Color Representations

Chromaticity Space

Using the CIE 1931 color matching functions $x(\lambda), y(\lambda), z(\lambda)$ a light stimulus $I(\lambda)$ can be represented using X, Y, Z

$$X = \int x(\lambda) I(\lambda) d\lambda \quad Y = \int y(\lambda) I(\lambda) d\lambda \quad Z = \int z(\lambda) I(\lambda) d\lambda$$

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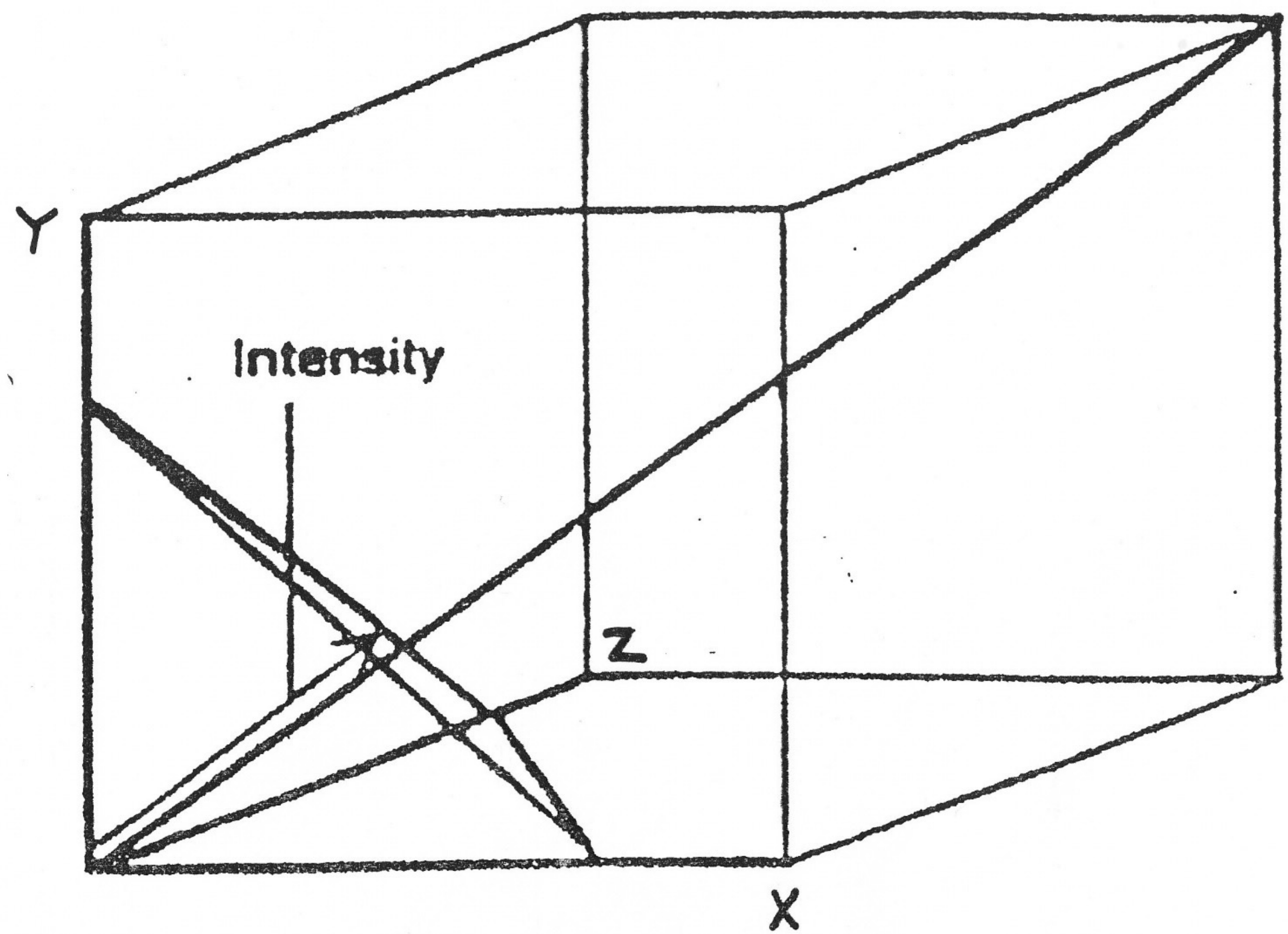
Often we are not interested in the intensity of a light stimulus.

Define $x = \dfrac{X}{X+Y+Z}$ $\quad y = \dfrac{Y}{X+Y+Z}$ $\quad z = \dfrac{Z}{X+Y+Z}$

$x + y + z = 1$ so x, y, z can be represented using (x, y)

The pair (x,y) is called chromaticity coordinates for a stimulus and the (x,y) plane is called the chromaticity diagram.



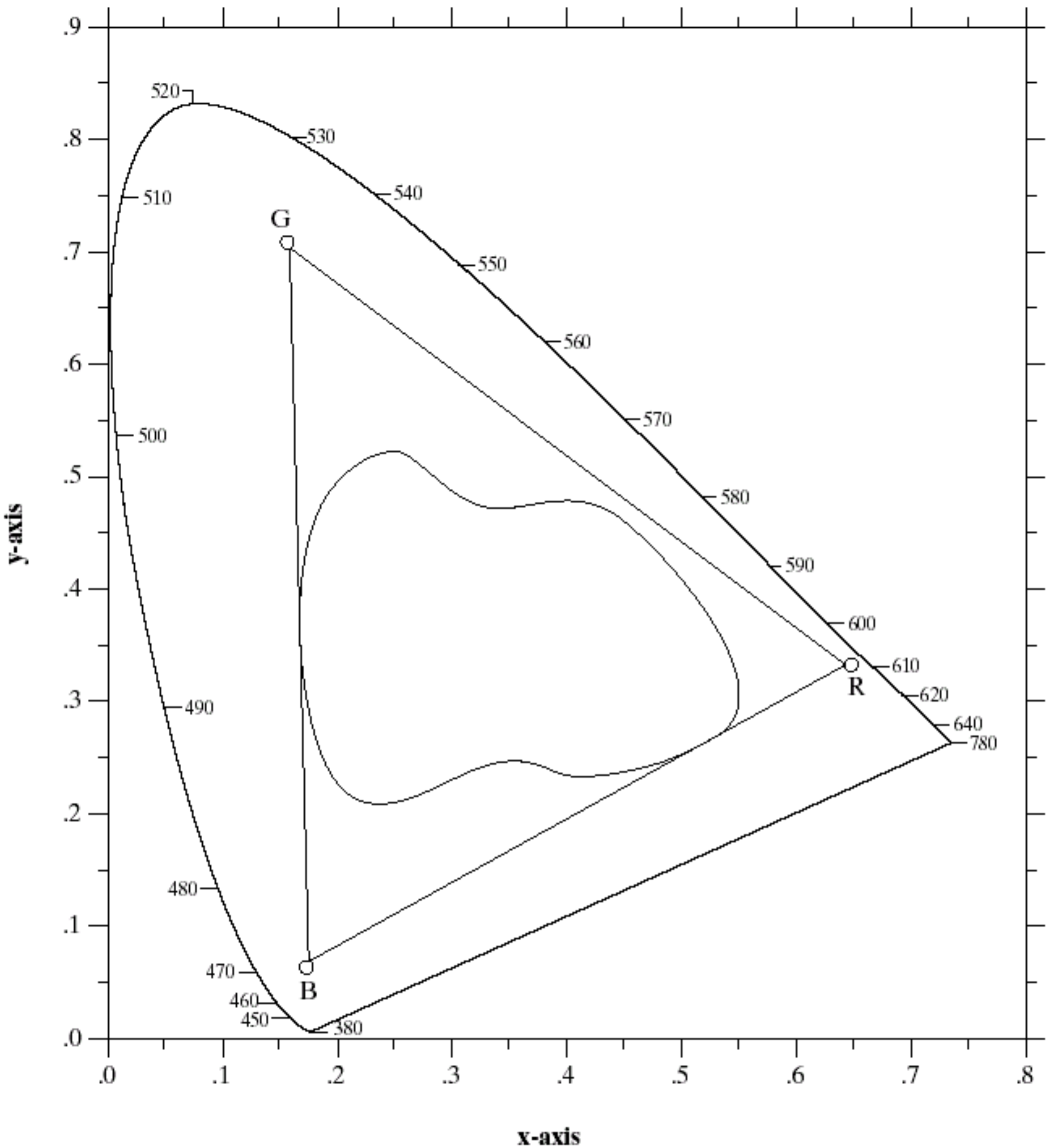
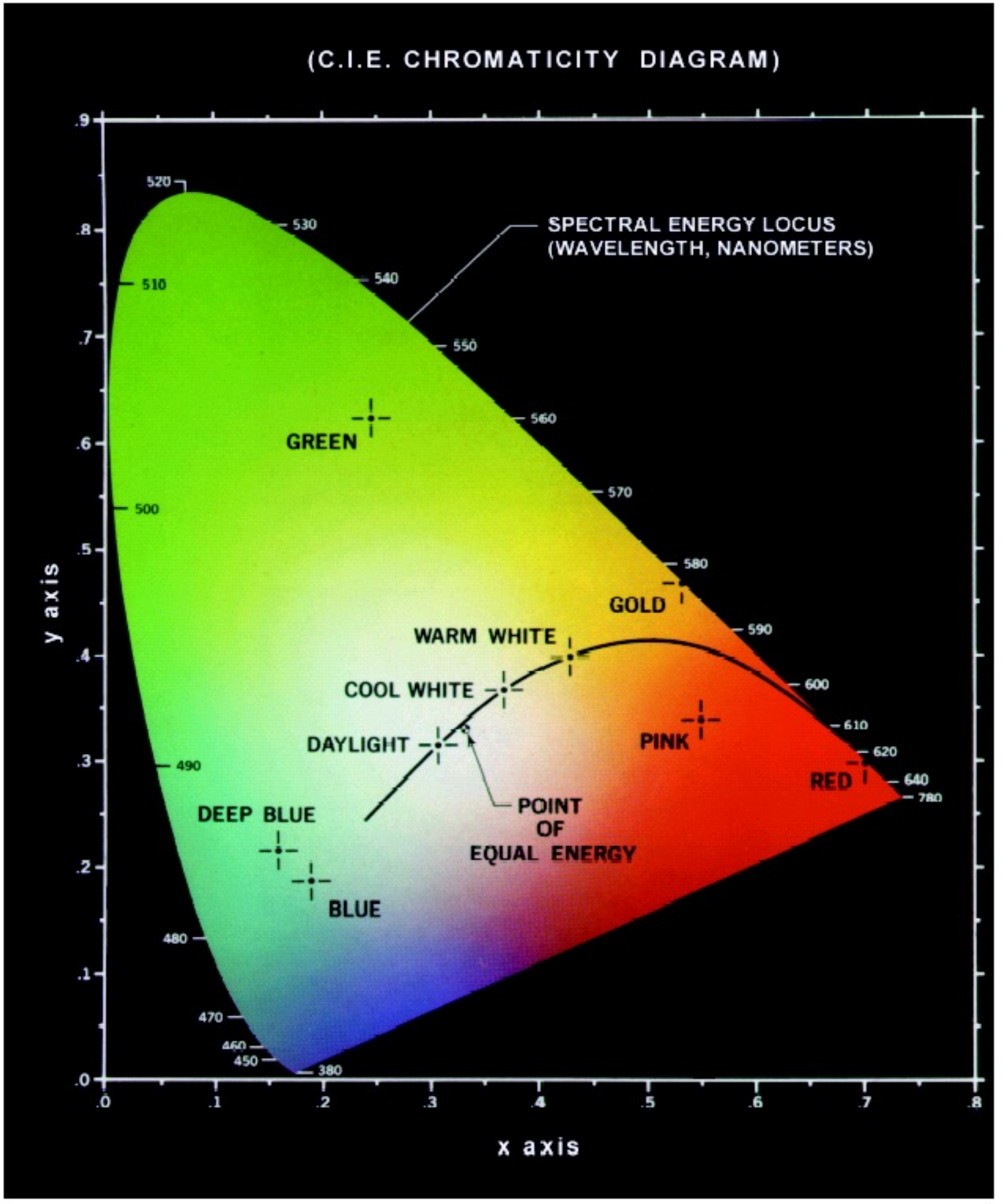


FIGURE 6.6 Typical color gamut of color monitors (triangle) and color printing devices (irregular region).

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



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Monochromatic stimuli are also called pure colors or maximally saturated colors.

The point $(x,y) = (\frac{1}{3}, \frac{1}{3})$ is called the white point or gray point and has saturation zero.

Given stimuli $I_1(\lambda)$ and $I_2(\lambda)$ with chromaticities (x_1, y_1) and (x_2, y_2), the chromaticity corresponding to $a_1 I_1(\lambda) + b\, I_2(\lambda)$ will lie on the line in the chromaticity diagram connecting (x_1, y_1) and (x_2, y_2)

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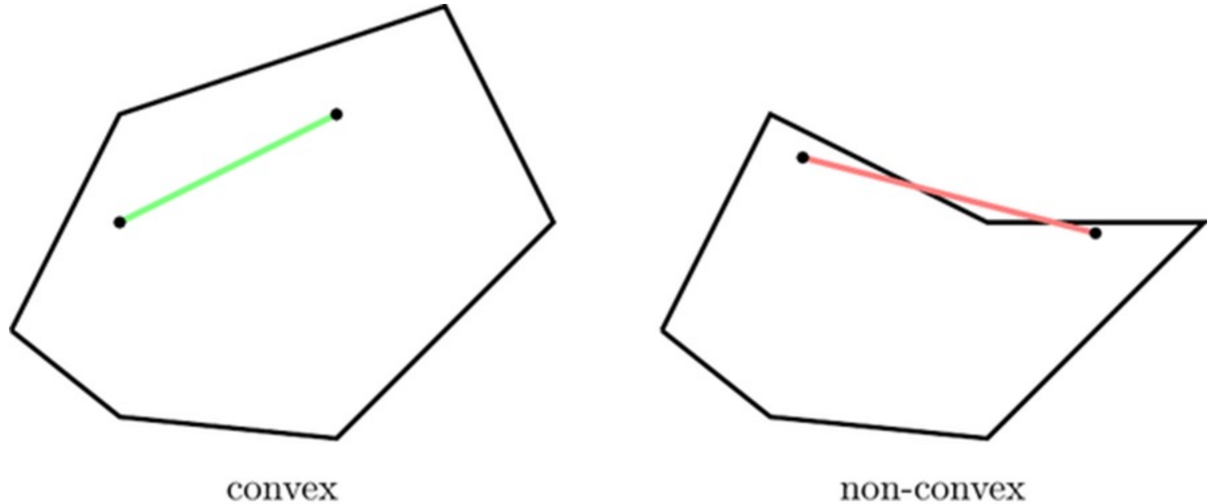
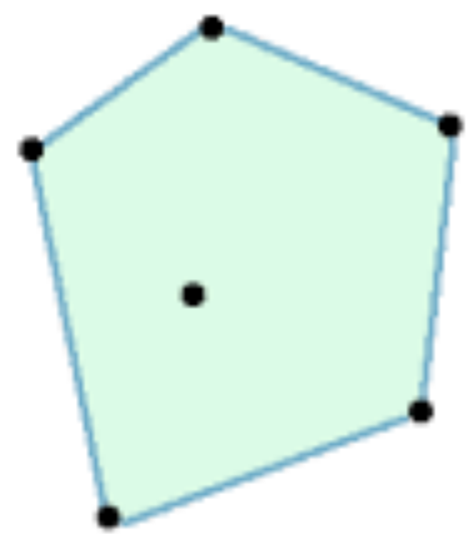
More generally, given stimuli $I_1(\lambda), I_2(\lambda), \ldots, I_N(\lambda)$ the chromaticity corresponding to additive combinations of the N stimuli will lie inside (or on) the convex hull of the points in chromaticity space defined by the chromaticities of $I_1(\lambda), I_2(\lambda), \ldots, I_N(\lambda)$.



Set of points



Convex Hull of Set of Points

The gamut of a monitor is all chromaticities that lie inside (or on) the triangle defined by the chromaticities of the display guns $D_R(\lambda)$, $D_G(\lambda)$, $D_B(\lambda)$

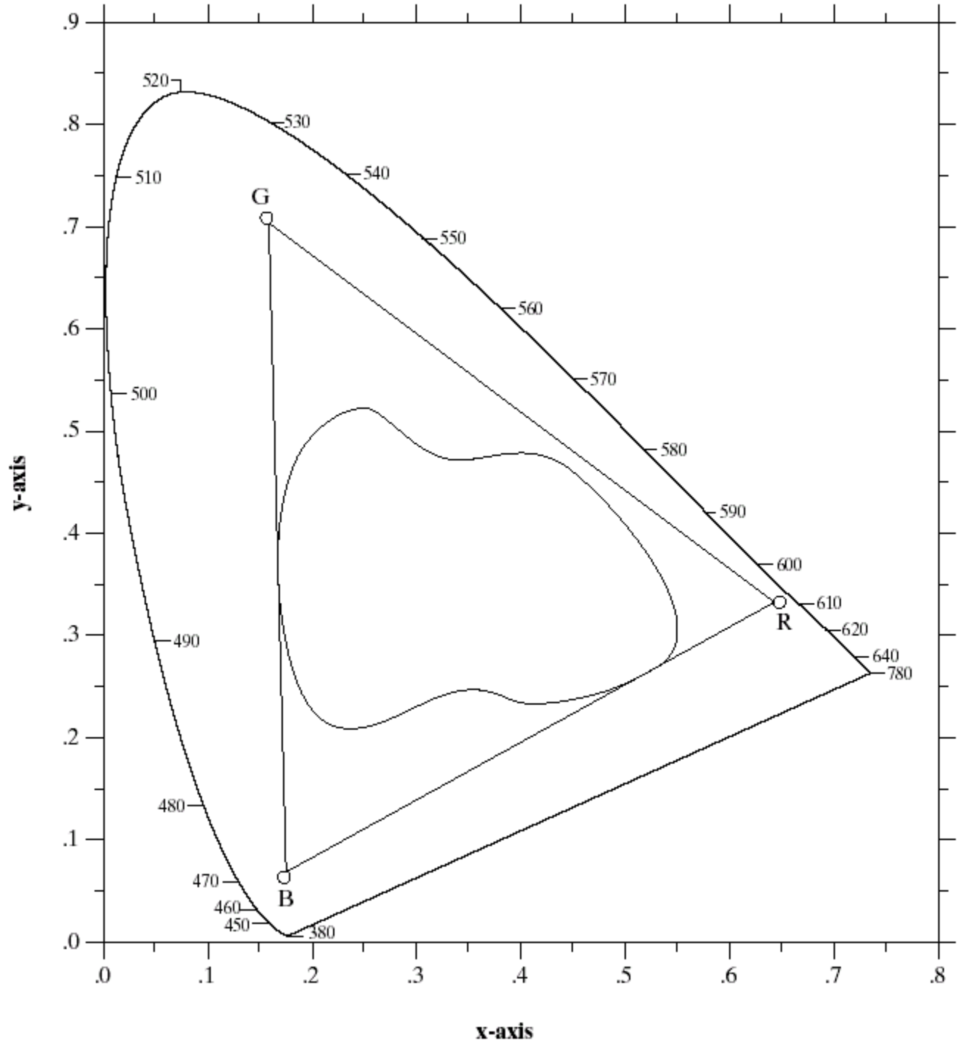


FIGURE 6.6 Typical color gamut of color monitors (triangle) and color printing devices (irregular region).

RGB and HSI Space

Given a set of 3 primaries, the representable colors will lie in RGB color space. Usually the 3 primaries are the 3 display guns for a monitor.

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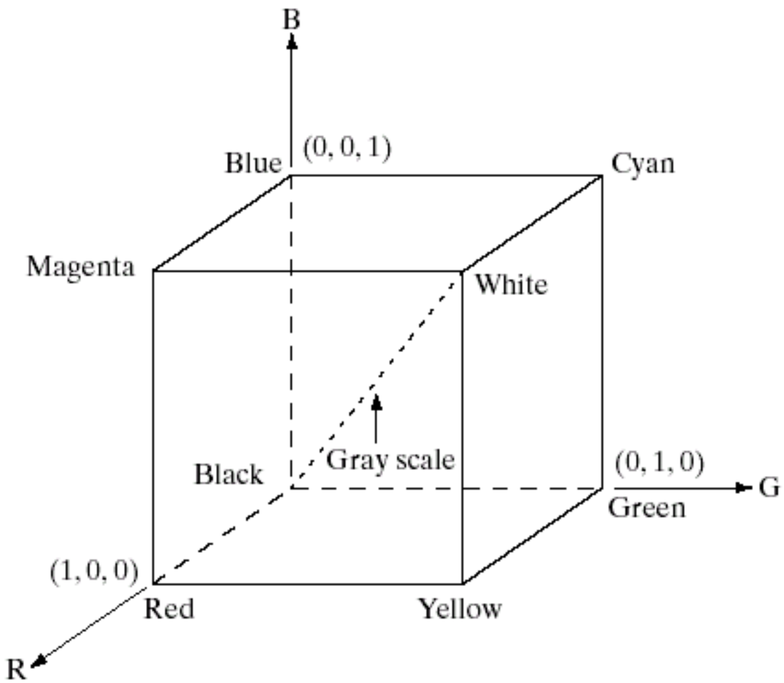

FIGURE 6.7 Schematic of the RGB color cube. Points along the main diagonal have gray values, from black at the origin to white at point (1, 1, 1).

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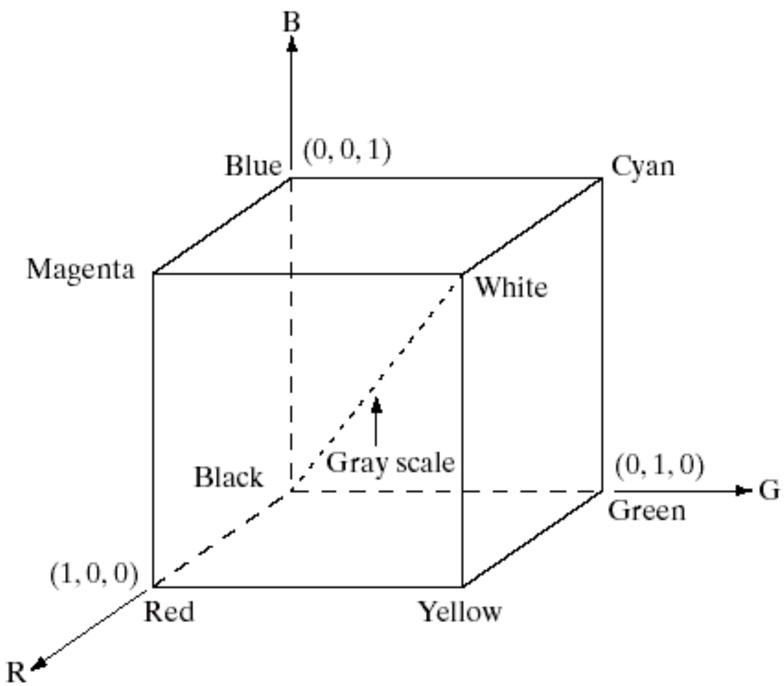

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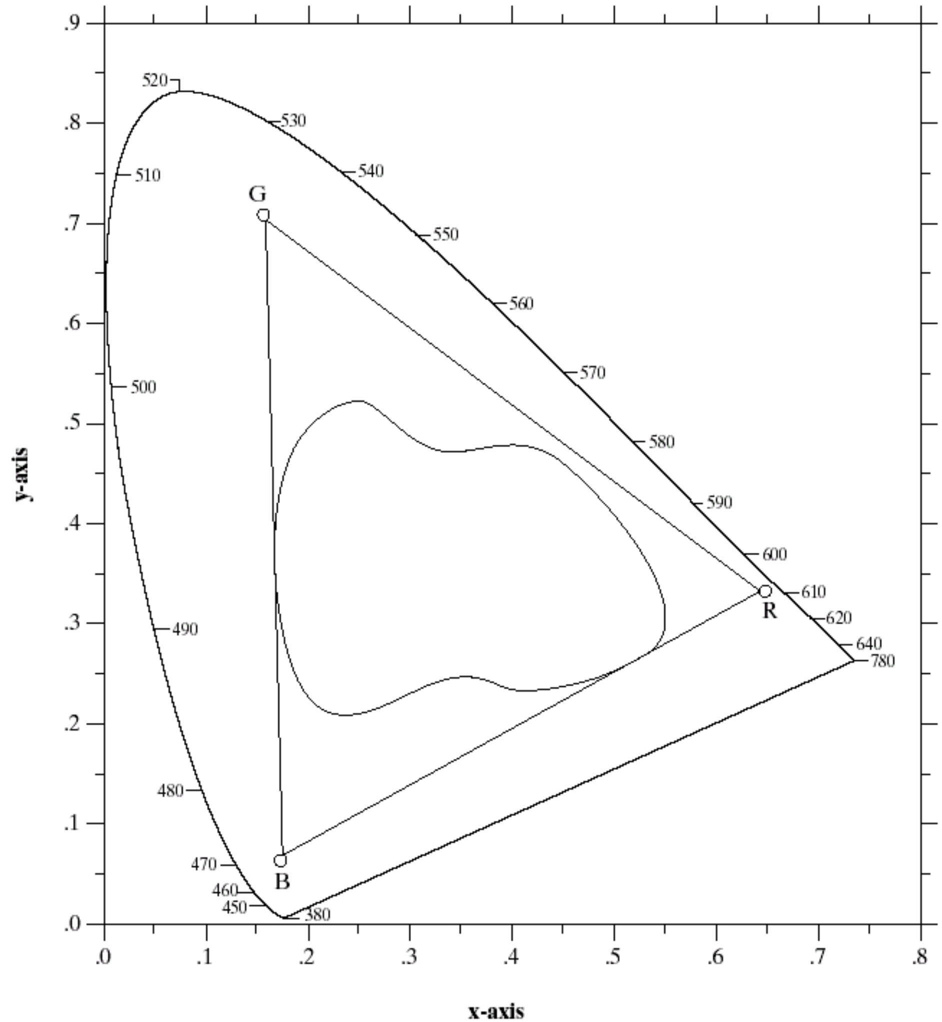

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Define the intensity I of (R, G, B) by

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

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The point in P for which $R = G = B = I_c$ is called the white point or gray point.

All points on a ray in P emanating from the gray point in one direction are said to have the same hue H and correspond to adding some amount of white to a monochromatic stimulus.

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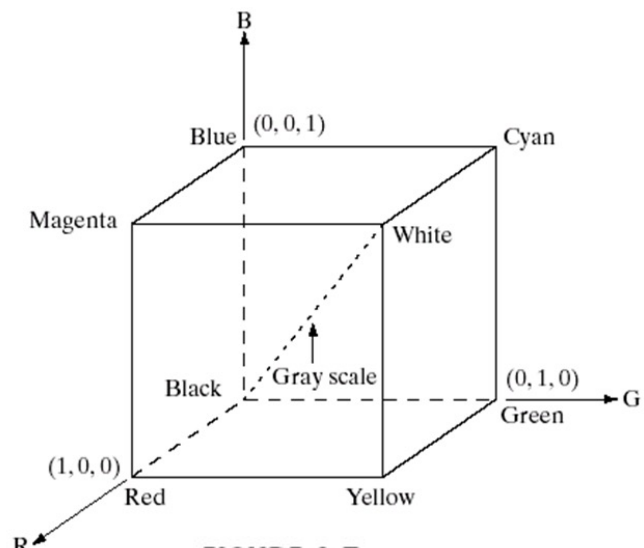

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All points on a ray in P emanating from the gray point in one direction are said to have the same hue H and correspond to adding some amount of white to a monochromatic stimulus.

Constant intensity plane

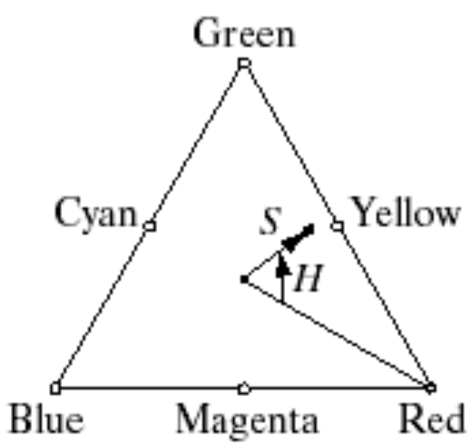
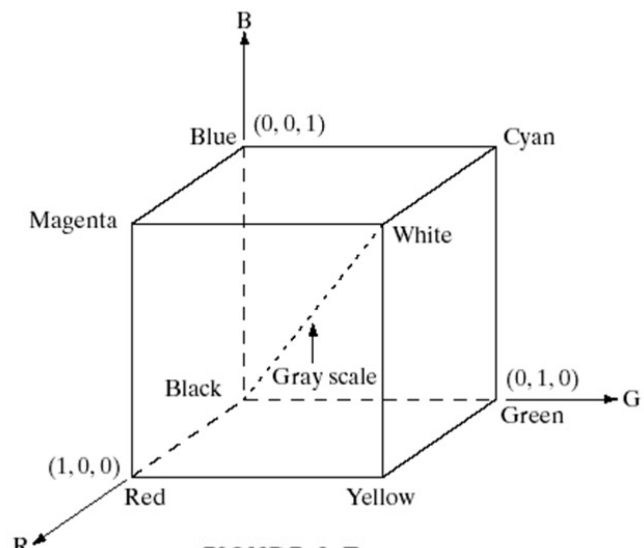


FIGURE 6.13 Hue and saturation



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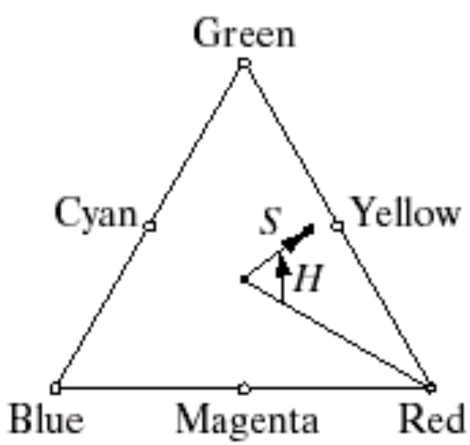

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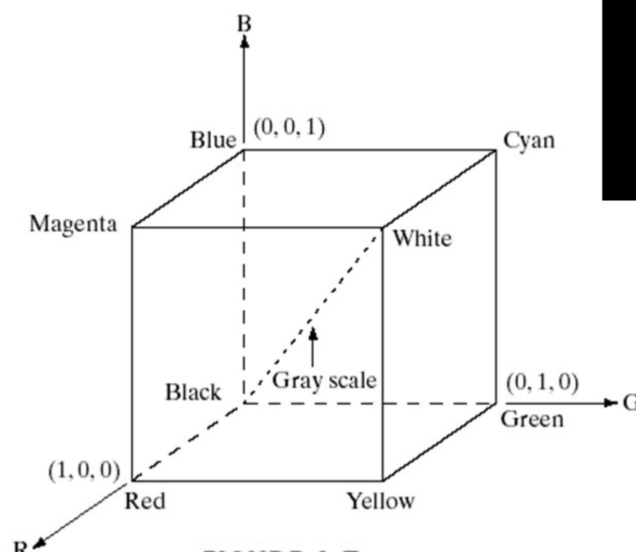

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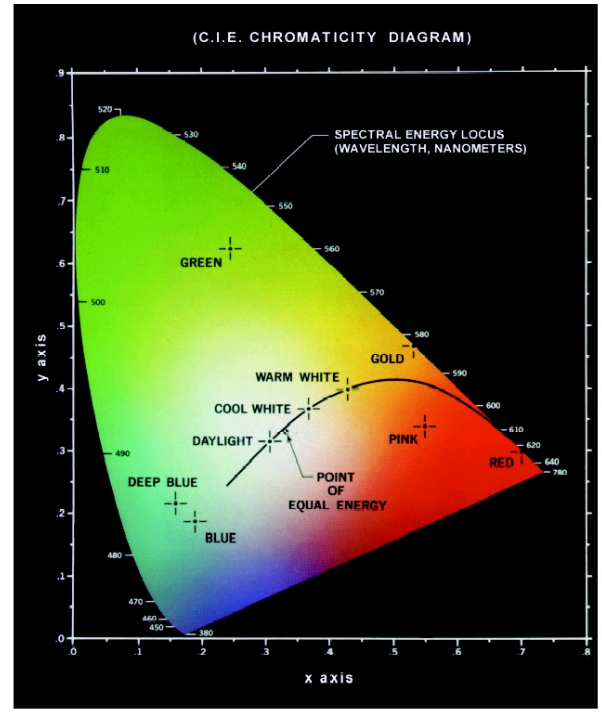
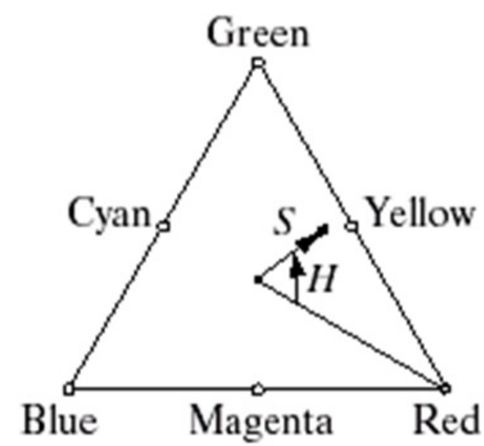


FIGURE 6.5

The hue of (R,G,B) is defined as an angle in the constant intensity plane that contains (R,G,B).



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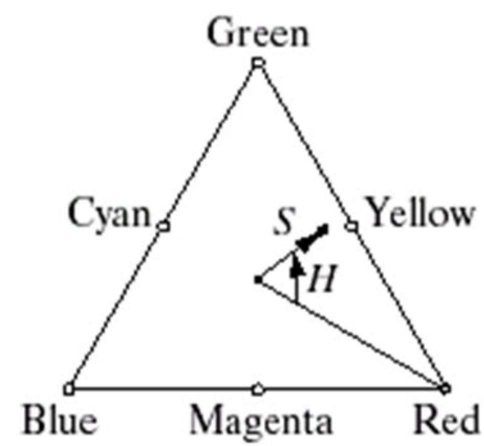
$$H = \begin{cases} \arccos\left(\dfrac{(R-G)+(R-B)}{2\sqrt{(R-G)^2+(R-B)(G-B)}}\right) \equiv h & G \geq B \text{ and not } R=G=B \\ 2\pi - h & G \leq B \text{ and not } R=G=B \\ \text{undefined} & R=G=B \end{cases}$$



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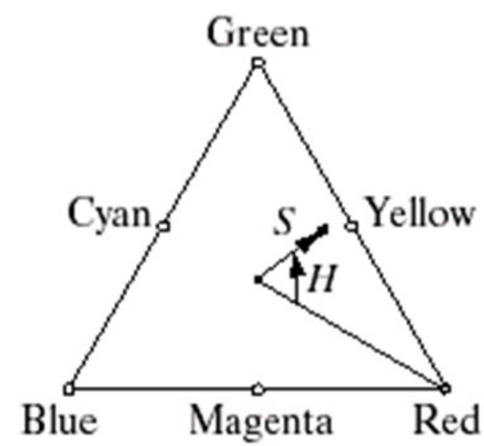

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Saturation S measures the purity of a color using

$$S = 1 - 3\min(r,g,b)$$

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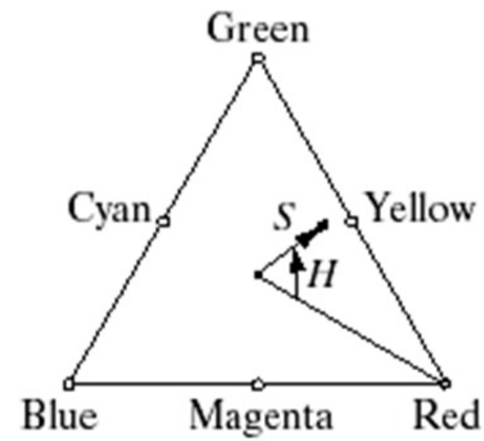

FIGURE 6.13 Hue and saturation

Saturation S measures the purity of a color using

$$S = 1 - 3\min(r,g,b)$$

Ex $r=g=b=\frac{1}{3} \Longrightarrow S=0$

Ex $r=0$ or $g=0$ or $b=0 \Longrightarrow S=1$

Color Mixtures

Additive Color Mixture – adding an amount of a primary increases the energy at certain wavelengths; large equal amounts of each primary combine to make white

Ex RGB monitors

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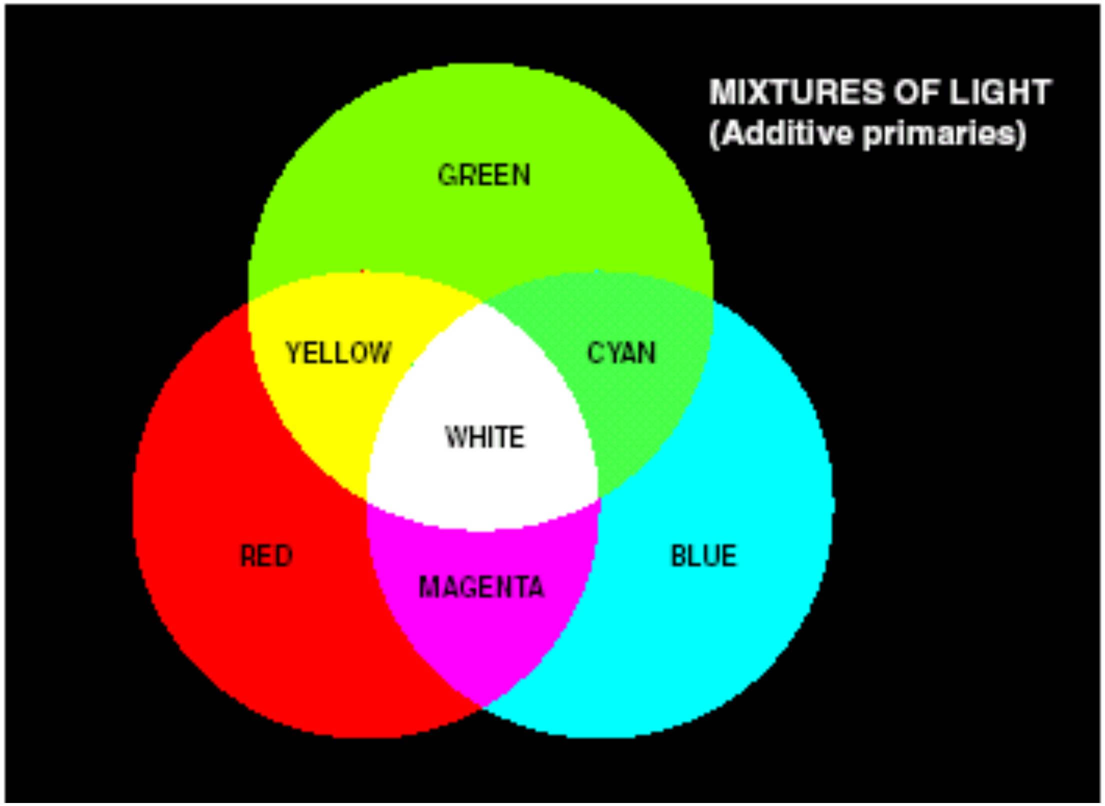

FIGURE 6.4

Subtractive Color Mixture – adding an amount of a primary decreases the energy at certain wavelengths; large equal amounts of each primary combine to make black

Ex CMY color printing

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Ex CMY color printing

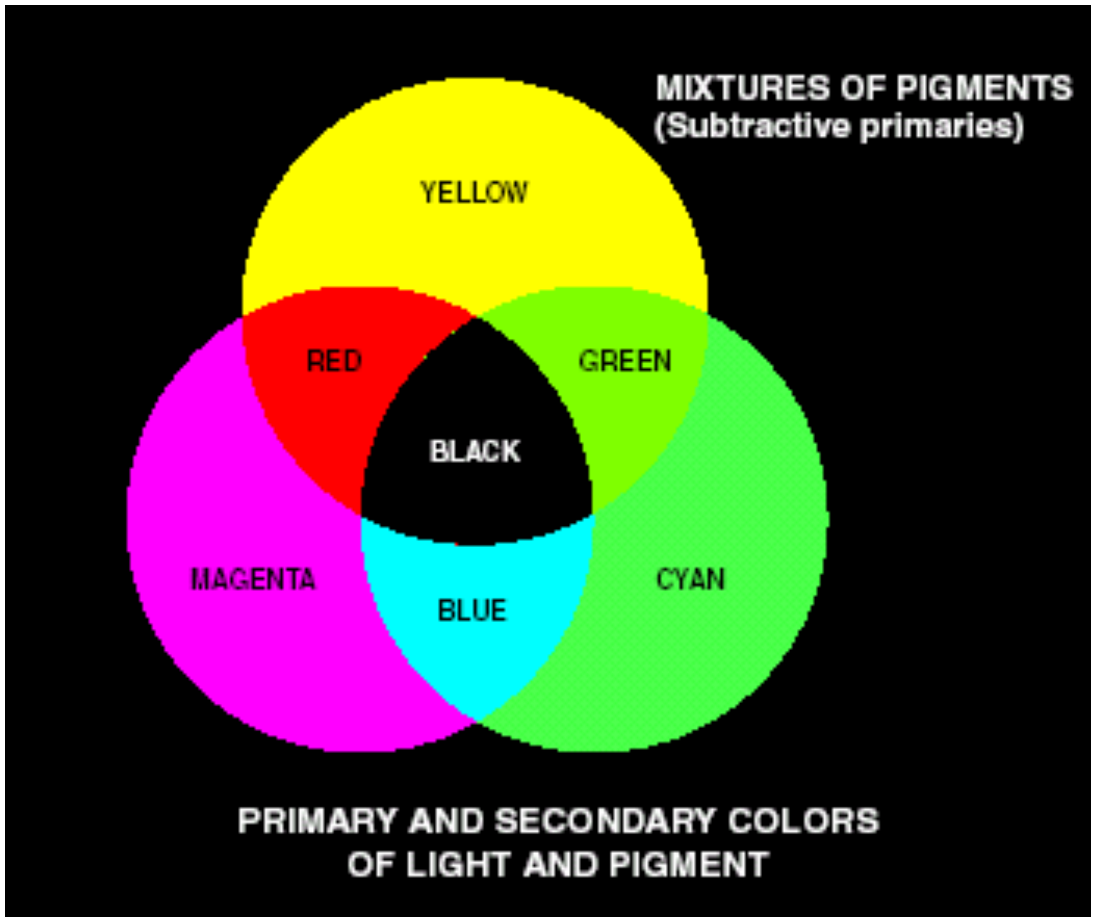

FIGURE 6.4

Color Printing

Color images are first formed from image irradiance functions $I(x,y,\lambda)$ using color filters with transmission functions $f_R(\lambda), f_G(\lambda), f_B(\lambda)$

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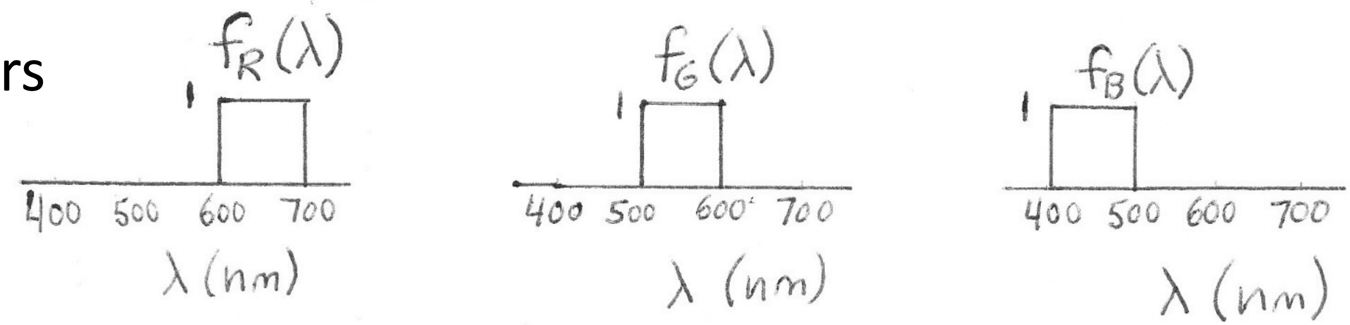
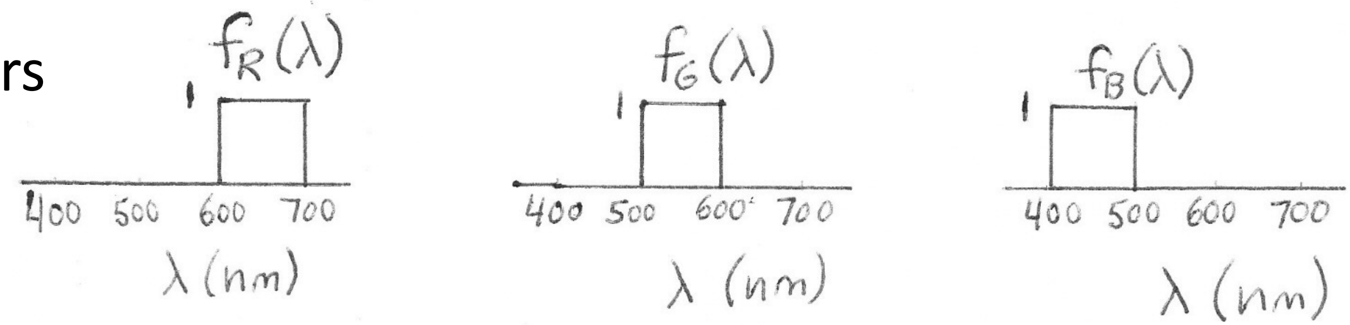
Idealized filters



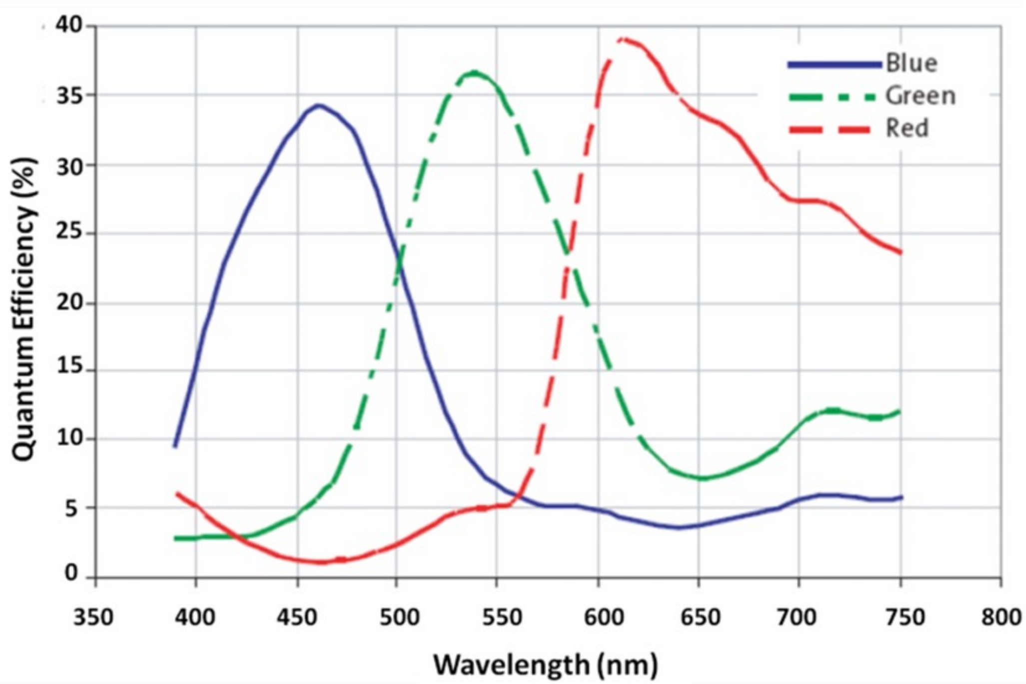
Color Printing

Color images are first formed from image irradiance functions $I(x,y,\lambda)$ using color filters with transmission functions $f_R(\lambda), f_G(\lambda), f_B(\lambda)$

Idealized filters



Real filters



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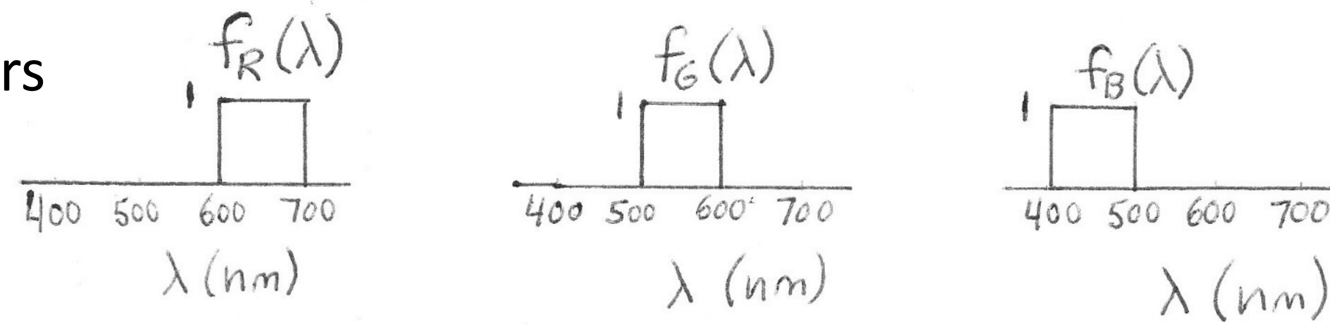

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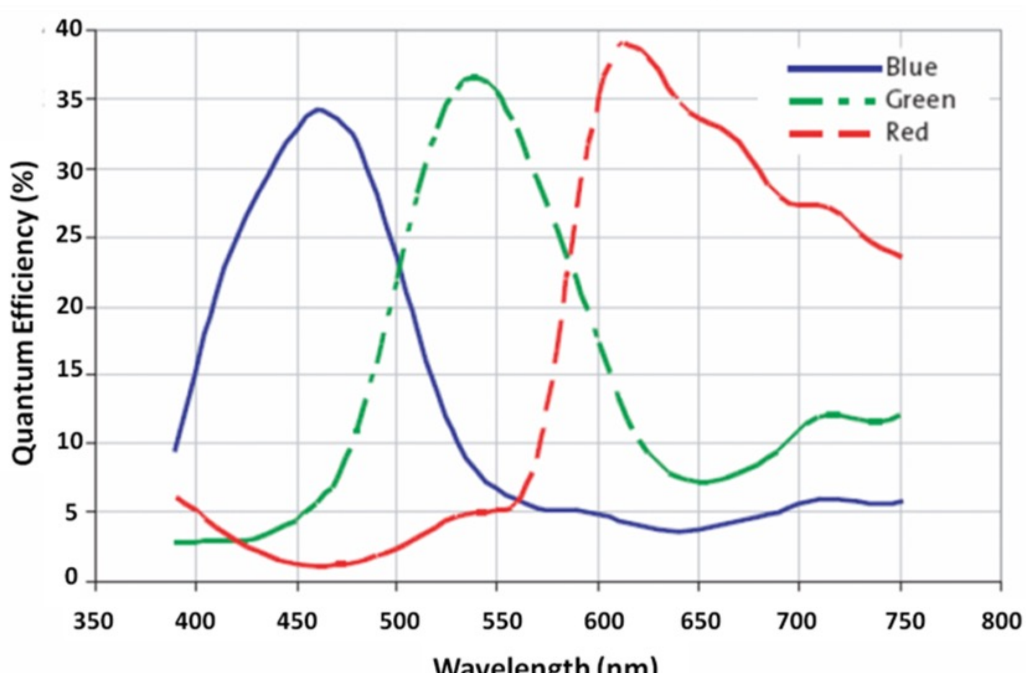

Color Image

$$R(x,y) = \int I(x,y,\lambda) f_R(\lambda)\, d\lambda$$

$$G(x,y) = \int I(x,y,\lambda) f_G(\lambda)\, d\lambda$$

$$B(x,y) = \int I(x,y,\lambda) f_B(\lambda)\, d\lambda$$

To print a color image, we mix inks at each pixel so that the pixel reflects light that appears similar to $I(x, y, \lambda)$

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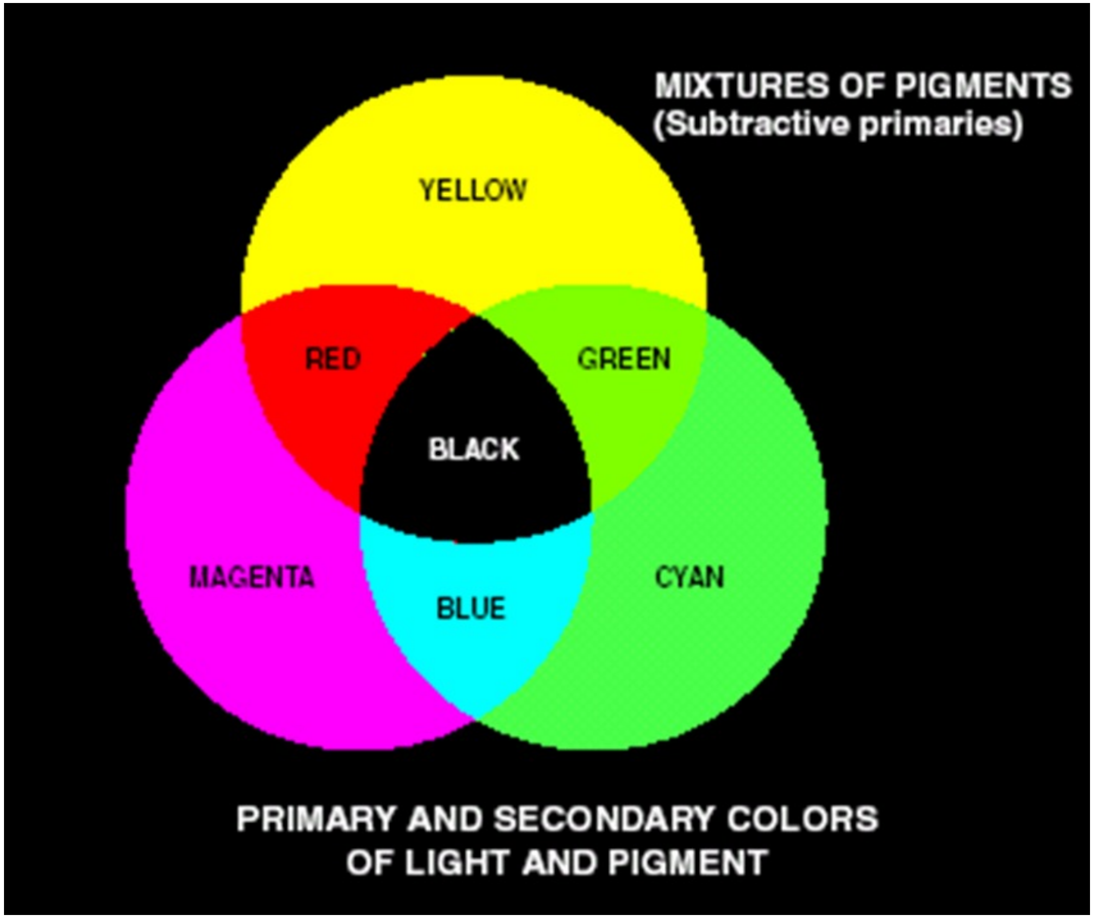

FIGURE 6.4

To print a color image, we mix inks at each pixel so that the pixel reflects light that appears similar to $I(x,y,\lambda)$

Can we just mix red, green, and blue ink? No.

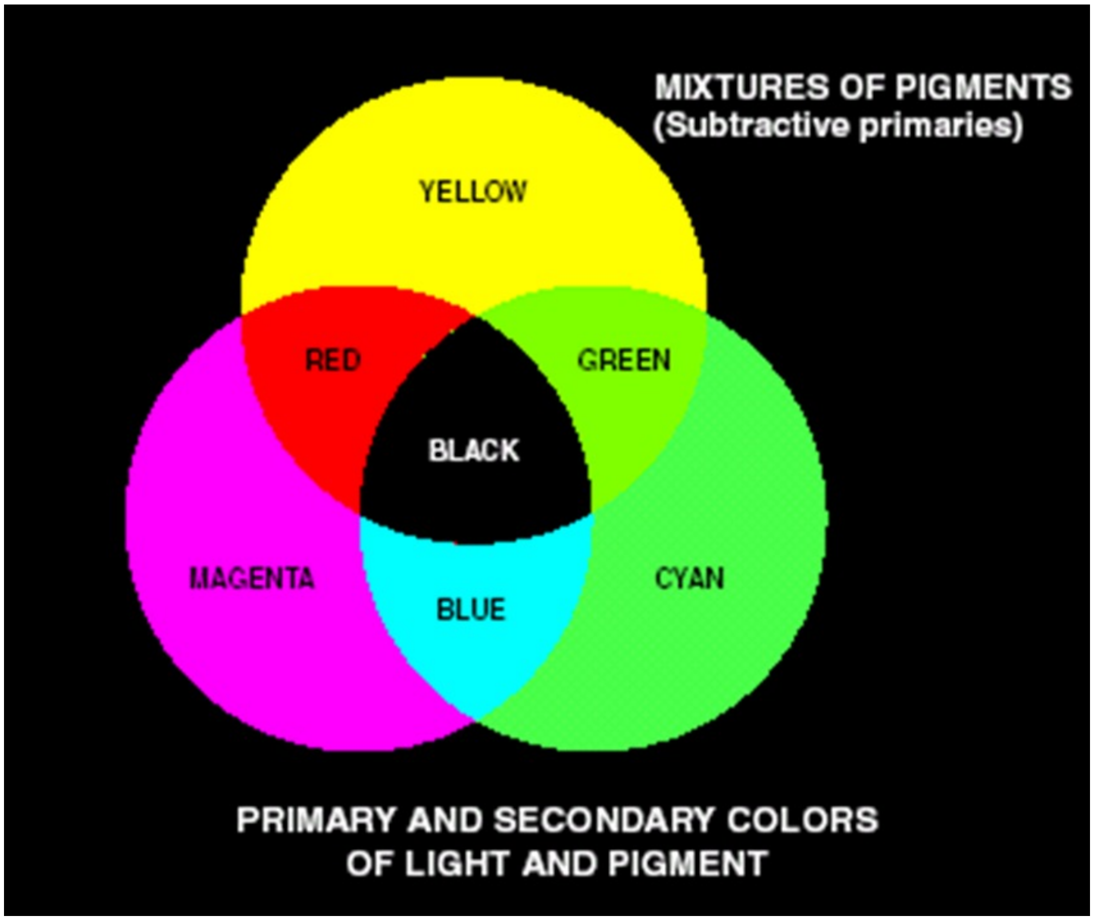

FIGURE 6.4

Inks used are cyan (C), magenta (M), yellow (Y) with reflectance functions $R_C(\lambda), R_M(\lambda), R_Y(\lambda)$

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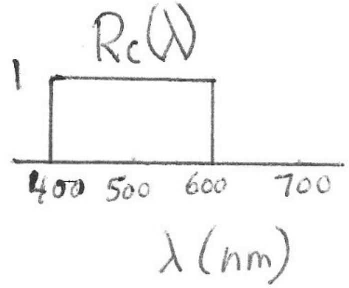
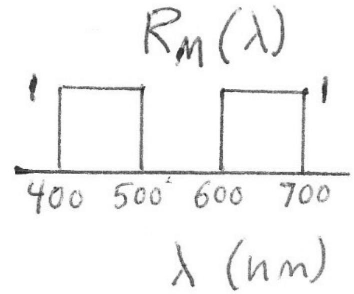
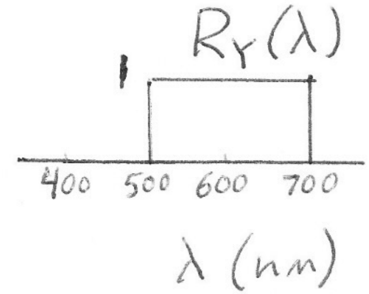
Idealized inks



reflects no red



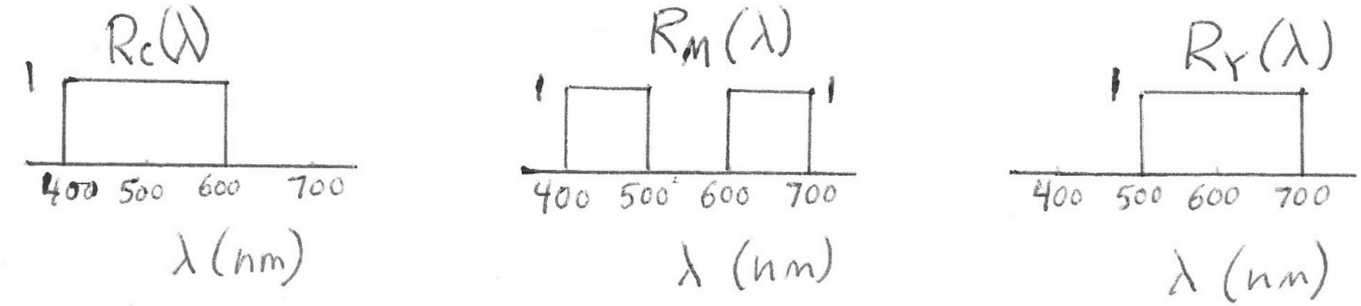
reflects no green



reflects no blue

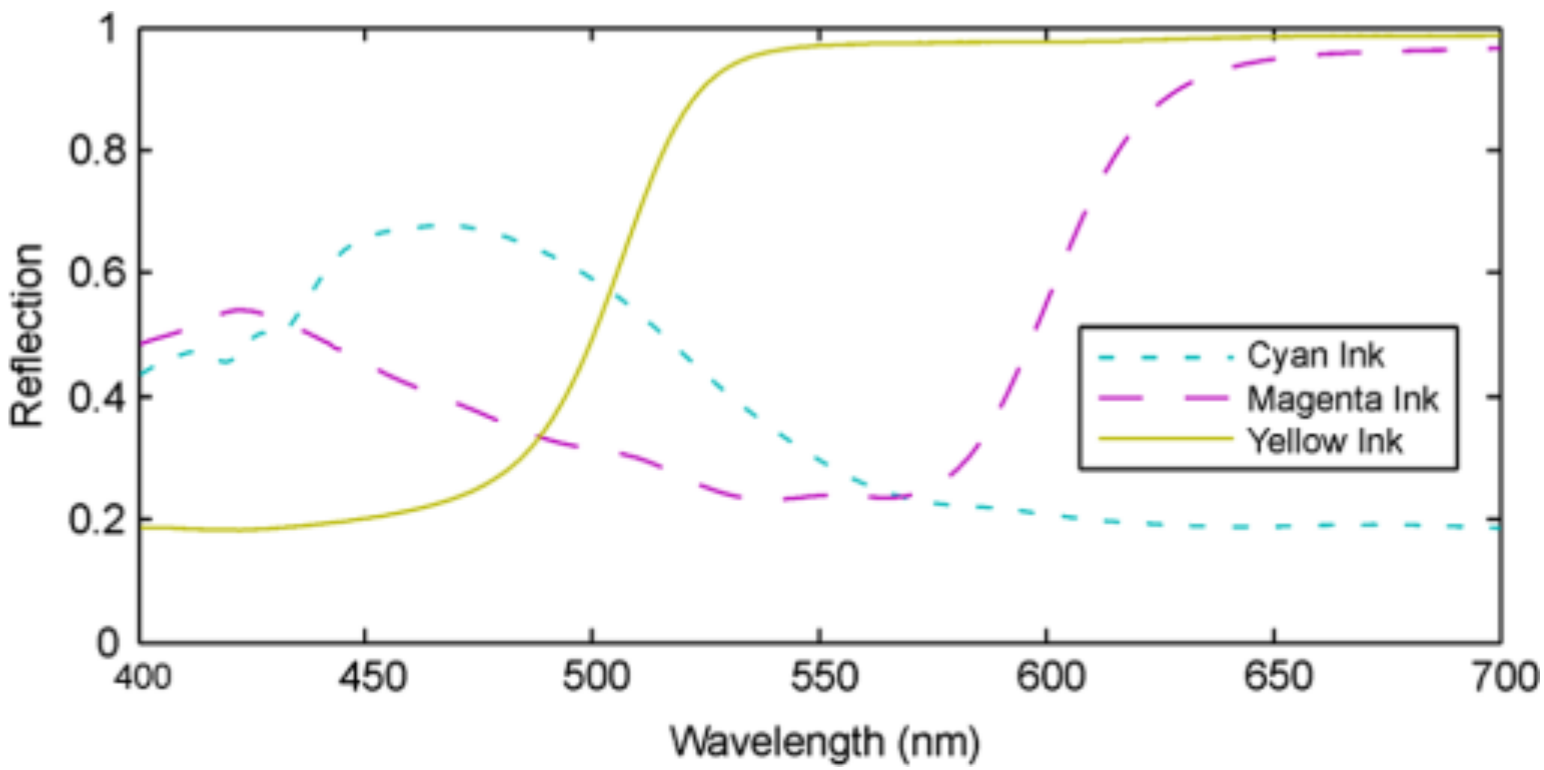
Inks used are cyan (C), magenta (M), yellow (Y) with reflectance functions $R_C(\lambda), R_M(\lambda), R_Y(\lambda)$

Idealized inks



reflects no red | reflects no green | reflects no blue

Real inks



Paper starts white. As we add cyan ink, we remove red light. As we add magenta ink, we remove green light. As we add yellow ink, we remove blue light.

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Assume RGB and CMY values are normalized to the range 0-1.

$$C(x,y) = 1 - R(x,y)$$
$$M(x,y) = 1 - G(x,y)$$
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Black ink (K) is often used with CMY to improve black appearance and reduce cost.

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Ex $C=0.4,\ M=0.3,\ Y=0.5 \rightarrow C=0.1, M=0.0, Y=0.2, K=0.3$

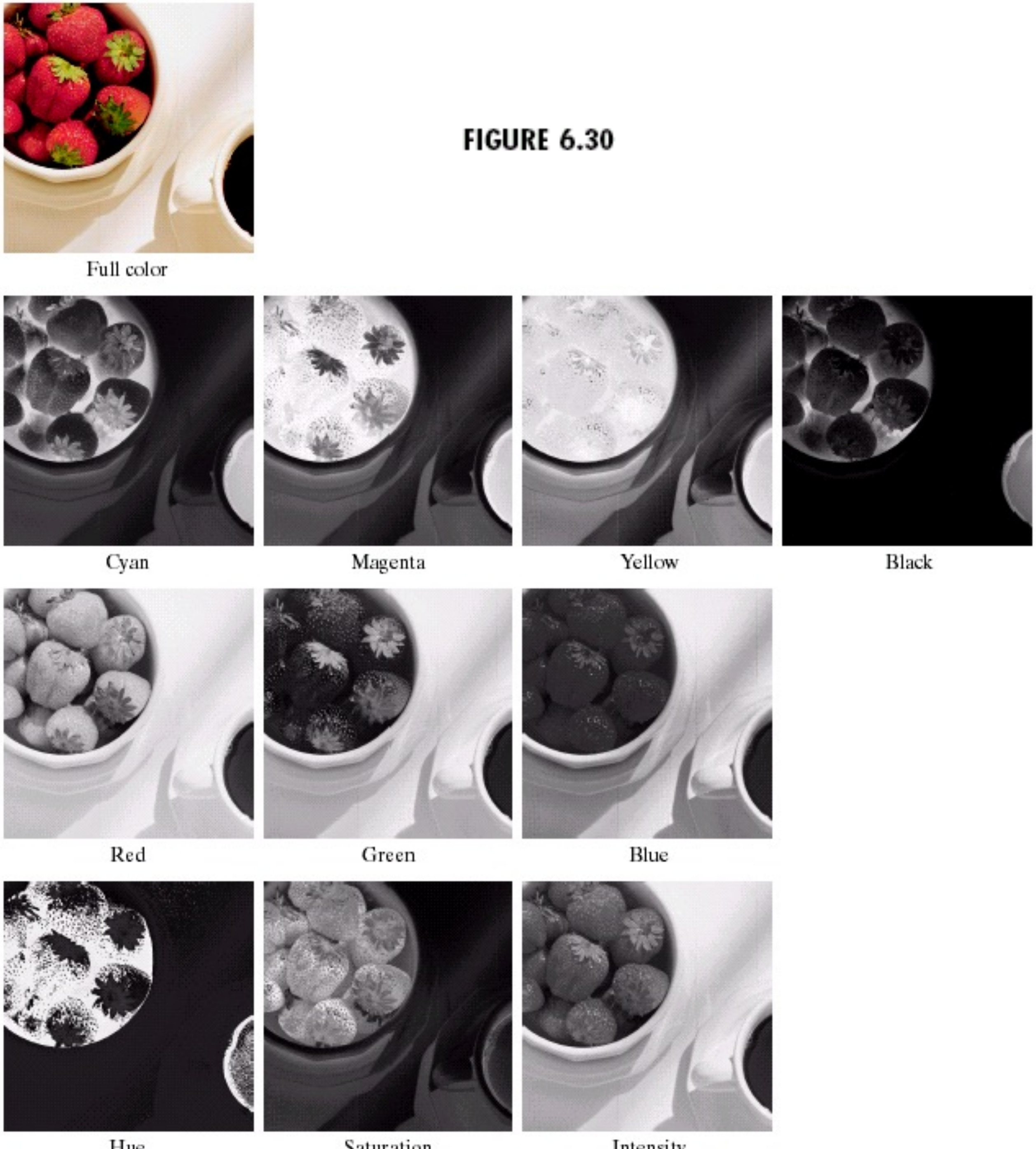
Full color
Cyan
Magenta
Yellow
Black
Red
Green
Blue
Hue
Saturation
Intensity

FIGURE 6.30

False Color for Visualization

Goal: transform a gray level image to a color image to improve its appearance for some purpose

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Intensity slicing - map ranges of gray levels in the input image $f(x,y)$ to colors in the output image $g(x,y)$

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Goal: transform a gray level image to a color image to improve its appearance for some purpose

Intensity slicing – map ranges of gray levels in the input image $f(x,y)$ to colors in the output image $g(x,y)$

If $0 \le f(x,y) \le \ell_1$ then $g(x,y) =$ color 1

If $\ell_1 + 1 \le f(x,y) \le \ell_2$ then $g(x,y) =$ color 2

$\vdots$ $\qquad\qquad\qquad\qquad$ $\vdots$

If $\ell_{n-1} + 1 \le f(x,y) \le \ell_n$ then $g(x,y) =$ color n

False Color for Visualization

Goal: transform a gray level image to a color image to improve its appearance for some purpose

Intensity slicing - map ranges of gray levels in the input image $f(x,y)$ to colors in the output image $g(x,y)$

$$\text{If } 0 \le f(x,y) \le l_1 \text{ then } g(x,y) = \text{color } 1$$
$$\text{If } l_1 + 1 \le f(x,y) \le l_2 \text{ then } g(x,y) = \text{color } 2$$
$$\vdots \qquad\qquad\qquad \vdots$$
$$\text{If } l_{n-1} + 1 \le f(x,y) \le l_n \text{ then } g(x,y) = \text{color } n$$

n = 2

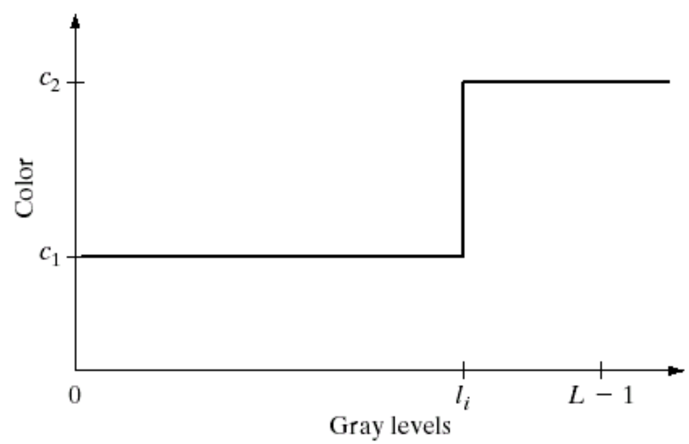
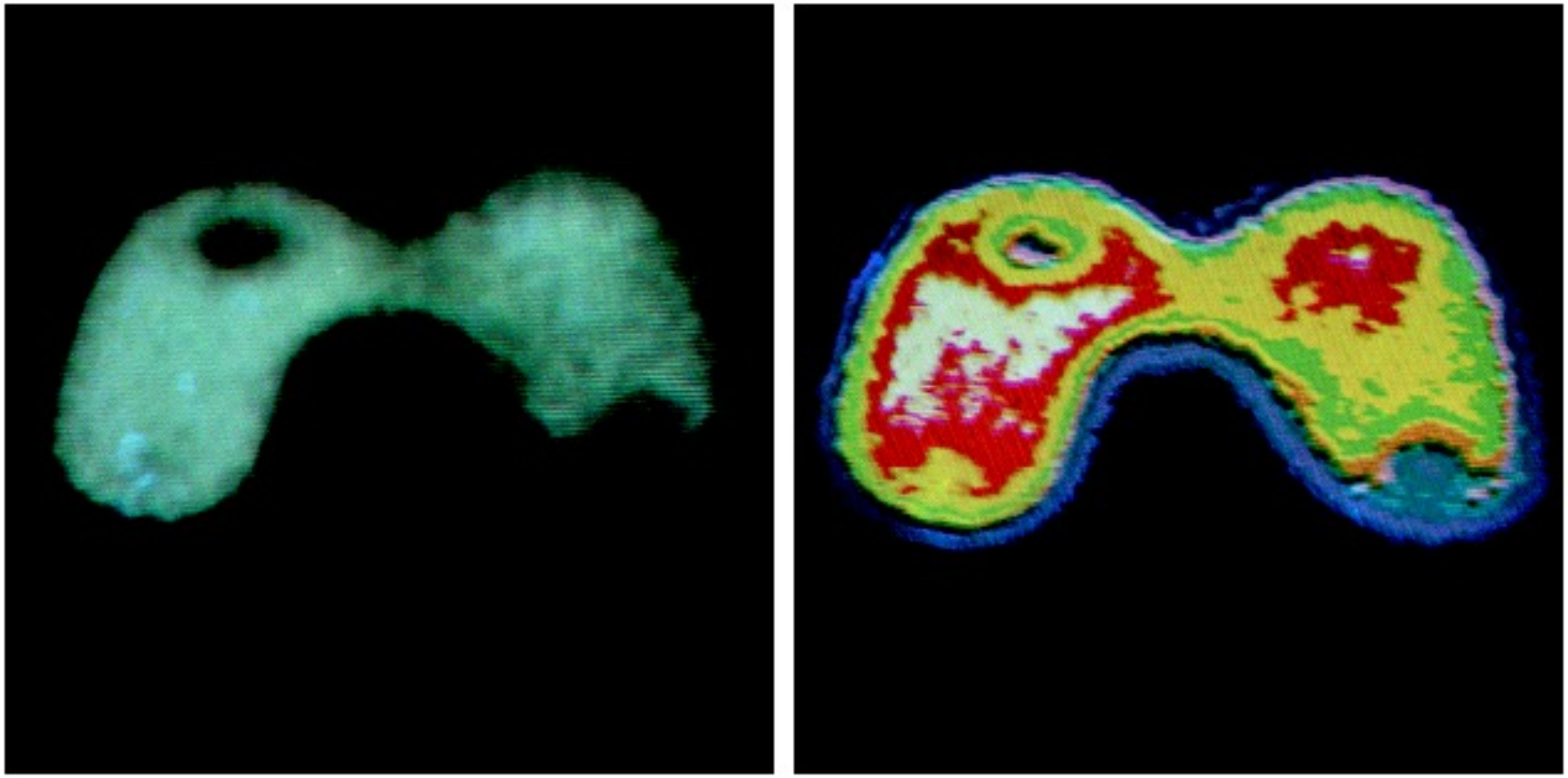


FIGURE 6.19 An alternative representation of the intensity-slicing technique.

n = 8



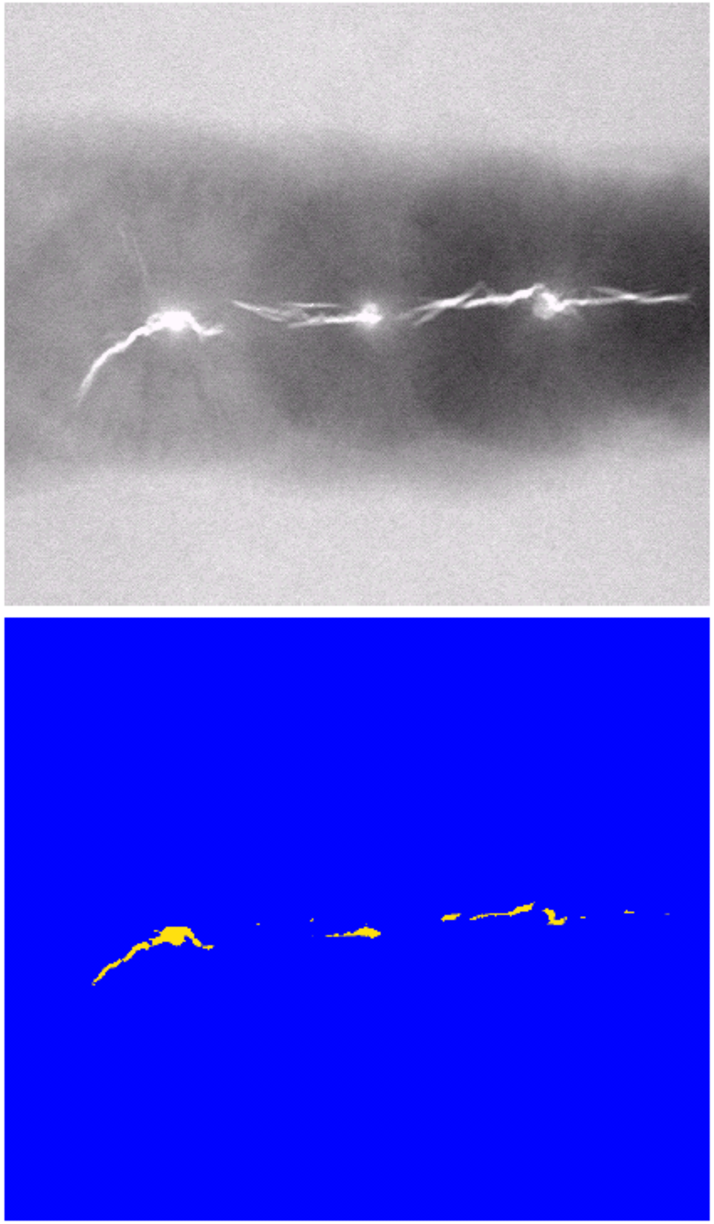
a b

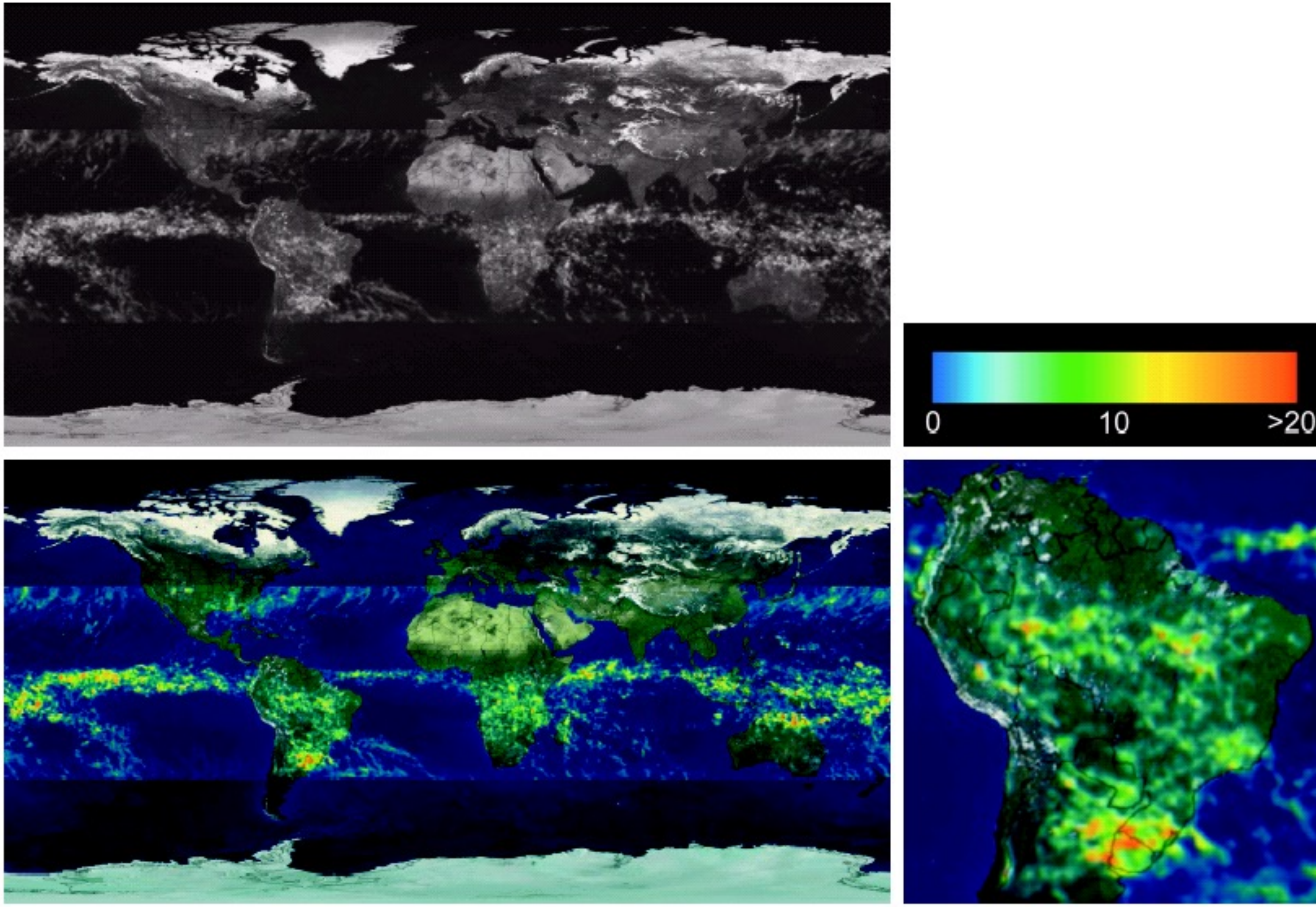
FIGURE 6.20 (a) Monochrome image of the Picker Thyroid Phantom. (b) Result of density slicing into eight colors. (Courtesy of Dr. J. L. Blankenship, Instrumentation and Controls Division, Oak Ridge National Laboratory.)

n = 2

a
b

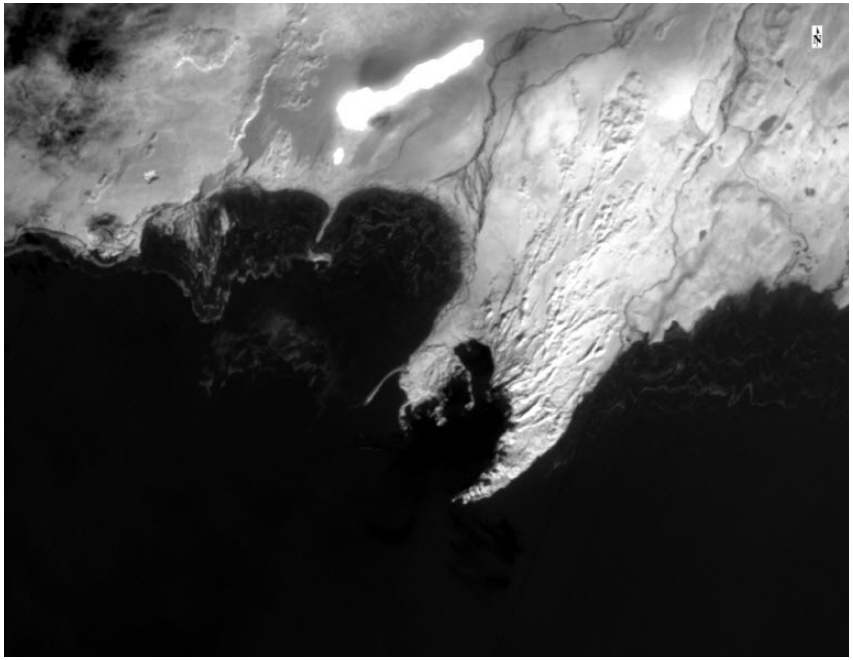
FIGURE 6.21 (a) Monochrome X-ray image of a weld. (b) Result of color coding. (Original image courtesy of X-TEK Systems, Ltd.)



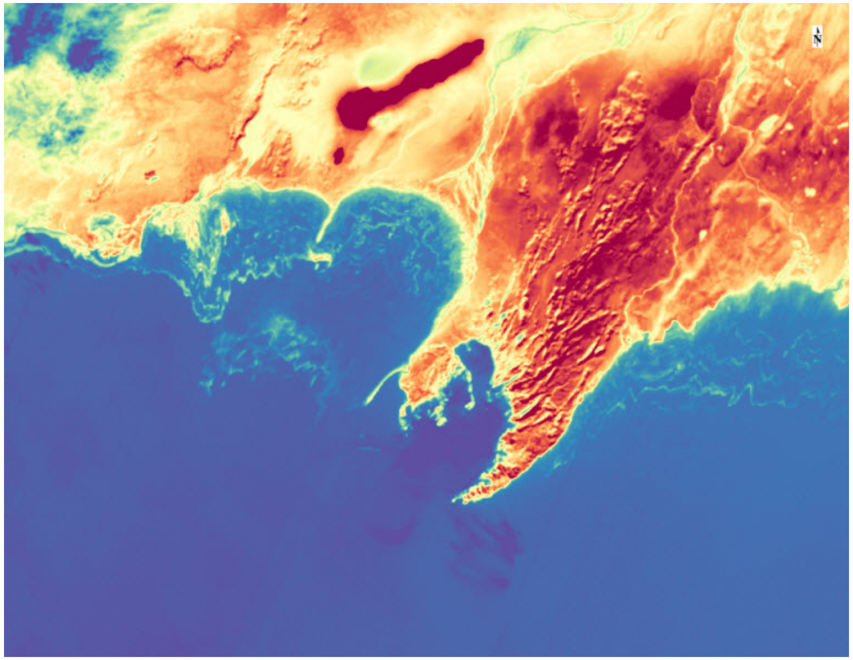


a b
c d

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.)



Landsat 8, Thermal IR band 1
Iceland with volcano and glacier



Hot mapped to red
Cold mapped to blue

Displaying Multispectral Images

TABLE 1.1
Thematic bands in NASA's LANDSAT satellite.

LANDSAT 4

Band No.	Name	Wavelength (μm)	Characteristics and Uses
1	Visible blue	0.45–0.52	Maximum water penetration
2	Visible green	0.52–0.60	Good for measuring plant vigor
3	Visible red	0.63–0.69	Vegetation discrimination
4	Near infrared	0.76–0.90	Biomass and shoreline mapping
5	Middle infrared	1.55–1.75	Moisture content of soil and vegetation
6	Thermal infrared	10.4–12.5	Soil moisture; thermal mapping
7	Middle infrared	2.08–2.35	Mineral mapping

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7	Middle infrared	2.08–2.35	Mineral mapping

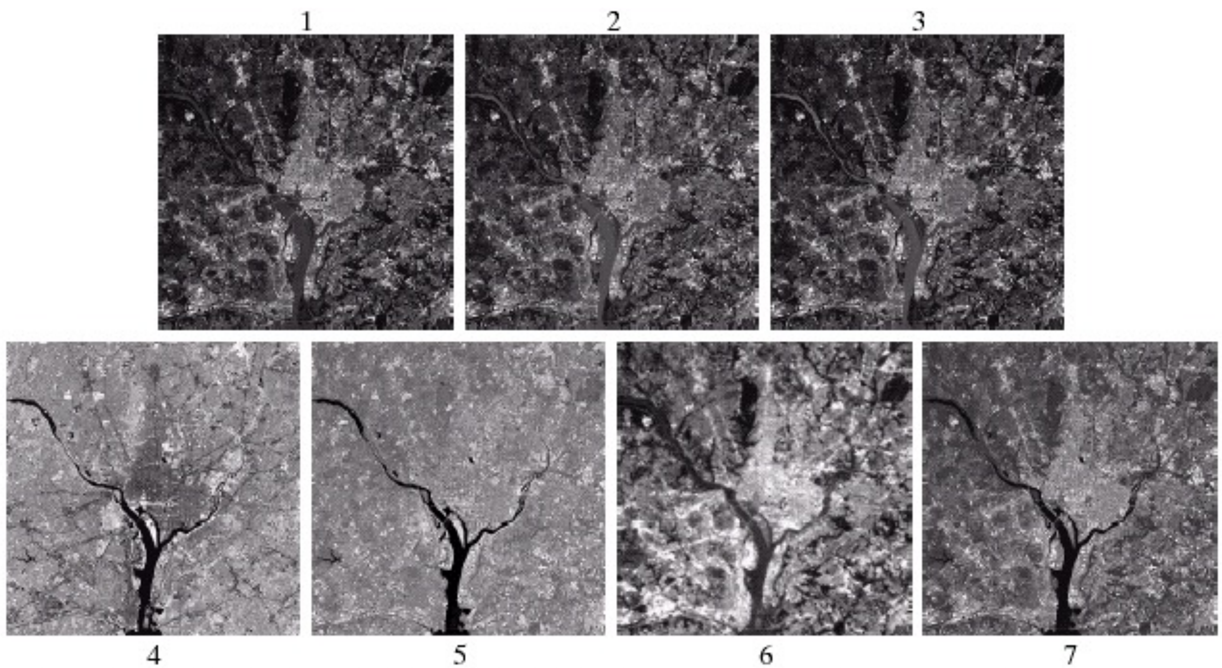
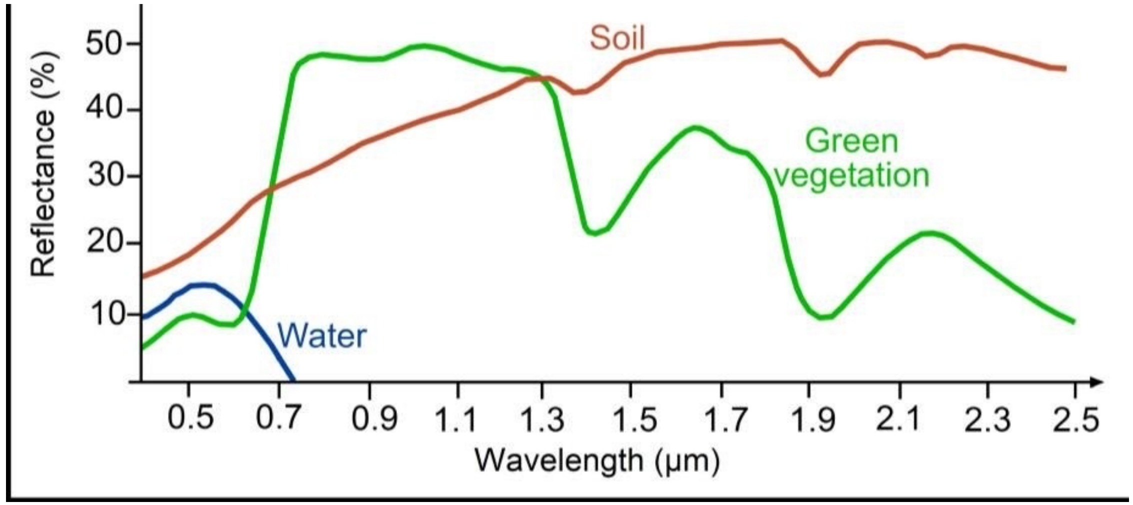


FIGURE 1.10 LANDSAT satellite images of the Washington, D.C. area. The numbers refer to the thematic bands in Table 1.1. (Images courtesy of NASA.)

Band No.	Name	Wavelength (μm)
1	Visible blue	0.45–0.52
2	Visible green	0.52–0.60
3	Visible red	0.63–0.69
4	Near infrared	0.76–0.90
5	Middle infrared	1.55–1.75
6	Thermal infrared	10.4–12.5
7	Middle infrared	2.08–2.35



Band No.	Name	Wavelength (μm)
1	Visible blue	0.45–0.52
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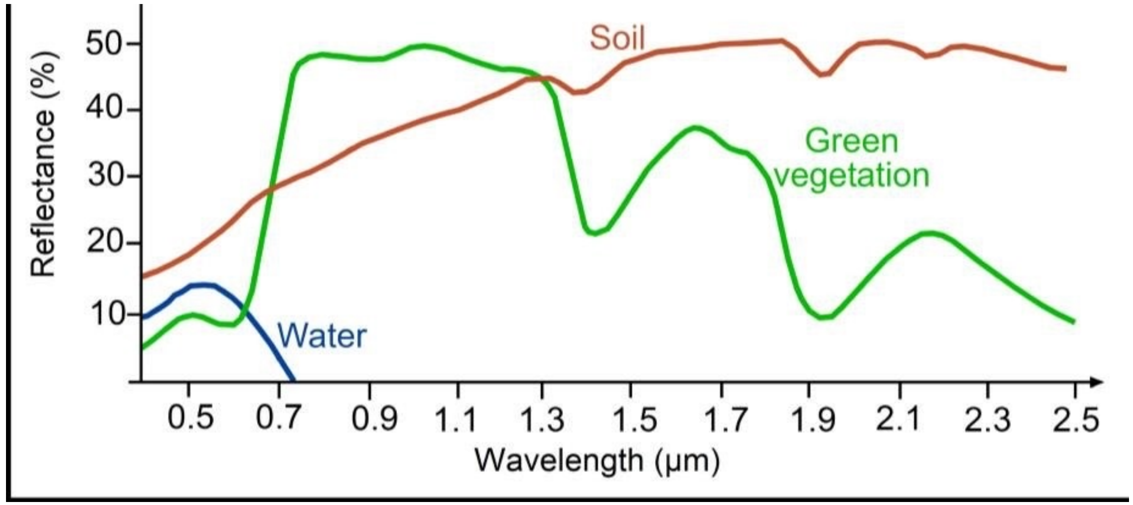


Water has best contrast for bands > 0.7 microns

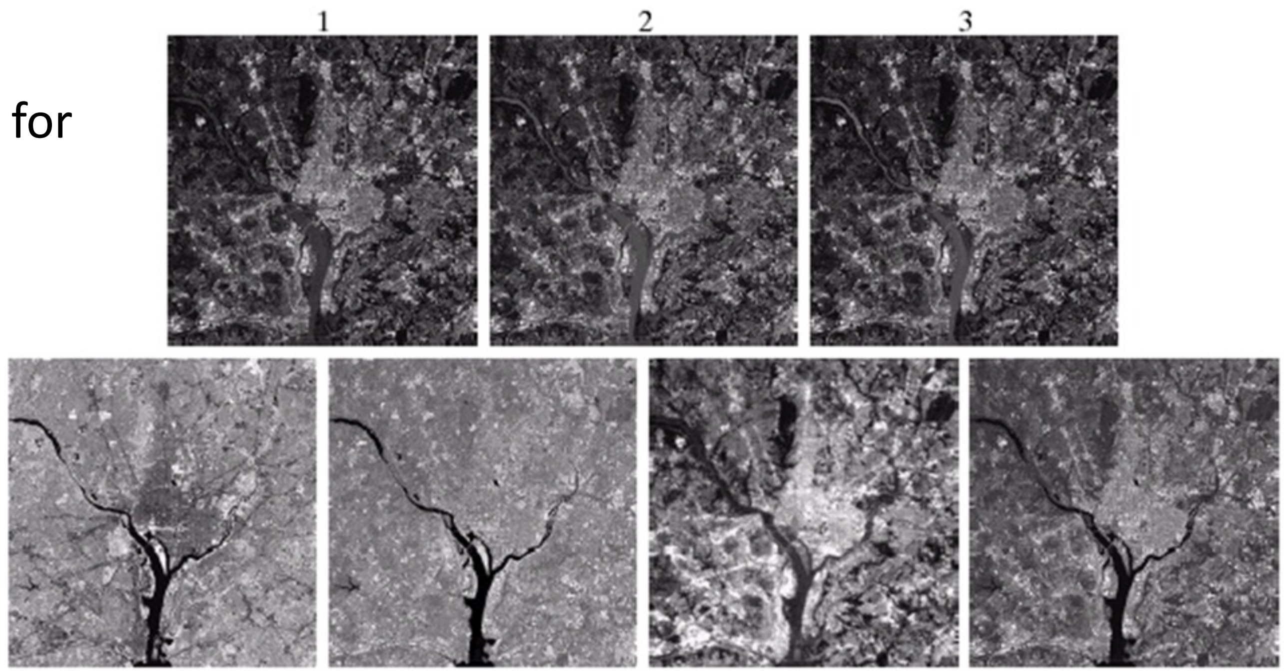
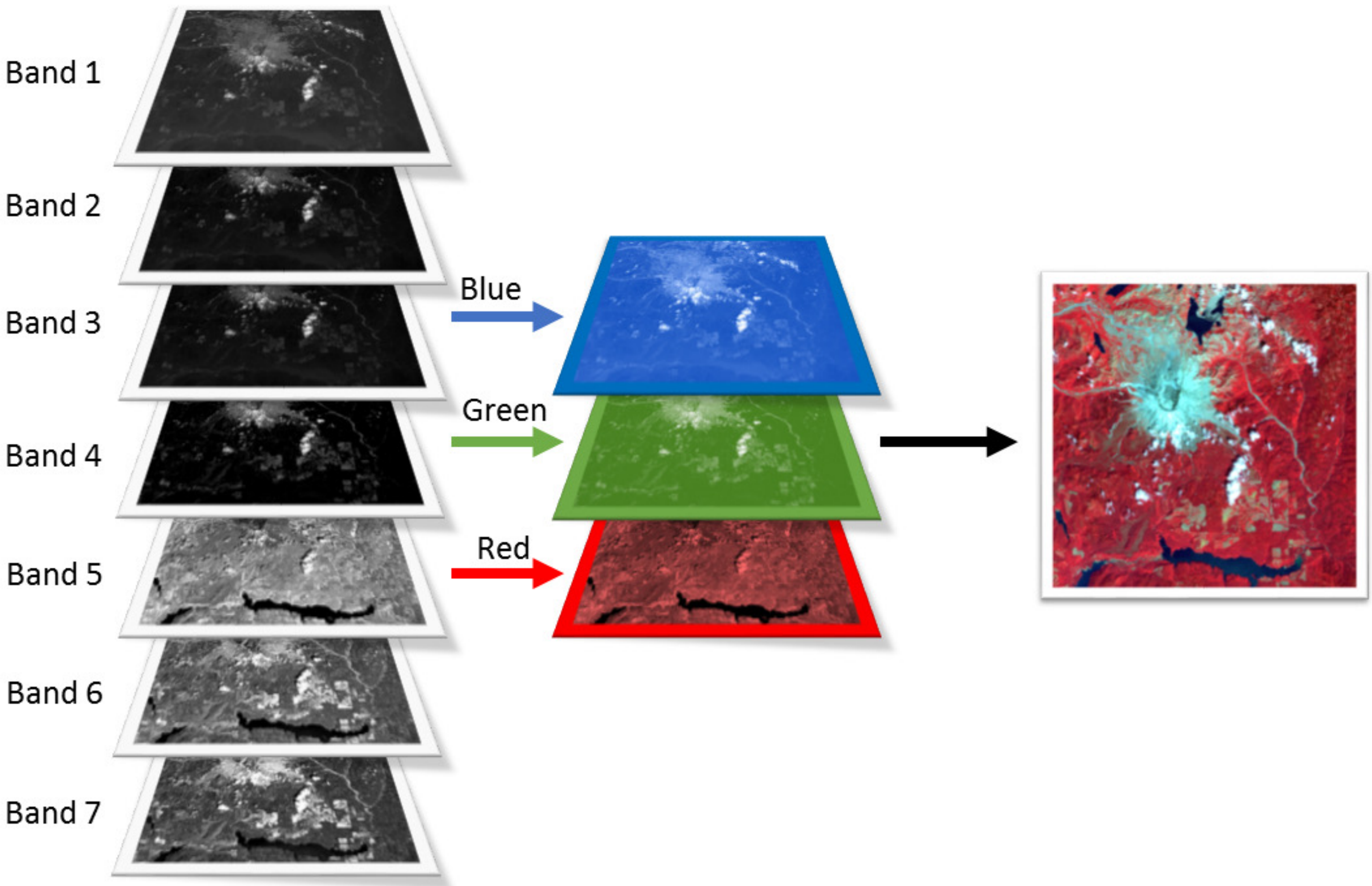
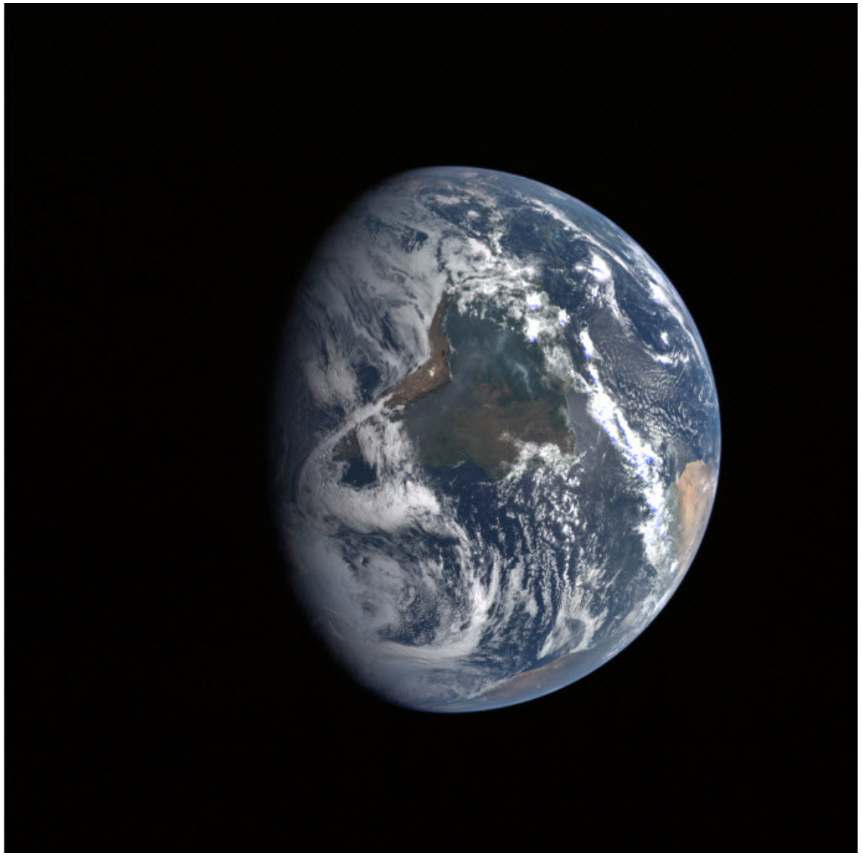


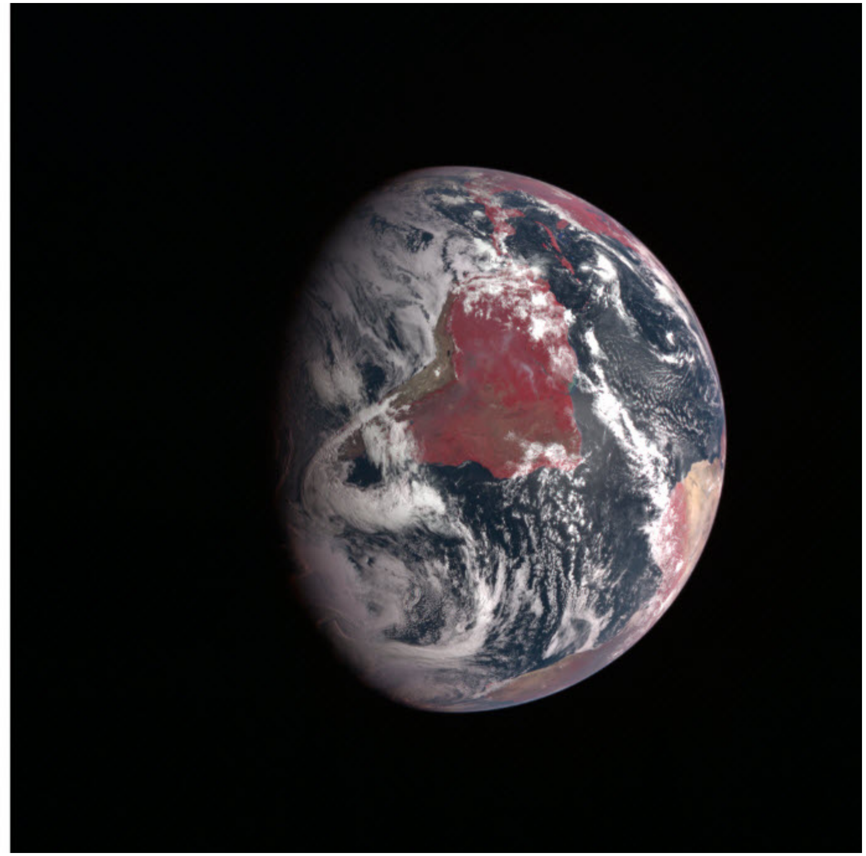
FIGURE 1.10 LANDSAT satellite images of the Washington, D.C. area. The numbers refer to the thematic bands in Table 1.1. (Images courtesy of NASA.)

Mapping Multispectral Images to RGB Images



Two Images of Earth





Band No.	Name	Wavelength (μm)
1	Visible blue	0.45–0.52
2	Visible green	0.52–0.60
3	Visible red	0.63–0.69
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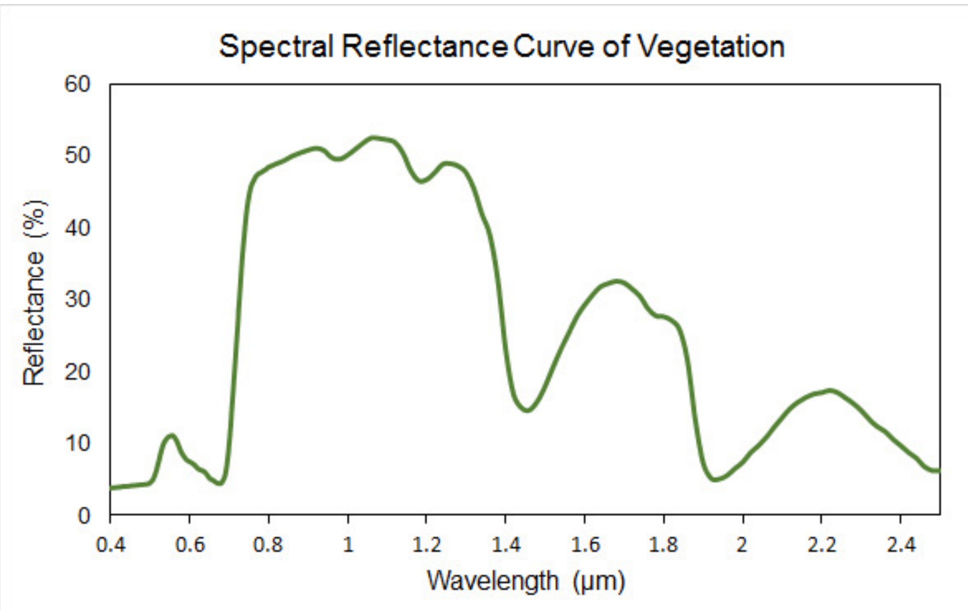

Band No.	Name	Wavelength (μm)
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2	Visible green	0.52–0.60
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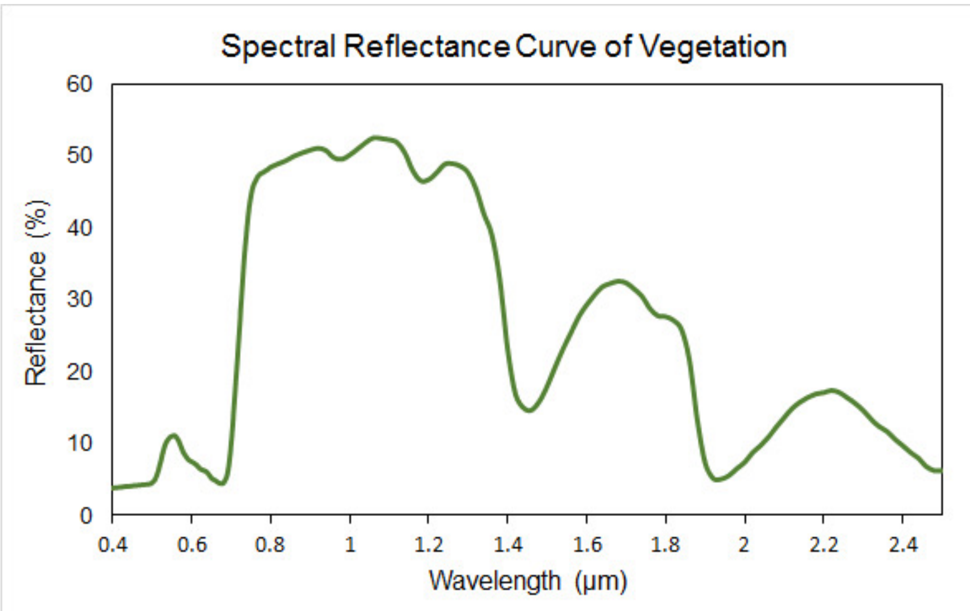
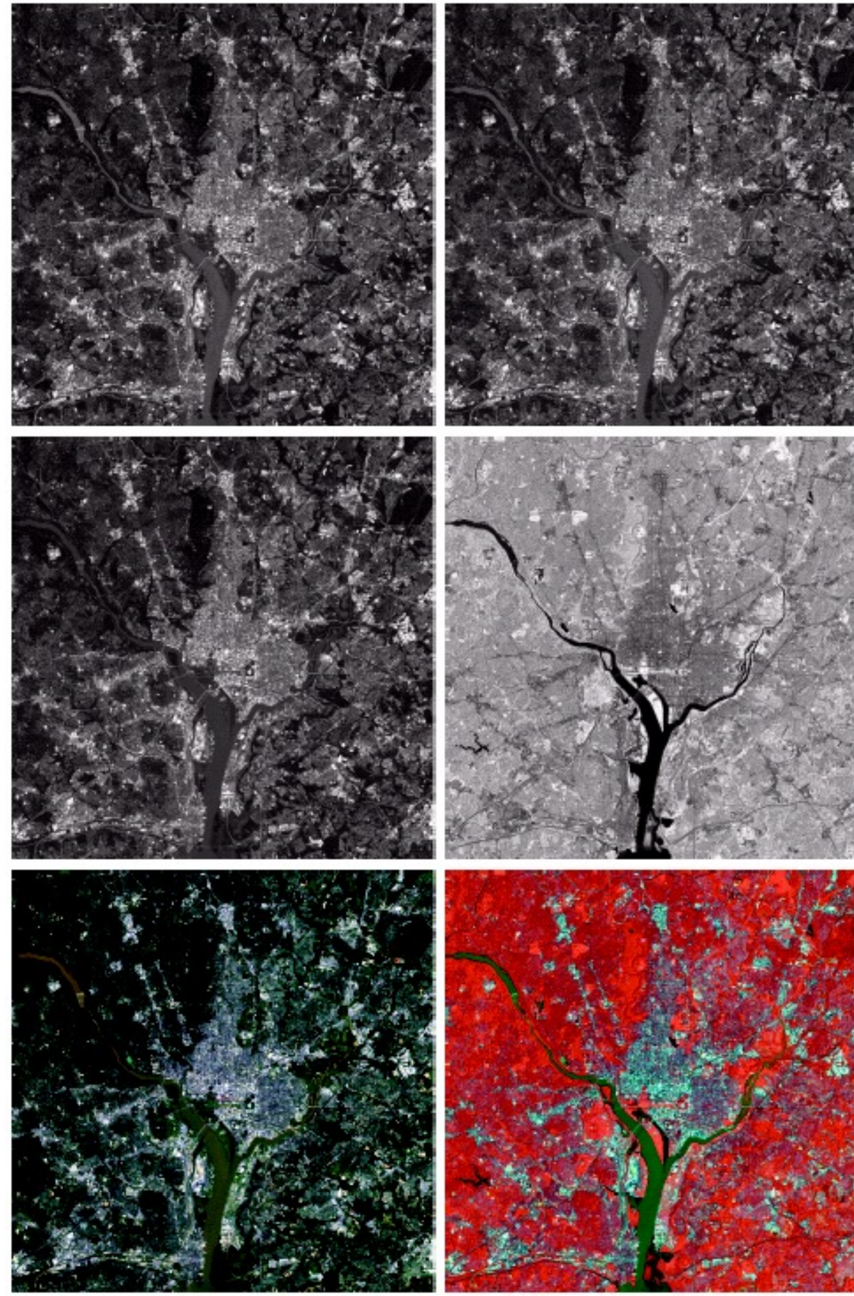


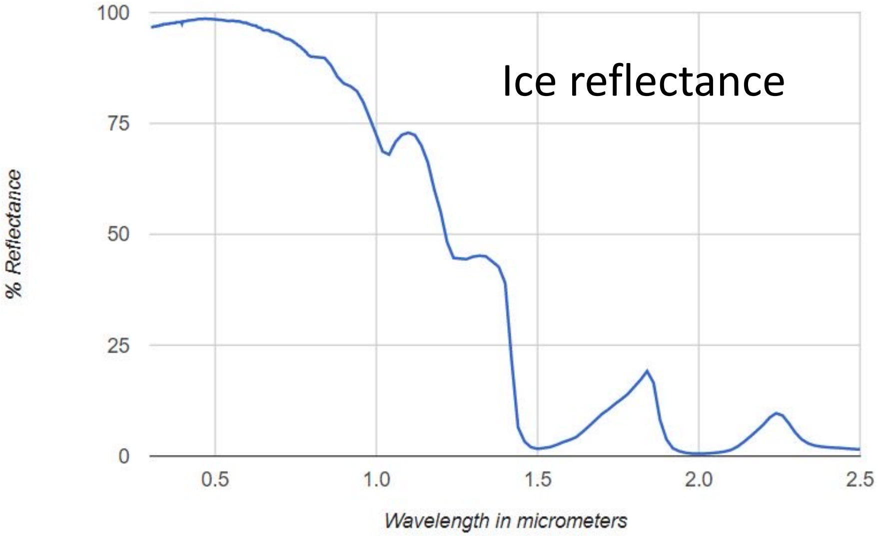


a b
c d
e f

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.)

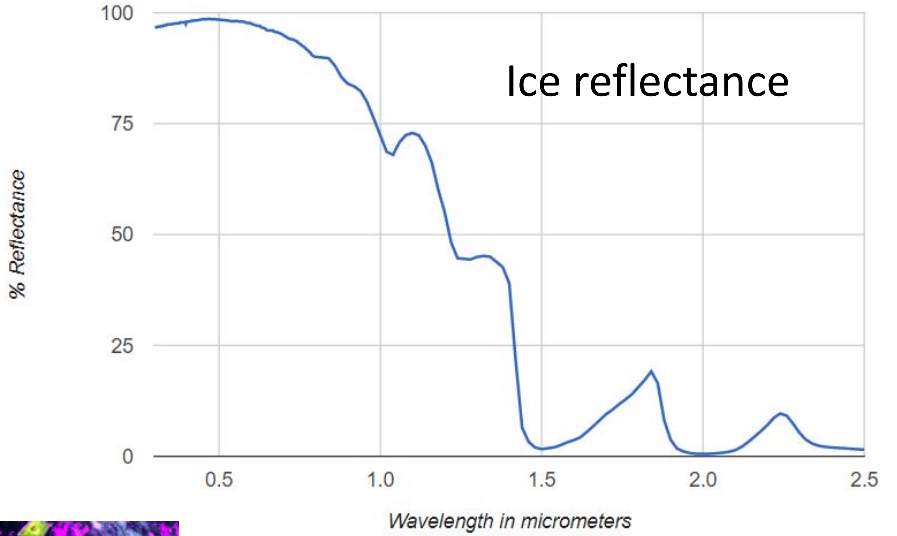
LANDSAT 8

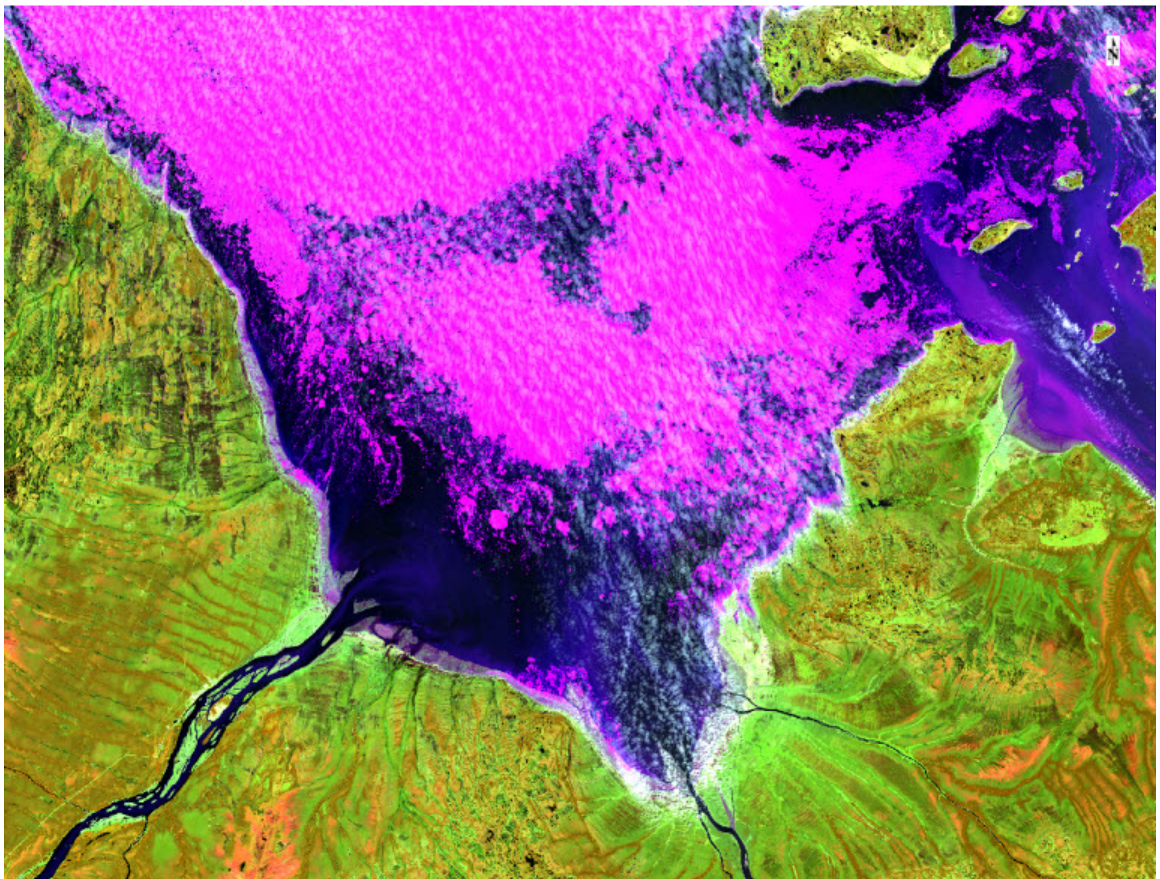
Band 4 – Red	0.64 – 0.67
Band 5 – Near Infrared (NIR)	0.85 – 0.88
Band 6 – SWIR 1	1.57 – 1.65



LANDSAT 8

Band 4 – Red	0.64 – 0.67
Band 5 – Near Infrared (NIR)	0.85 – 0.88
Band 6 – SWIR 1	1.57 – 1.65



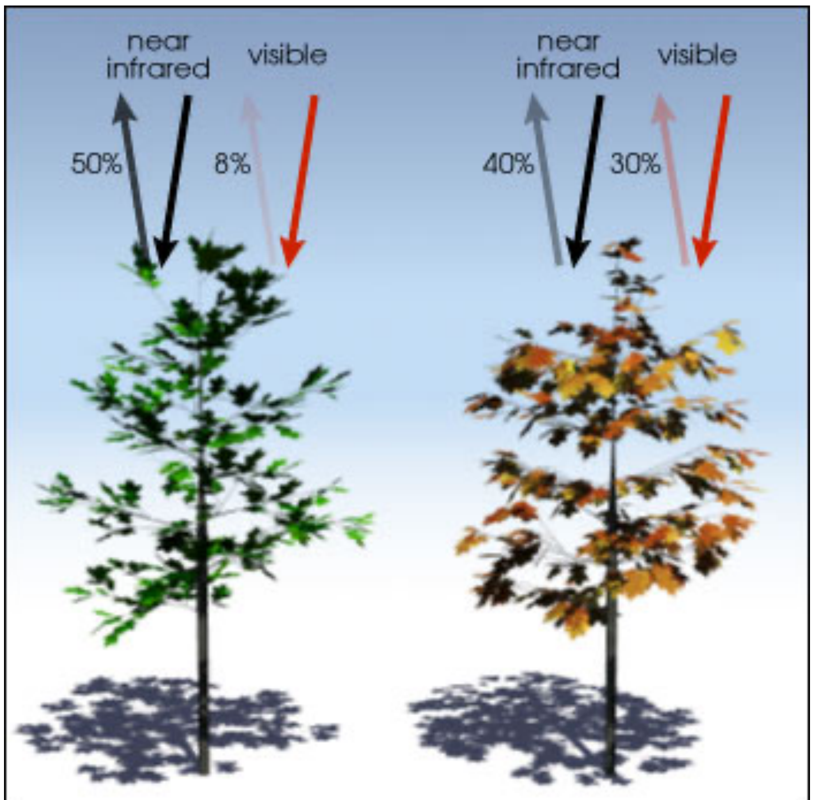


Hudson Bay

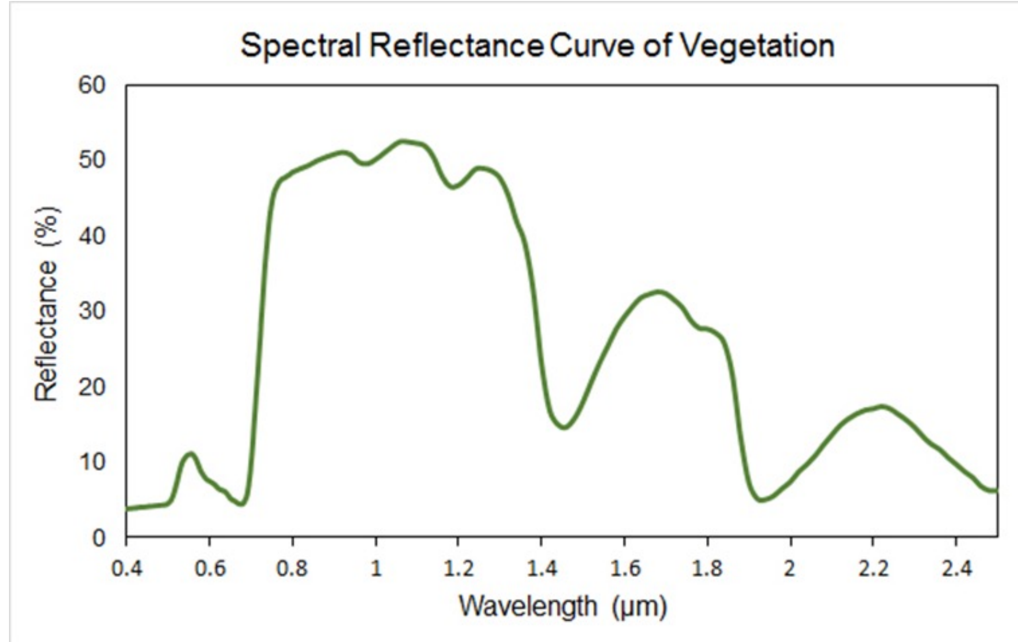
(R,G,B) =
(Band 5, Band 6, Band 4)

NDVI (Normalized Difference Vegetation Index)

$$NDVI(x,y) = \frac{NIR(x,y) - RED(x,y)}{NIR(x,y) + RED(x,y)}$$



$$\frac{(0.50 - 0.08)}{(0.50 + 0.08)} = 0.72 \qquad \frac{(0.4 - 0.30)}{(0.4 + 0.30)} = 0.14$$



Band No.	Name	Wavelength (μm)
1	Visible blue	0.45–0.52
2	Visible green	0.52–0.60
3	Visible red	0.63–0.69
4	Near infrared	0.76–0.90

NDVI for a Region in Victoria, Australia