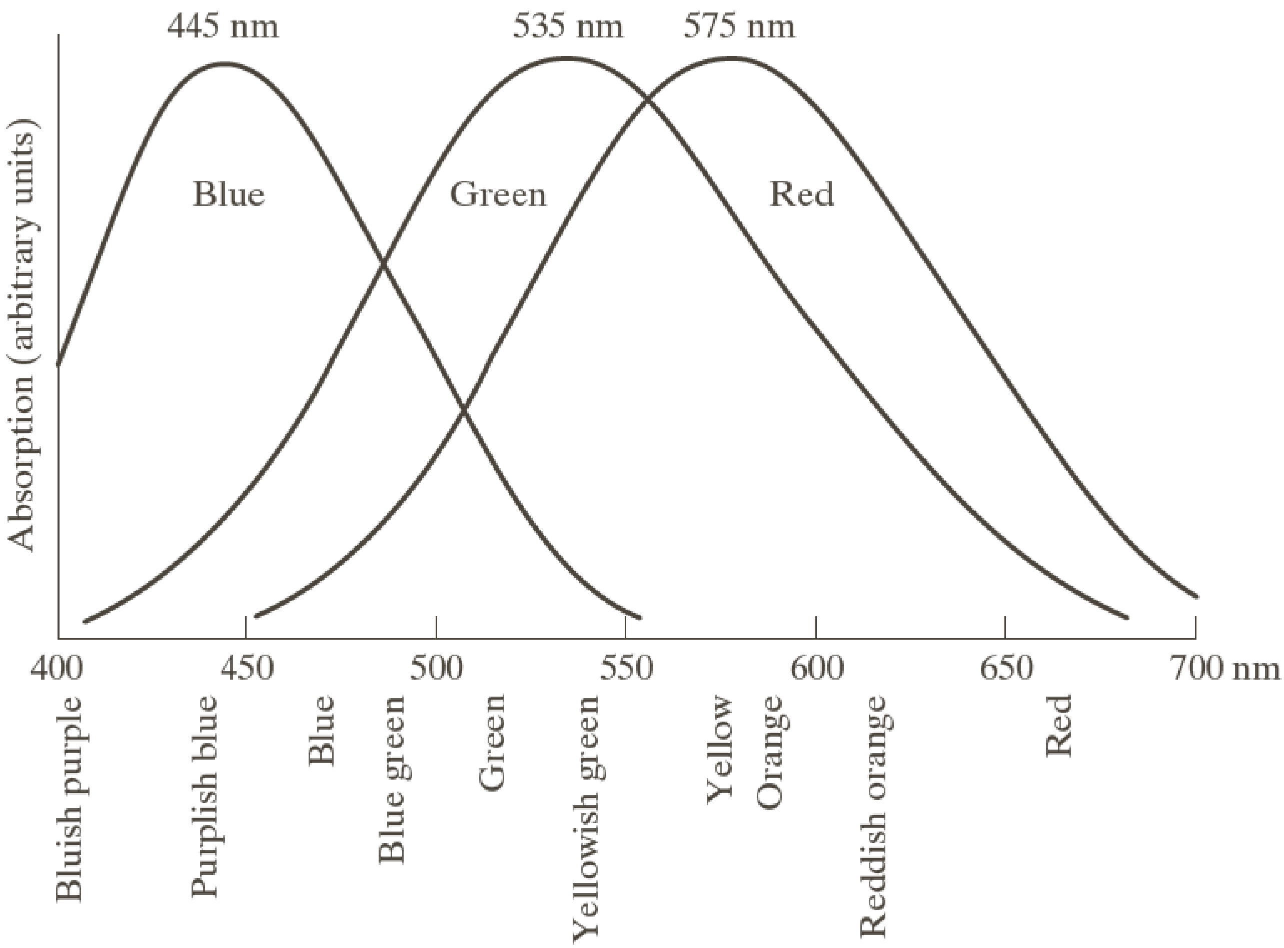


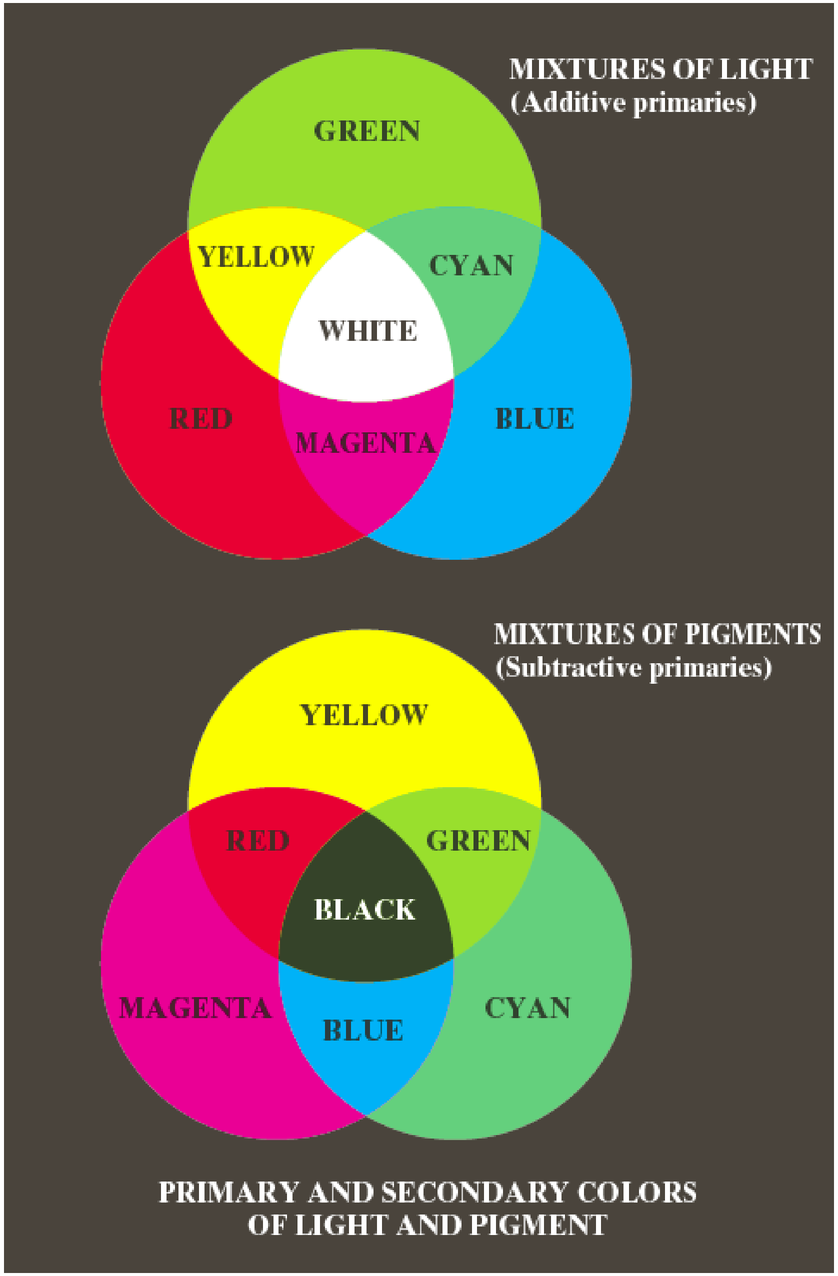
FIGURE 6.3 Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.

- Cones are the sensors in the eye responsible for color vision. 6 to 7 million cones in the human eye can be divided into three principle categories: red, green, and blue

Color Fundamentals

- Approximately 65% of all cones are sensitive to red light, 33% are sensitive to green light, and only about 2% are sensitive to blue (but the blue cones are the most sensitive)
- According to CIE (International Commission on Illumination) wavelengths of blue = 435.8 nm, green = 546.1 nm, and red = 700 nm

Color Fundamentals



a
b

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

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**

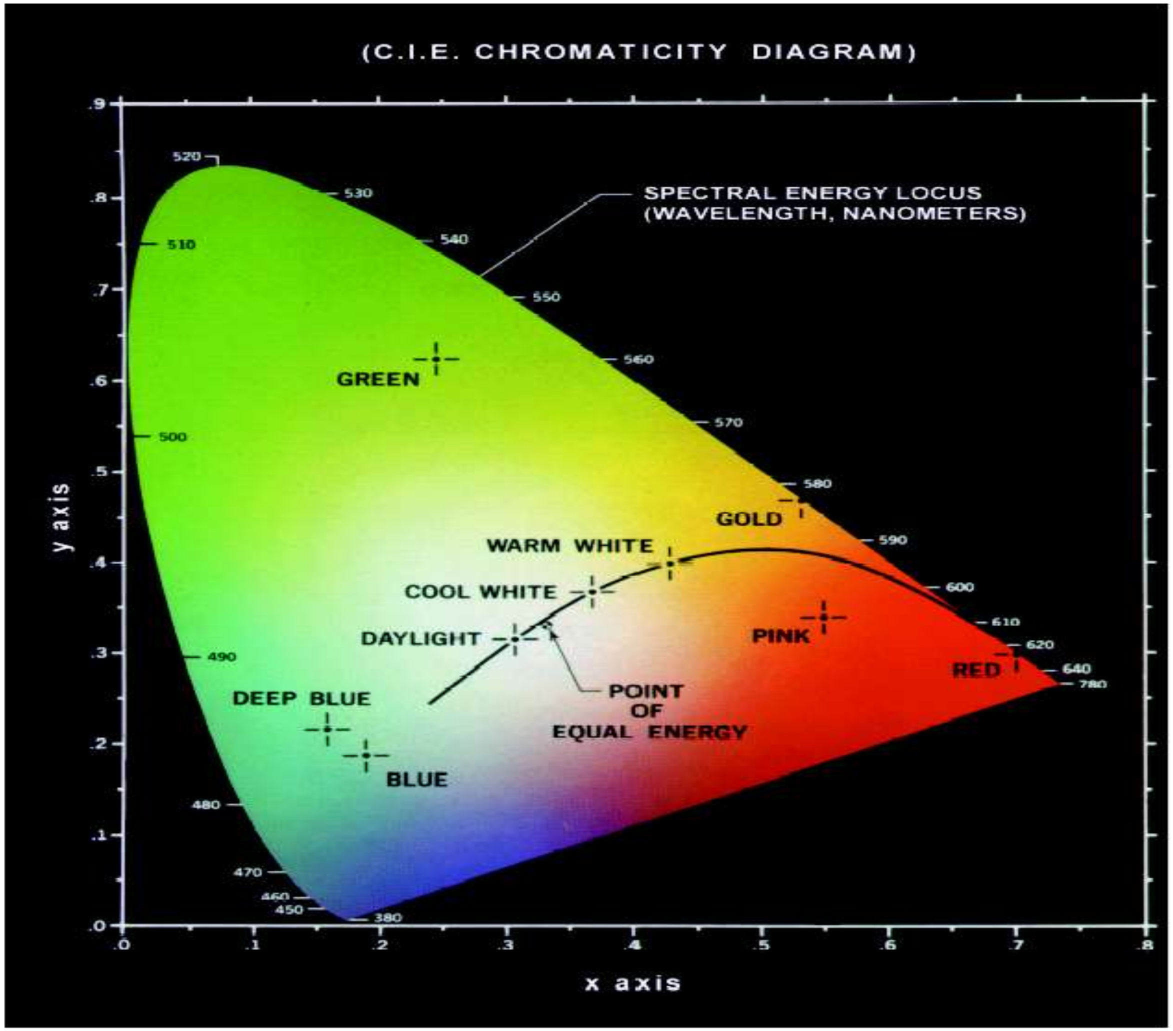
$$x = \frac{X}{X+Y+Z} \qquad y = \frac{Y}{X+Y+Z} \qquad z = \frac{Z}{X+Y+Z}$$

$$x + y + z = 1$$

Color Fundamentals

- Another approach for specifying colors is to use the CIE chromaticity diagram

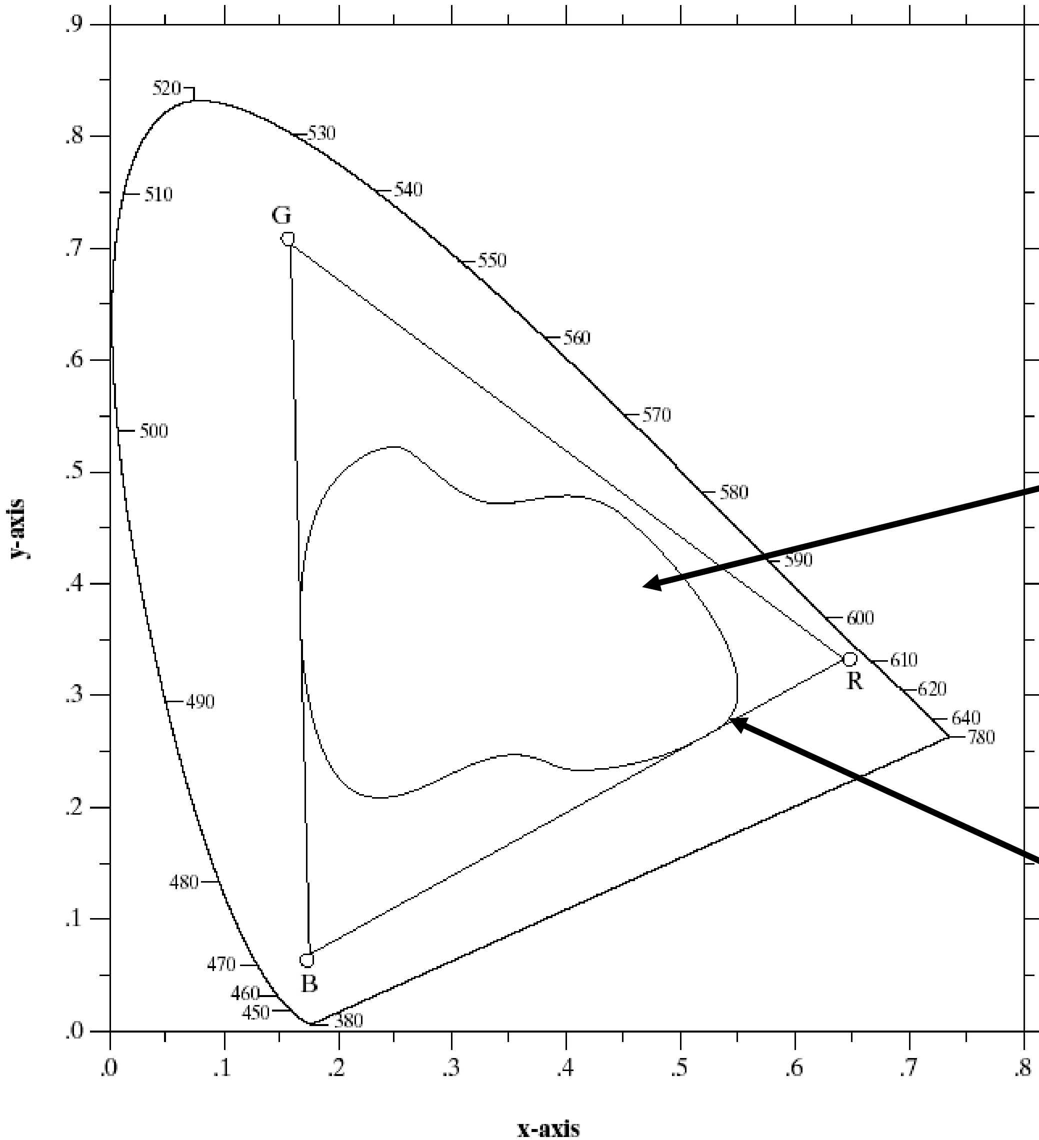
FIGURE 6.5 Chromaticity diagram. (Courtesy of the General Electric Co., Lamp Business Division.)



Color Fundamentals

- For any value of x and y, the corresponding value of z is obtained by noting that $z = 1-(x+y)$
- 62% green, 25% red, and 13% blue
- Pure colors are at boundary which are fully saturated
- Any point within boundary represents some mixture of spectrum colors
- Equal energy and equal fractions of the three primary colors represents white light
- The saturation at the point of equal energy is zero
- Chromaticity diagram is useful for color mixing

Color Fundamentals



Color Gamut produced by *RGB monitors*

Color Gamut produced by high quality color *printing device*

FIGURE 6.6 Typical color gamut of color monitors (triangle) and color printing devices (irregular region).

Color Fundamentals

- Printing gamut is irregular because color printing is a combination of additive and subtractive color mixing, a process that is much more difficult to control than that of displaying colors on a monitor, which is based on the addition of three highly controllable light primaries

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

RGB Color Models

- Each color appears in its primary spectral components of red, green, and blue.
- Model based on a Cartesian coordinate system

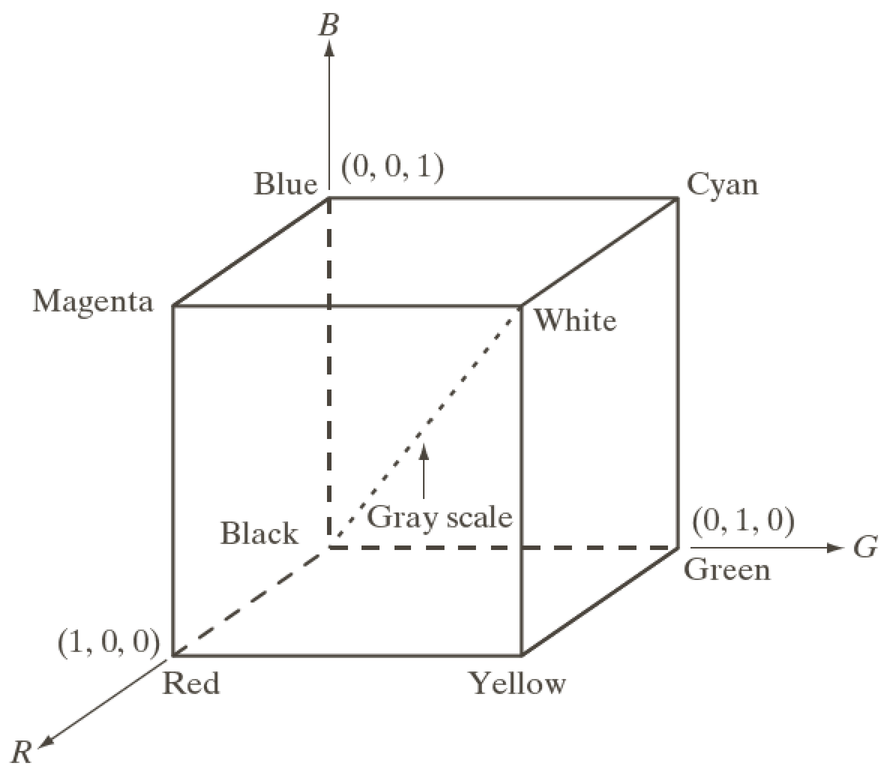


FIGURE 6.7 Schematic of the RGB color cube. Points along the main diagonal have gray values, from black at the origin to white at point (1, 1, 1).

RGB Color Models

- RGB primary values are at three corners; the secondary colors cyan, magenta, and yellow are at the other corners; black is at the origin; and white is at the corner
- In this model, the gray scale (points of equal RGB values) extends from black to white along the line joining these two points
- The different colors in this model are points on or inside the cube, and are defined by vectors extending from the origin
- RGB images consist three images (R, G, and B planes)
- When fed into an RGB monitor, these three images combine on the screen to produce a composite color image

RGB Color Models

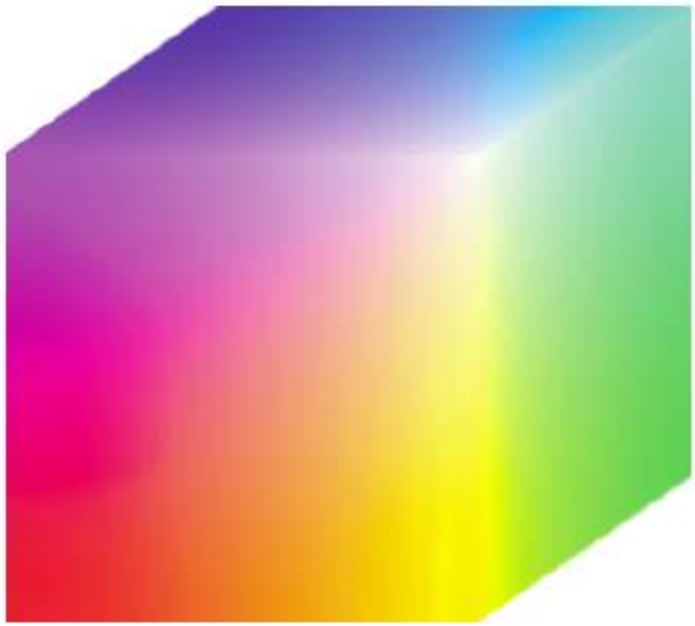
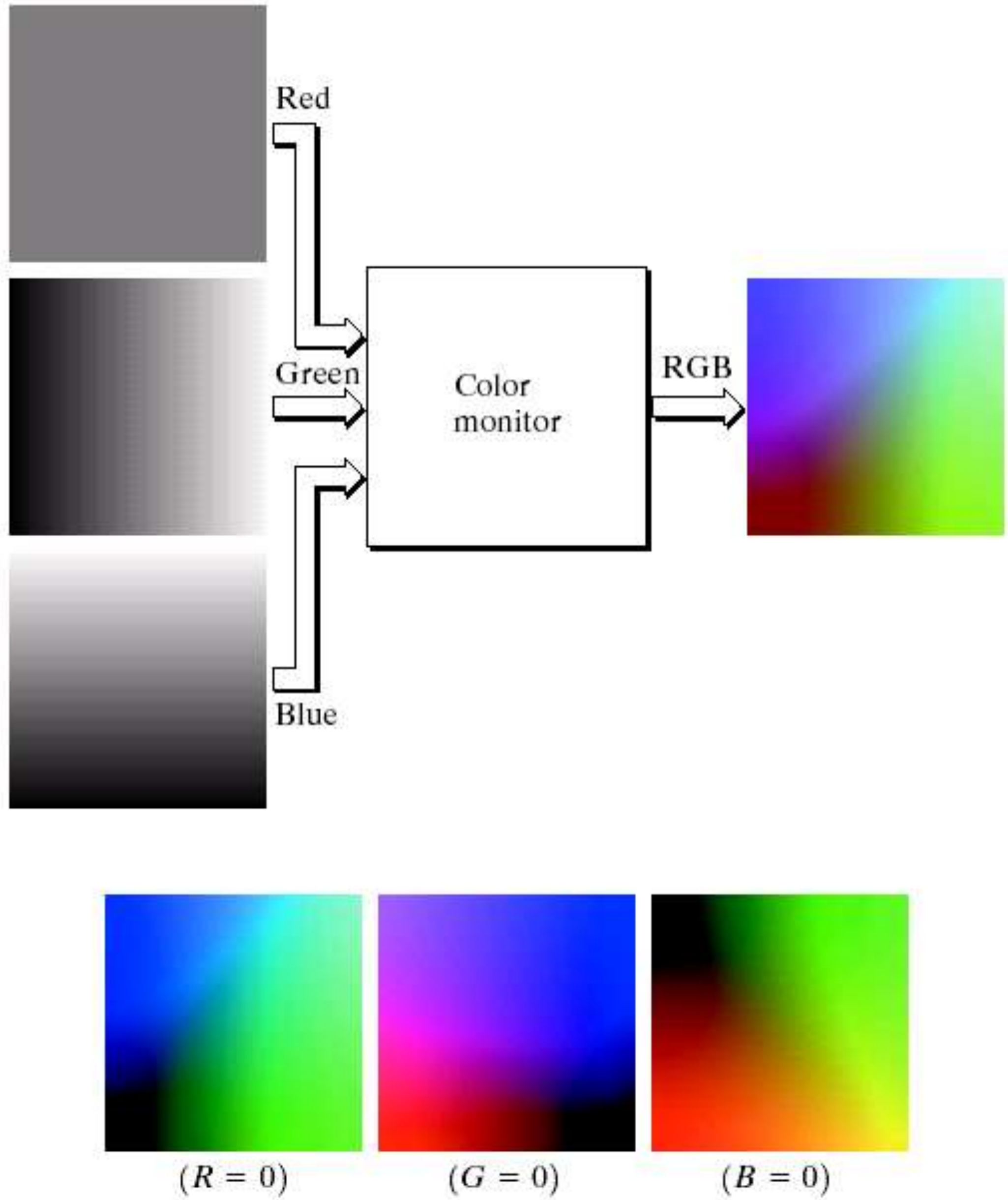


FIGURE 6.8 RGB 24-bit color cube.

- Number of bits used to represent each pixel in RGB space is called the *pixel depth*
- RGB image has 24 bit pixel depth
- True color or full color image is a 24 bit RGB image
- Total colors in 24-bit image is $(2^8)^3$ = 16,777,216

RGB Color Models



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.

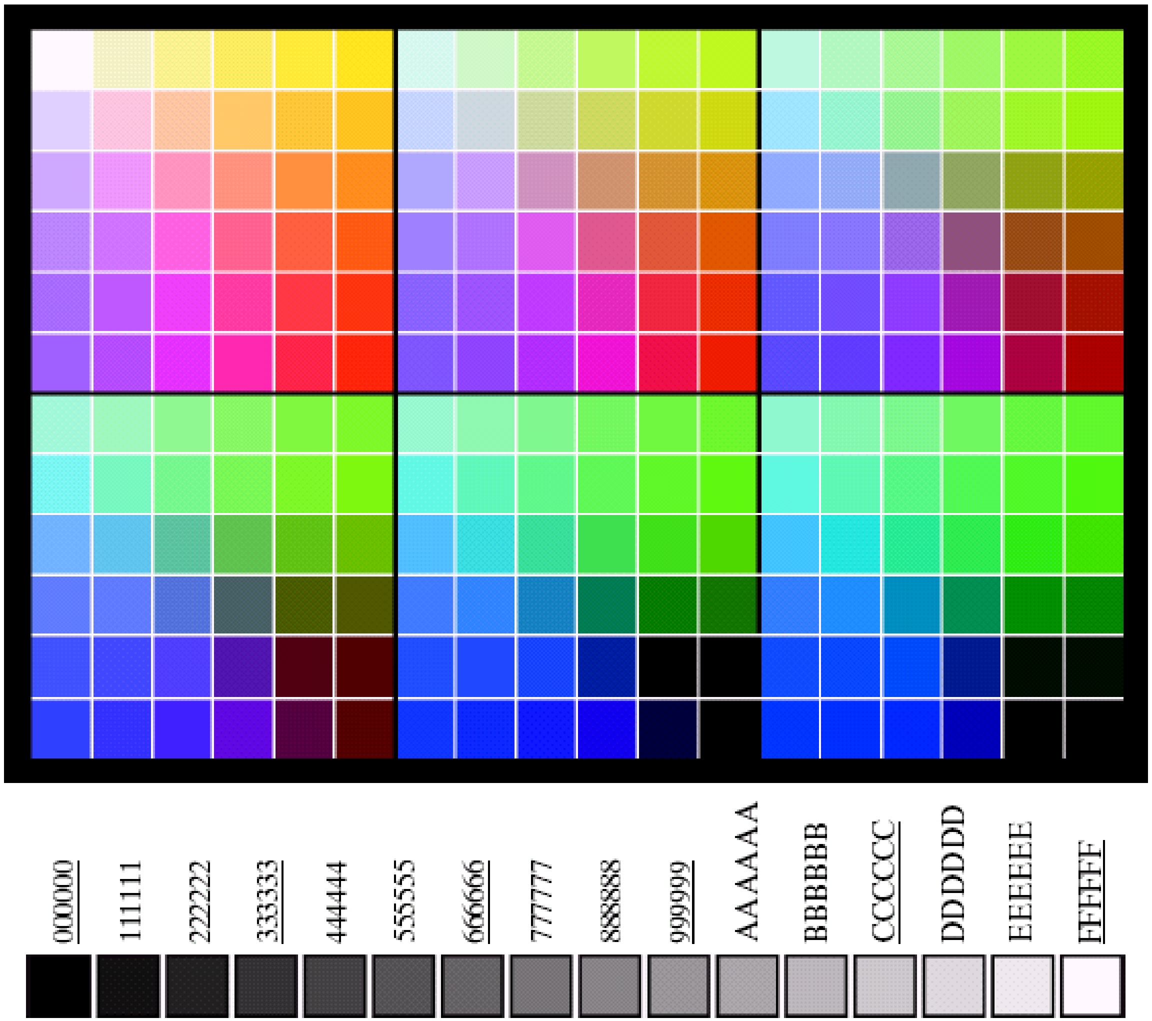
RGB Color Models

- Many systems in use today are limited to 256 colors
- Many applications require few colors only
- Given the variety of systems in current use, it is of considerable interest to have subset of colors that are likely to be reproduced faithfully, this subset of colors are called the set of *safe RGB colors,* or the set of *all-systems-safe colors*
- In internet applications, they are called *safe Web colors* or *safe browser colors*
- On the assumption that 256 colors is the minimum number of colors that can be reproduced faithfully
- Forty of these 256 colors are known to be processed differently by various operating systems

RGB Color Models

Number System	Color Equivalents					
Hex	00	33	66	99	CC	FF
Decimal	0	51	102	153	204	255

TABLE 6.1 Valid values of each RGB component in a safe color.



a
b

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).

CMY and CMYK Color Models

- CMY are the secondary colors of light, or, alternatively, the primary colors of pigments
- For example, when a surface coated with cyan pigment is illuminated with white light, no red light is reflected from the surface because cyan subtracts red light from reflected white light
- Color printers and copiers require CMY data input or perform RGB to CMY conversion internally

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

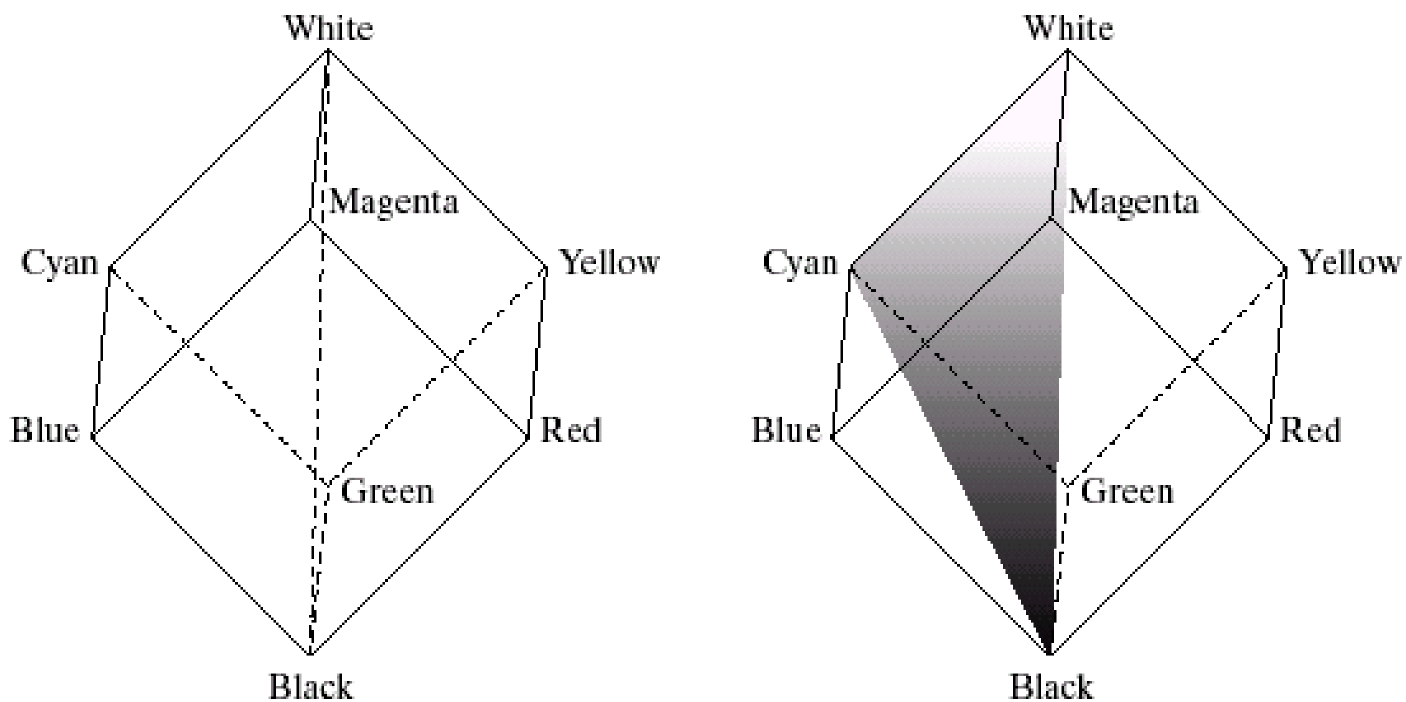
CMY and CMYK Color Models

- 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
- So, in order to produce true black, a fourth color, black, is added, giving rise to the CMYK color model

HSI Color Model

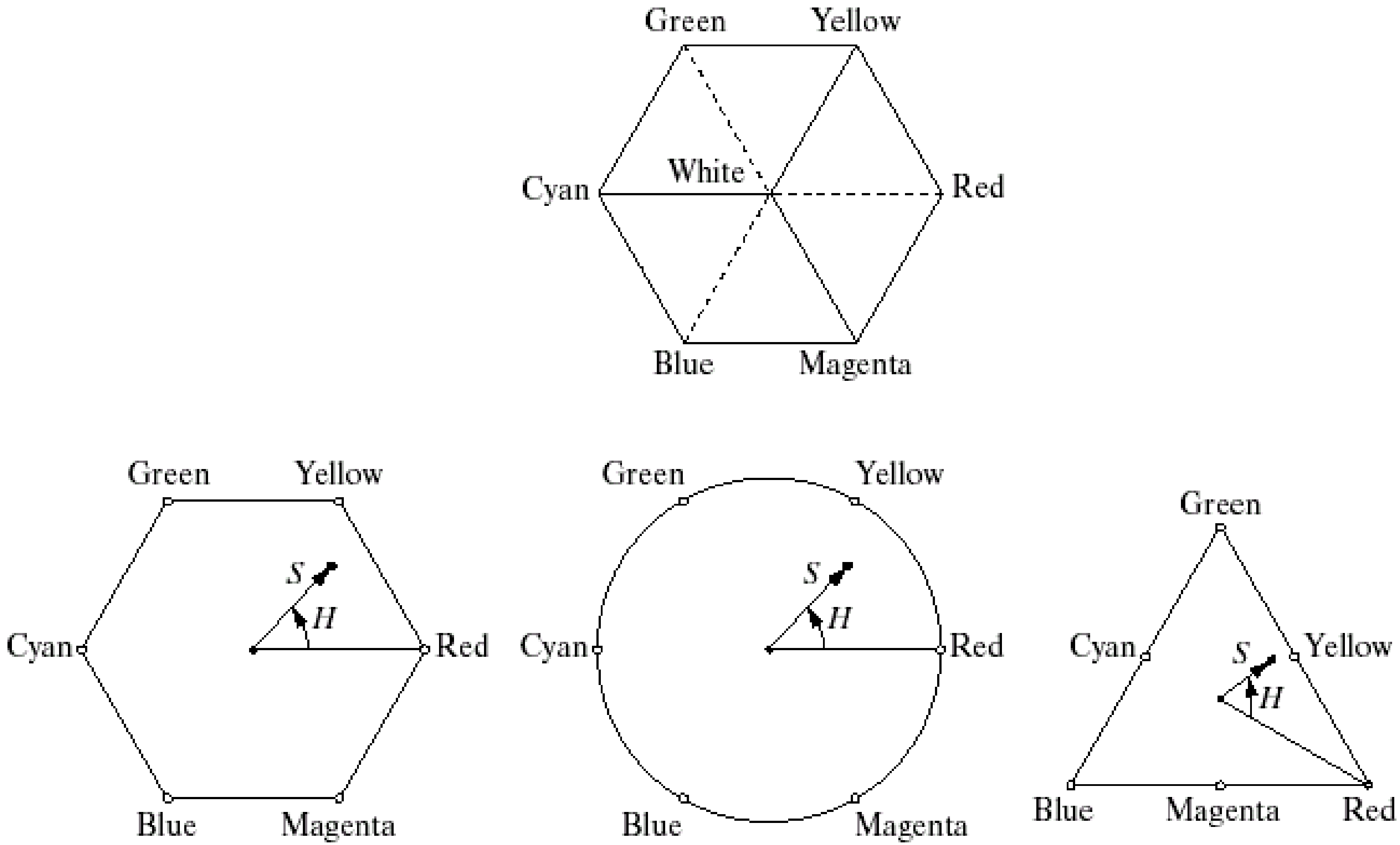
- Unfortunately, the RGB, CMY, and other similar color models are not well suited for *describing* colors in terms that are practical for human interpretation
- For example, one does not refer to the color of an automobile by giving the percentage of the primaries composing its color
- We do not think of color images as being composed of three primary images that combine to form that single image
- When human view a color object, we describe it by its hue, saturation, and brightness

HSI Color Model



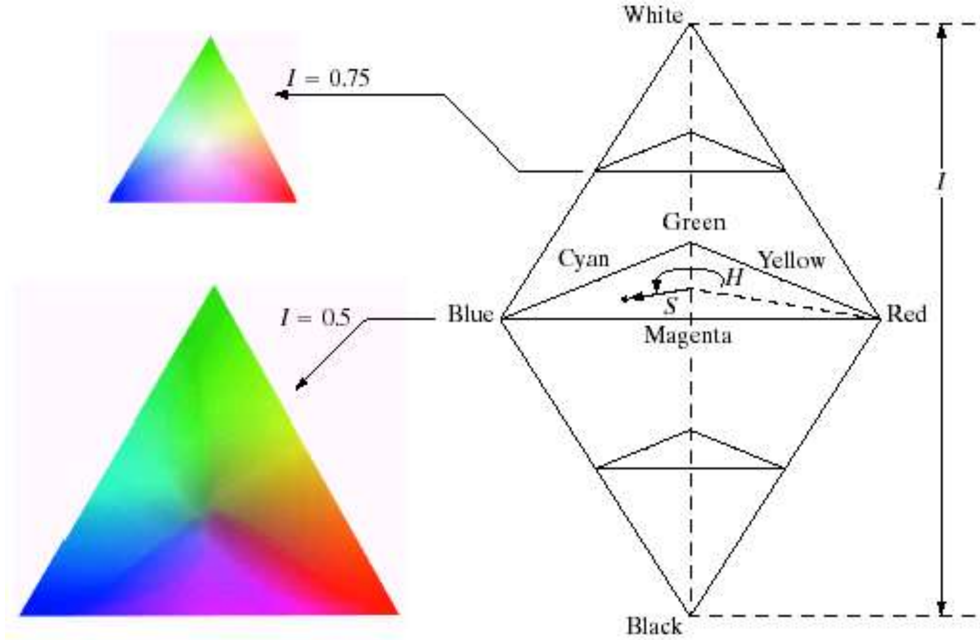
a b

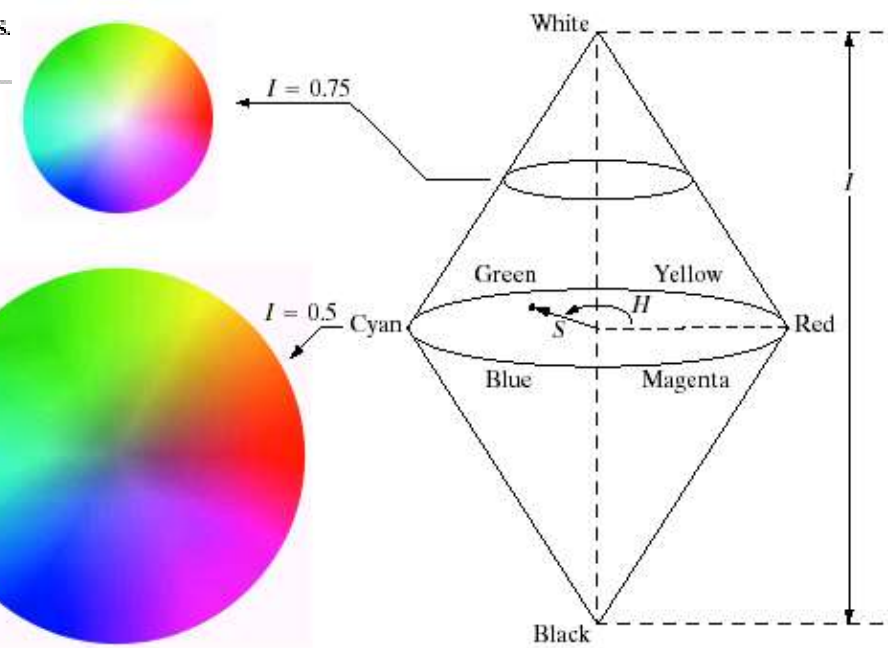
FIGURE 6.12 Conceptual relationships between the RGB and HSI color models.



a
b c d

FIGURE 6.13 Hue and saturation in the HSI color model. The dot is an arbitrary color point. The angle from the red axis gives the hue, and the length of the vector is the saturation. The intensity of all colors in any of these planes is given by the position of the plane on the vertical intensity axis.





a
b

FIGURE 6.14 The HSI color model based on (a) triangular and (b) circular color planes. The triangles and circles are perpendicular to the vertical intensity axis.

Converting from RGB to HSI

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

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

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

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

Converting from HSI to RGB

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

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

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

$$G = 3I - (R + B)$$

Converting from HSI to RGB

- GB sector: $120^{\circ} \leq H < 240^{\circ}$

$$H = H - 120^{\circ}$$

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

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

$$B = 3I - (R + G)$$

Converting from HSI to RGB

- GB sector: $240^{\circ} \leq H < 360^{\circ}$

$$H = H - 240^{\circ}$$

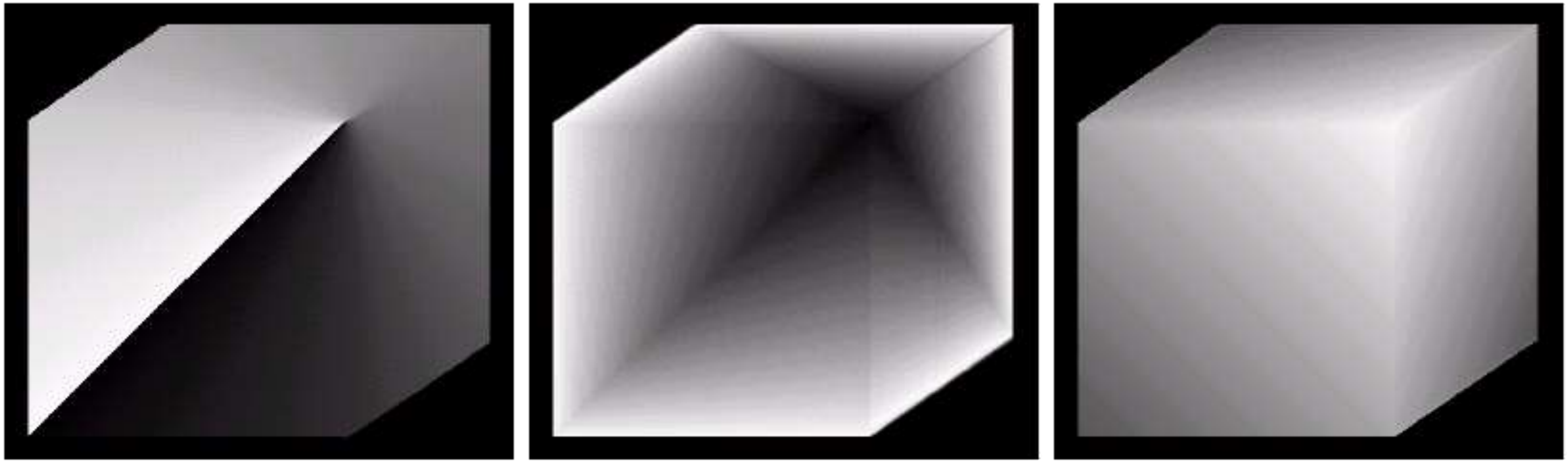
$$G = I(1 - S)$$

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

$$R = 3I - (G + B)$$

HSI Color Model

- HSI (Hue, saturation, intensity) color model, decouples the intensity component from the color-carrying information (hue and saturation) in a color image



a b c

FIGURE 6.15 HSI components of the image in Fig. 6.8. (a) Hue, (b) saturation, and (c) intensity images.

Pseudocolor Image Processing

- Pseudocolor (false color) image processing consists of assigning colors to gray values based on a specified criterion
- It is different than the process associated with the color images
- Principal use of pseudocolor is for human visualization and interpretation of gray scale events in an image or sequence of images
- Two methods for pseudocolor image processing:
- 1) Intensity Slicing
- 2) Intensity to Color Transformations

Intensity Slicing

- Also called density slicing and piece wise linear function
- If an image is interpreted as a 3-D function, the method can be viewed as one of placing planes parallel to the coordinate plane of the image; each plane then “slices” of the function in the area of intersection

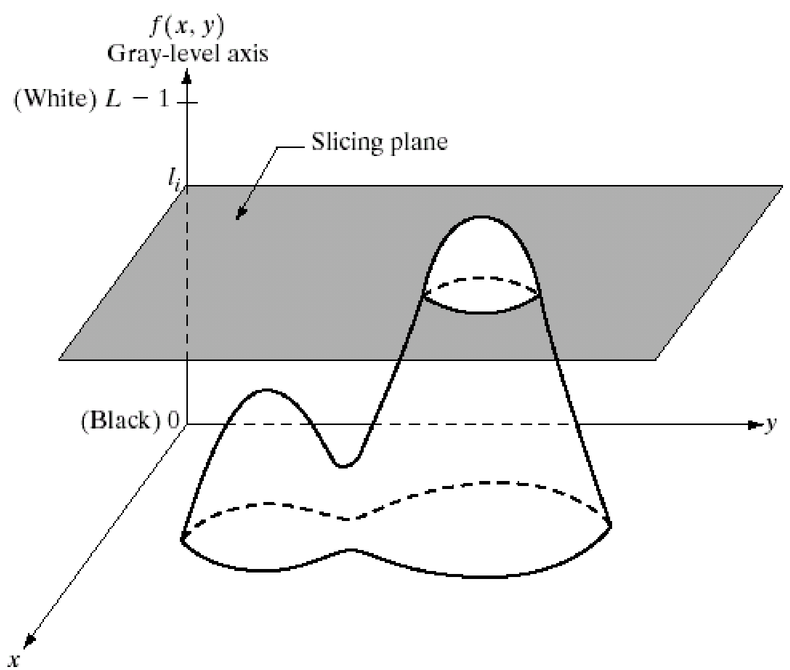


FIGURE 6.18 Geometric interpretation of the intensity-slicing technique.

Intensity Slicing

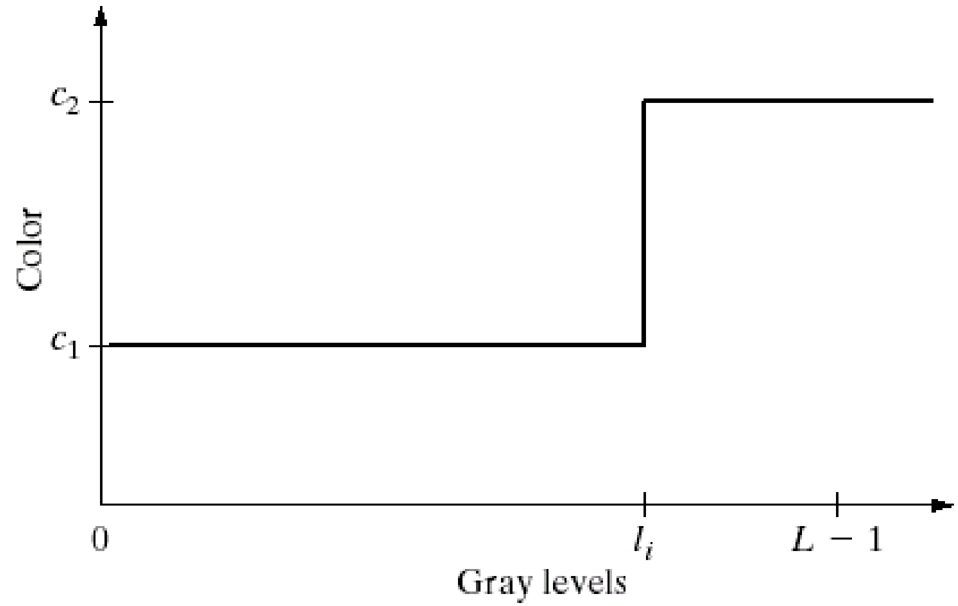
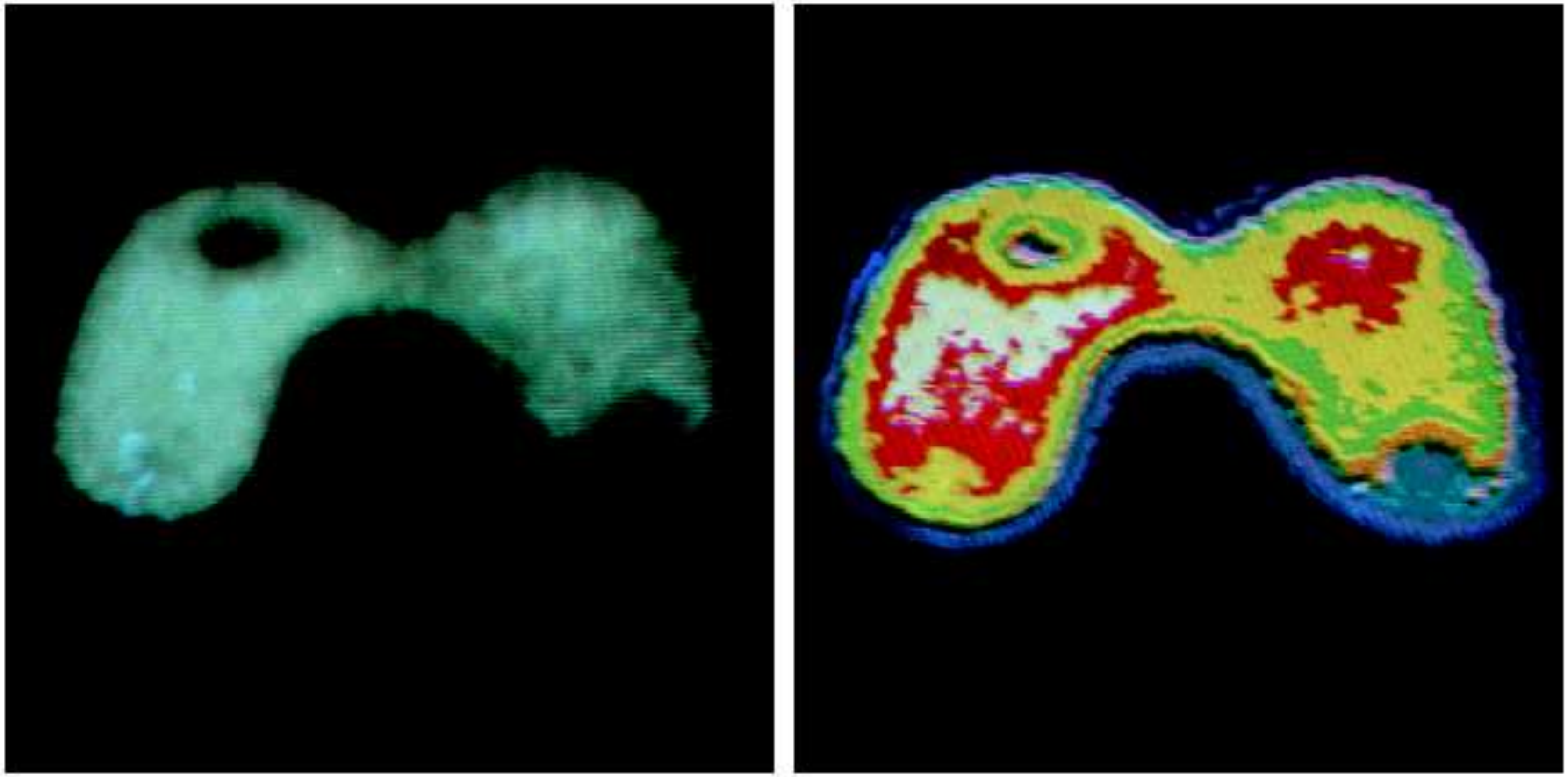


FIGURE 6.19 An alternative representation of the intensity-slicing technique.

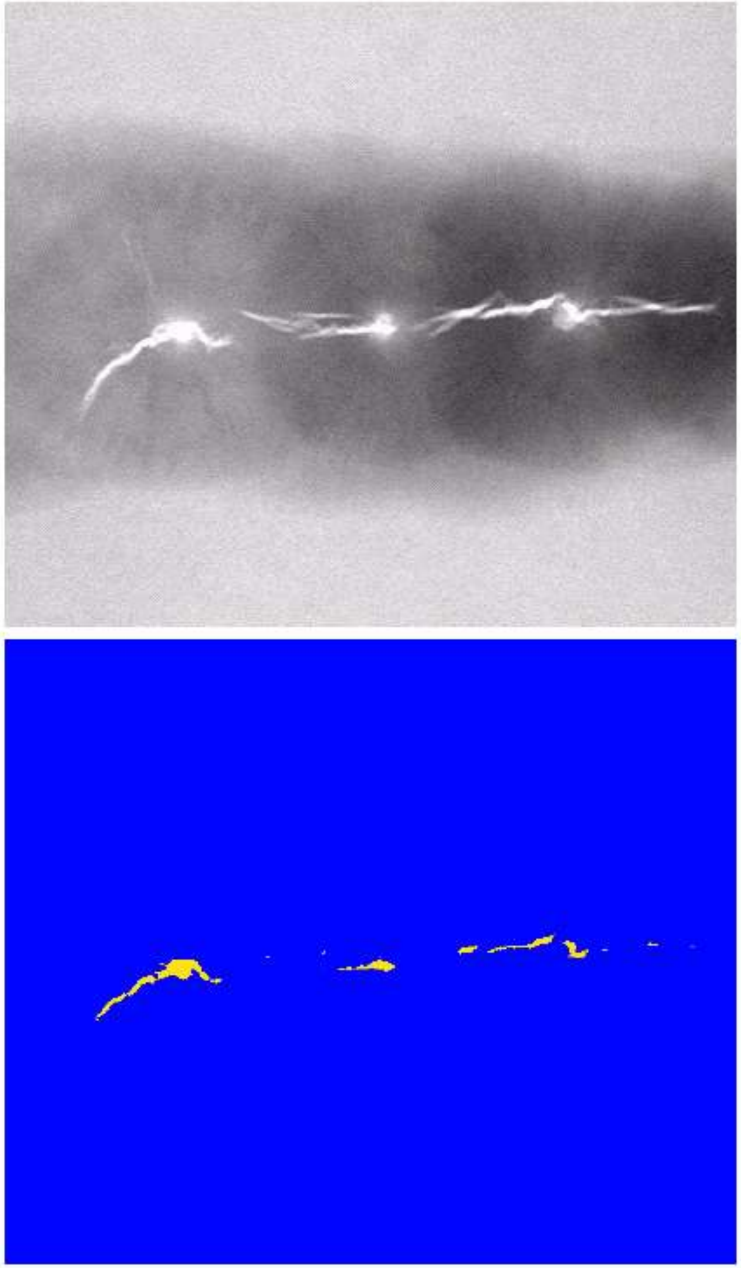
Intensity Slicing



a b

FIGURE 6.20 (a) Monochrome image of the Picker Thyroid Phantom. (b) Result of density slicing into eight colors. (Courtesy of Dr. J. L. Blankenship, Instrumentation and Controls Division, Oak Ridge National Laboratory.)

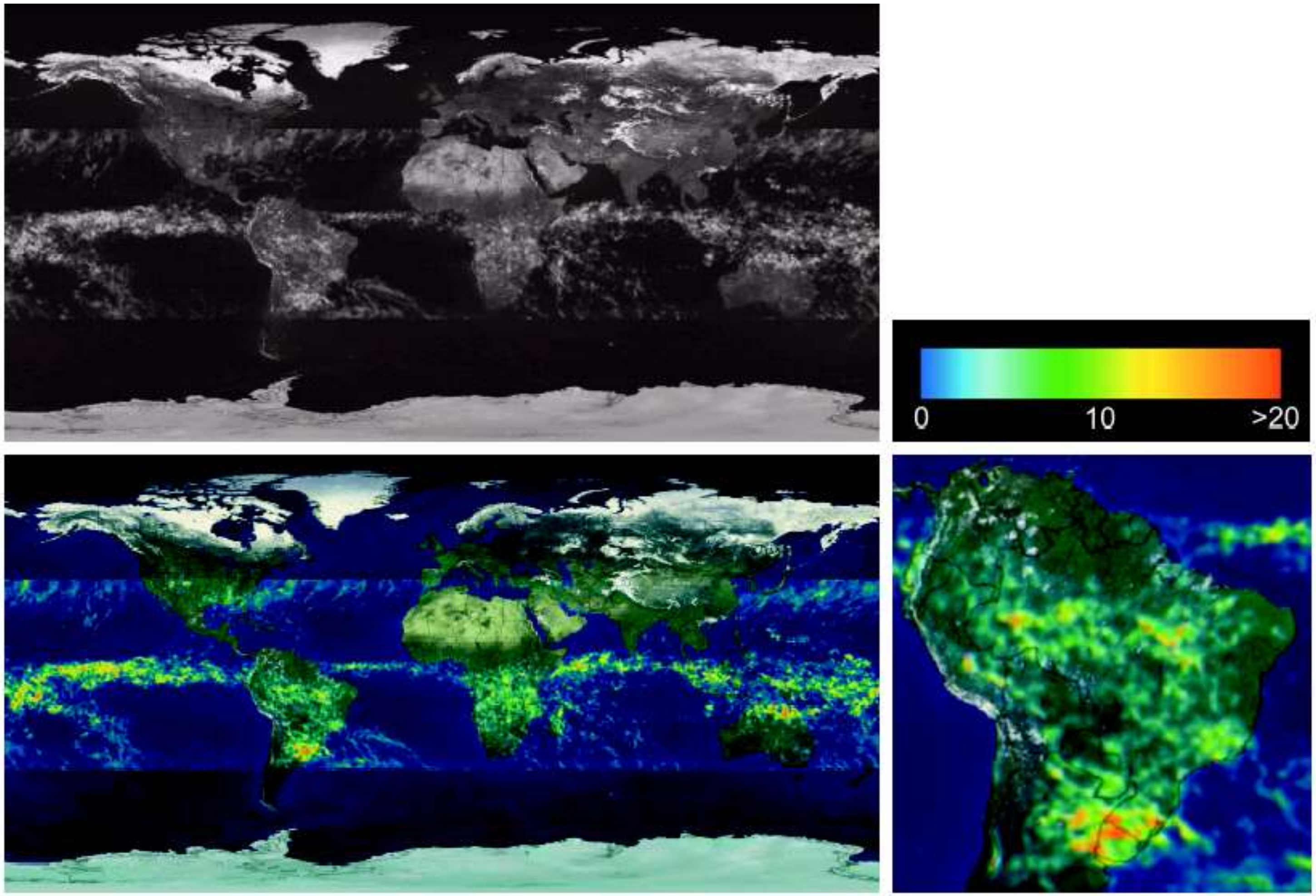
Intensity Slicing



a
b

FIGURE 6.21
(a) Monochrome X-ray image of a weld. (b) Result of color coding. (Original image courtesy of X-TEK Systems, Ltd.)

Intensity Slicing



a b
c d

FIGURE 6.22 (a) Gray-scale image in which intensity (in the lighter horizontal band shown) corresponds to average monthly rainfall. (b) Colors assigned to intensity values. (c) Color-coded image. (d) Zoom of the South America region. (Courtesy of NASA.)

Intensity to Color Transformations

- Achieving a wider range of pseudocolor enhancement results than simple slicing technique
- Idea underlying this approach is to perform three independent transformations on the intensity of any input pixel
- Three results are then fed separately into the red, green, and blue channels of a color television monitor
- This produces a composite image whose color content is modulated by the nature of the transformation functions
- Not the functions of position
- Nonlinear function

Intensity to Color Transformations

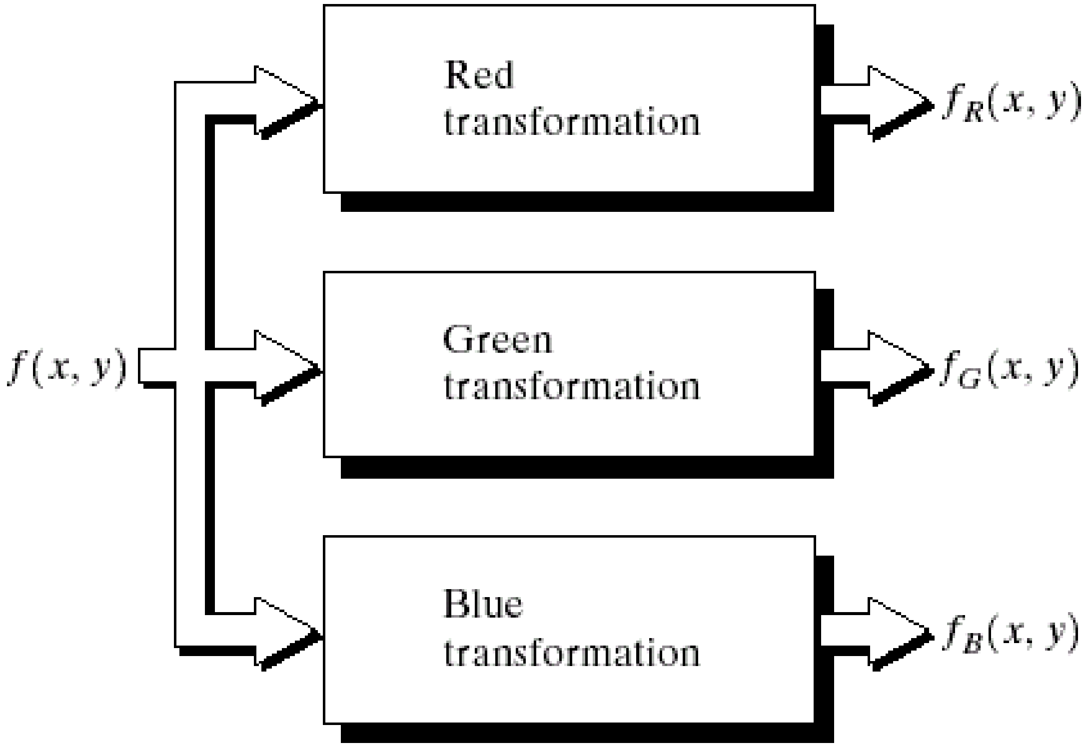
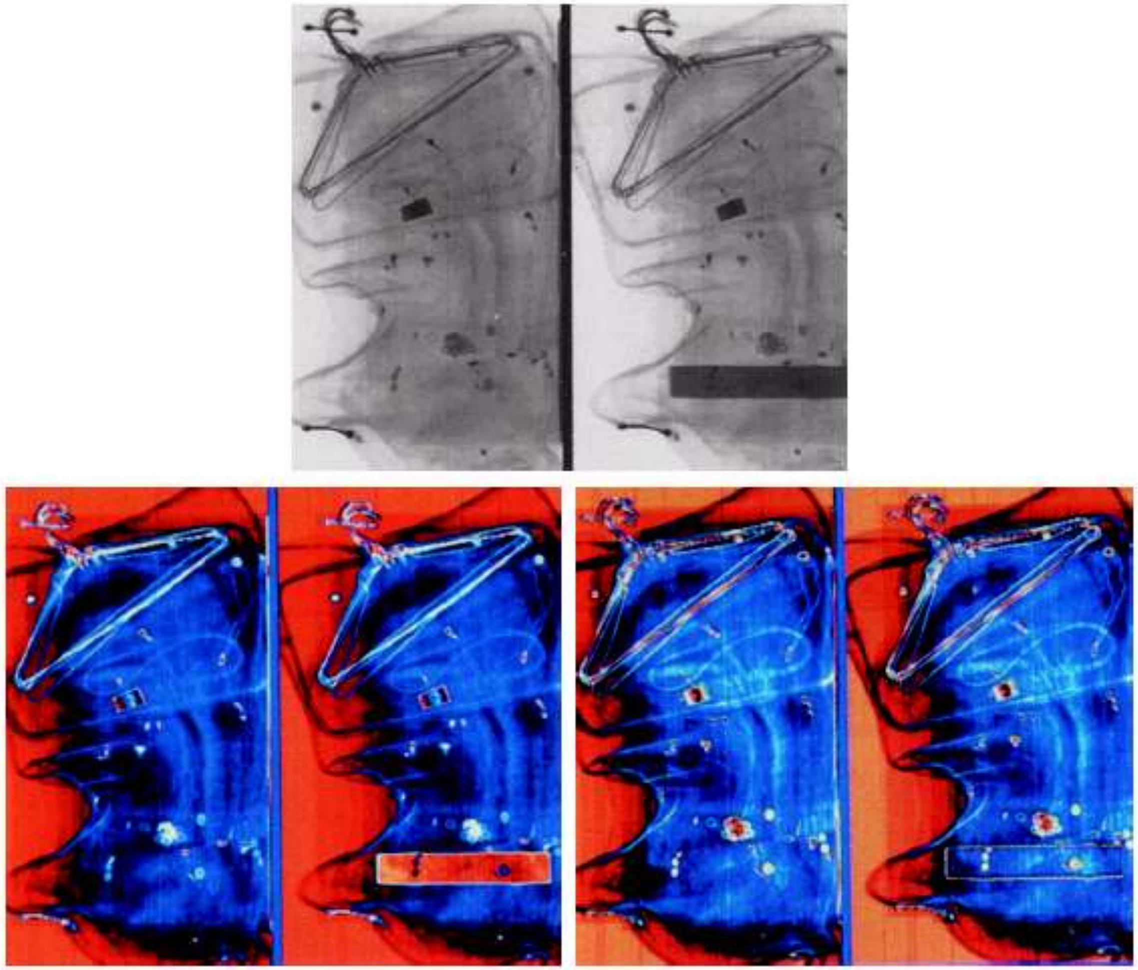


FIGURE 6.23 Functional block diagram for pseudocolor image processing. f_R, f_G, and f_B are fed into the corresponding red, green, and blue inputs of an RGB color monitor.

Intensity to Color Transformations



a
b c

FIGURE 6.24 Pseudocolor enhancement by using the gray-level to color transformations in Fig. 6.25. (Original image courtesy of Dr. Mike Hurwitz, Westinghouse.)

Intensity to Color Transformations

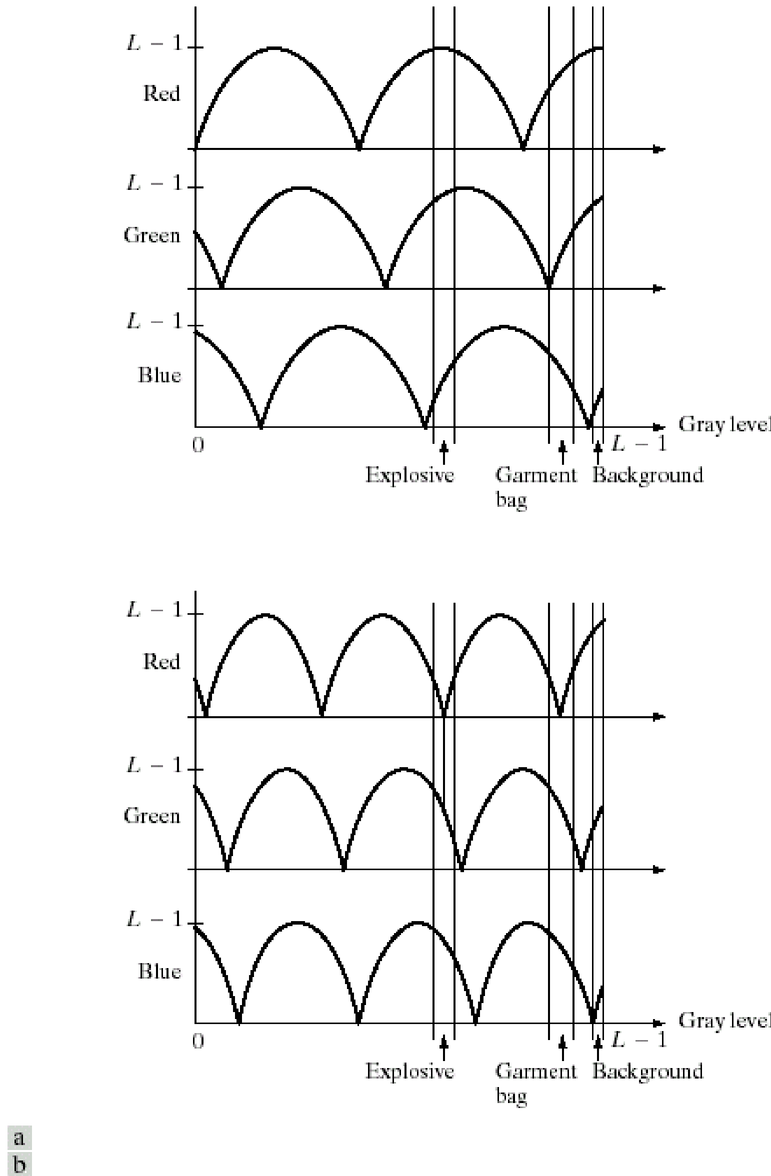


FIGURE 6.25 Transformation functions used to obtain the images in Fig. 6.24.

Intensity to Color Transformations

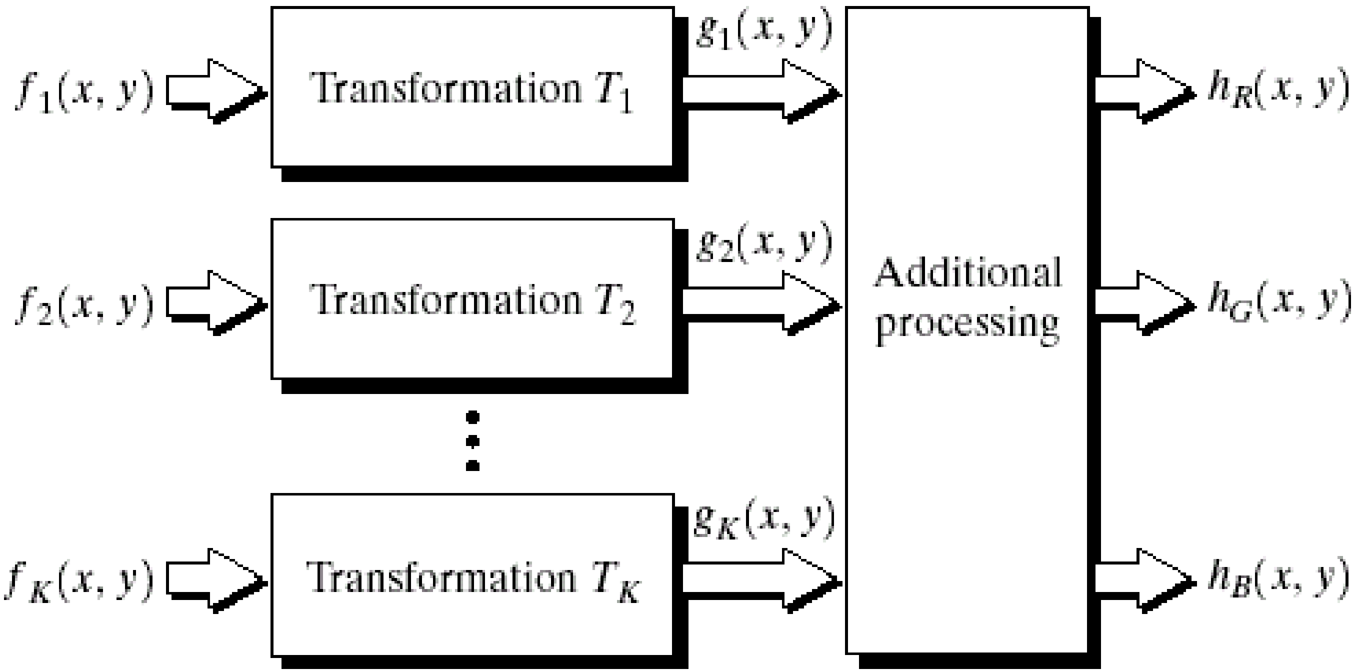
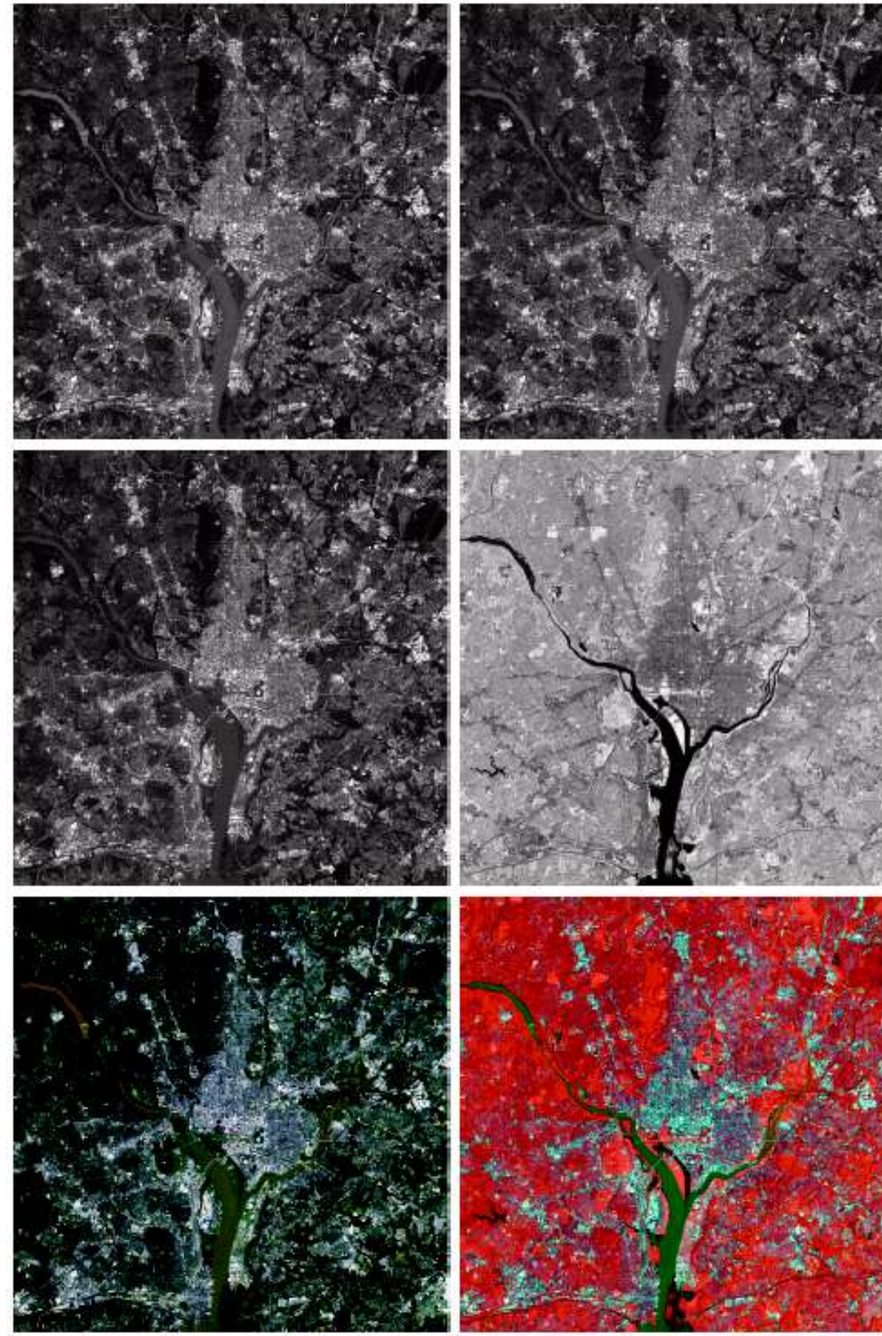
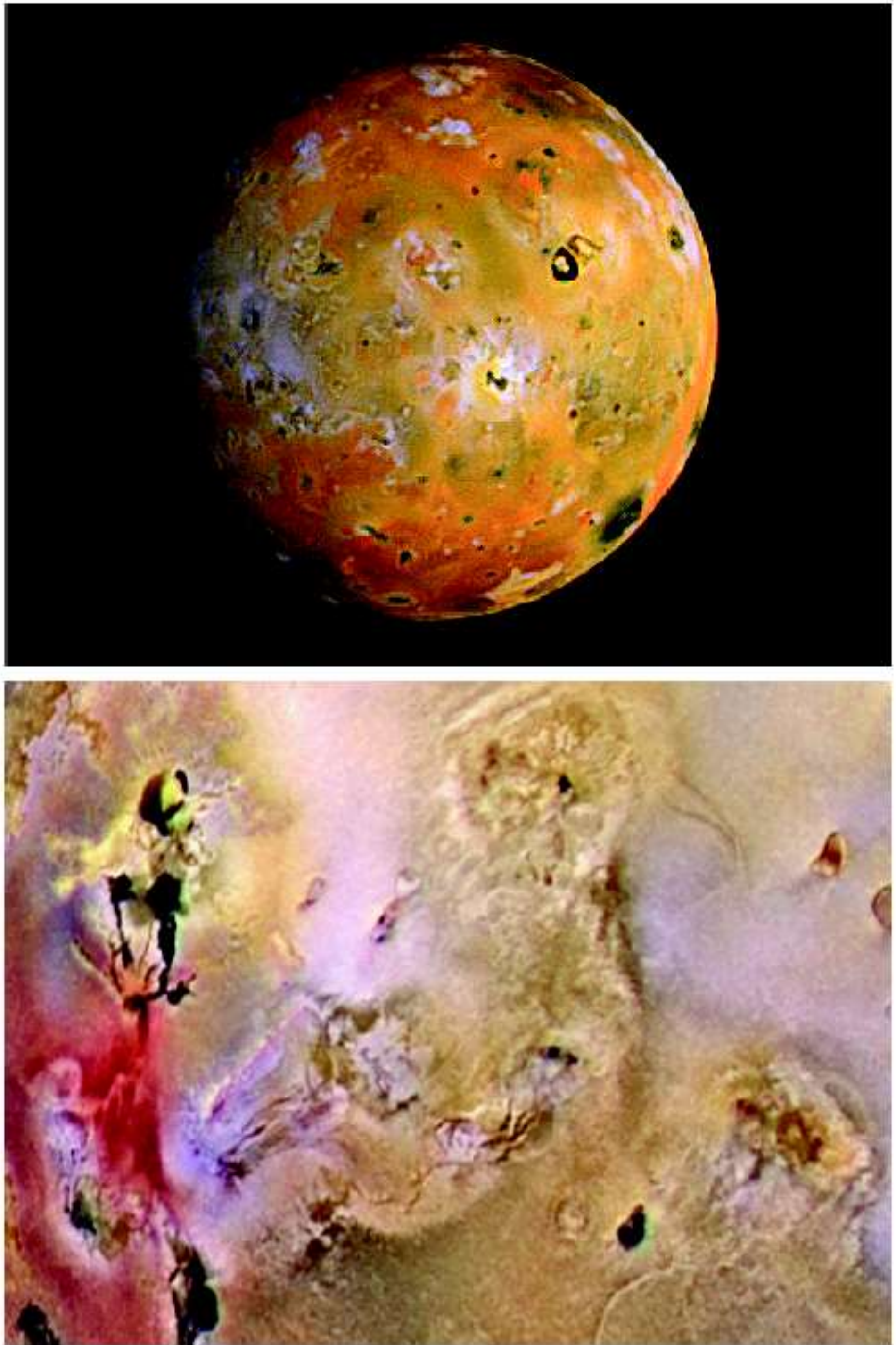


FIGURE 6.26 A pseudocolor coding approach used when several monochrome images are available.



a b
c d
e f

FIGURE 6.27 (a)–(d) Images in bands 1–4 in Fig. 1.10 (see Table 1.1). (e) Color composite image obtained by treating (a), (b), and (c) as the red, green, blue components of an RGB image. (f) Image obtained in the same manner, but using in the red channel the near-infrared image in (d). (Original multispectral images courtesy of NASA.)



a
b

FIGURE 6.28
(a) Pseudocolor rendition of Jupiter Moon Io.
(b) A close-up.
(Courtesy of NASA.)