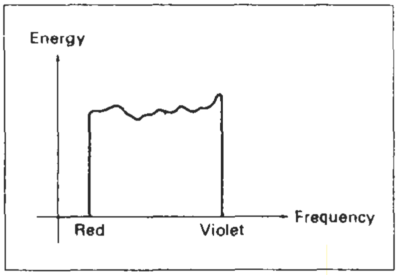

Figure 15-3
Energy distribution of a white-light source.

perceived characteristic is the **purity**, or **saturation**, of the light. Purity describes how washed out or how "pure" the color of the light appears. Pastels and pale colors are described as less pure. These three characteristics, dominant frequency, brightness, and purity, are commonly used to describe the different properties we perceive in a source of light. The term **chromaticity** is used to refer collectively to the two properties describing color characteristics: purity and dominant frequency.

Energy emitted by a white-light source has a distribution over the visible frequencies as shown in Fig. 15-3. Each frequency component within the range from red to violet contributes more or less equally to the total energy, and the color of the source is described as white. When a dominant frequency is present, the energy distribution for the source takes a form such as that in Fig. 15-4. We would now describe the light as having the color corresponding to the dominant frequency. The energy density of the dominant light component is labeled as E_D in this figure, and the contributions from the other frequencies produce white light of energy density E_W. We can calculate the brightness of the source as the area under the curve, which gives the total energy density emitted. Purity depends on the difference between E_D and E_W. The larger the energy E_D of the dominant frequency compared to the white-light component E_W, the more pure the light. We have a purity of 100 percent when $E_W = 0$ and a purity of 0 percent when $E_W = E_D$.

When we view light that has been formed by a combination of two or more sources, we see a resultant light with characteristics determined by the original sources. Two different-color light sources with suitably chosen intensities can be used to produce a range of other colors. If the two color sources combine to pro-

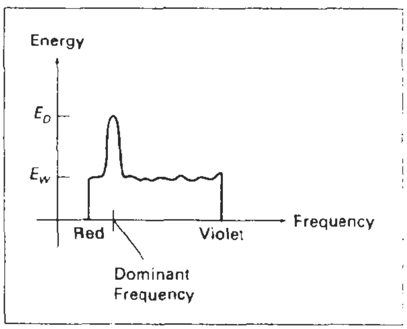

Figure 15-4
Energy distribution of a light source with a dominant frequency near the red end of the frequency range.

color palettes to a user often employ two or more color models. One model provides an intuitive color interface for the user, and others describe the color components for the output devices.

15-4
RGB COLOR MODEL

Based on the *tristimulus theory* of vision, our eyes perceive color through the stimulation of three visual pigments in the cones of the retina. These visual pigments have a peak sensitivity at wavelengths of about 630 nm (red), 530 nm (green), and 450 nm (blue). By comparing intensities in a light source, we perceive the color of the light. This theory of vision is the basis for displaying color output on a video monitor using the three color primaries, red, green, and blue, referred to as the RGB color model.

We can represent this model with the unit cube defined on R, G, and B axes, as shown in Fig. 15-11. The origin represents black, and the vertex with coordinates (1, 1, 1) is white. Vertices of the cube on the axes represent the primary colors, and the remaining vertices represent the complementary color for each of the primary colors.

As with the XYZ color system, the RGB color scheme is an additive model. Intensities of the primary colors are added to produce other colors. Each color point within the bounds of the cube can be represented as the triple (R, G, B), where values for R, G, and B are assigned in the range from 0 to 1. Thus, a color C_λ is expressed in RGB components as

$$C_\lambda = R\mathbf{R} + G\mathbf{G} + B\mathbf{B} \qquad (15\text{-}5)$$

The magenta vertex is obtained by adding red and blue to produce the triple (1, 0, 1), and white at (1, 1, 1) is the sum of the red, green, and blue vertices. Shades of gray are represented along the main diagonal of the cube from the origin (black) to the white vertex. Each point along this diagonal has an equal contribution from each primary color, so that a gray shade halfway between black and

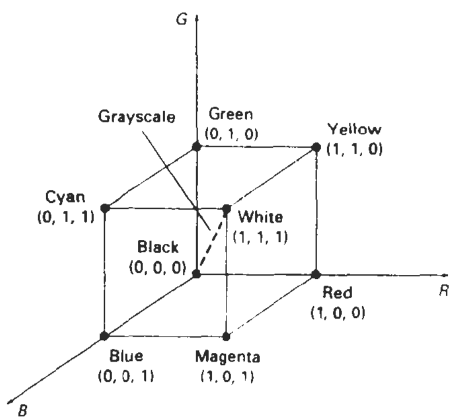

Figure 15-11
The RGB color model, defining colors with an additive process within the unit cube.

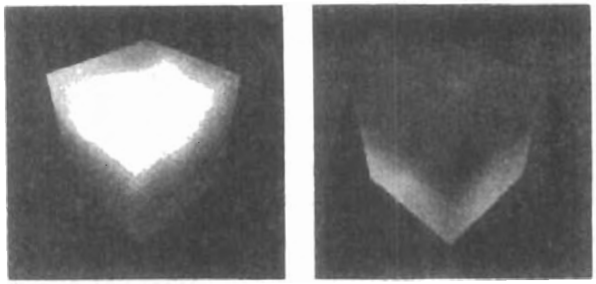
(a) (b)

Figure 15-12
Two views of the RGB color cube: (a) along the grayscale diagonal from white to black and (b) along the grayscale diagonal from black to white.

TABLE 15-1
RGB (*X*, *Y*) CHROMACITY 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)

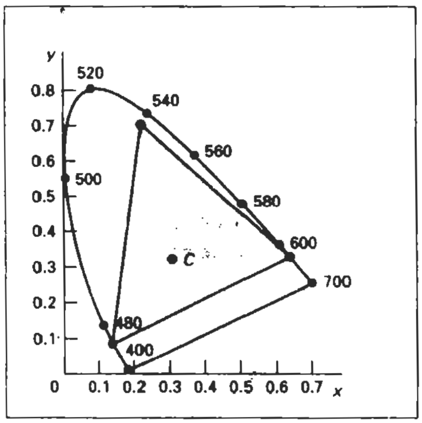

Figure 15-13
RGB color gamut.

white is represented as (0.5, 0.5, 0.5). The color graduations along the front and top planes of the RGB cube are illustrated in Fig. 15-12.

Chromaticity coordinates for an NTSC standard RGB phosphor are listed in Table 15-1. Also listed are the RGB chromaticity coordinates for the CIE RGB color model and the approximate values used for phosphors in color monitors. Figure 15-13 shows the color gamut for the NTSC standard RGB primaries.

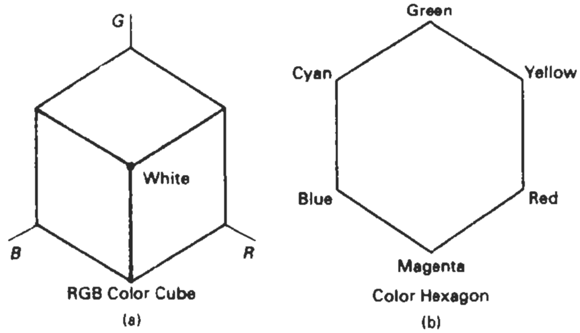

Figure 15-15
When the RGB color cube (a) is viewed along the diagonal from white to black, the color-cube outline is a hexagon (b).

The three-dimensional representation of the HSV model is derived from the RGB cube. If we imagine viewing the cube along the diagonal from the white vertex to the origin (black), we see an outline of the cube that has the hexagon shape shown in Fig. 15-15. The boundary of the hexagon represents the various hues, and it is used as the top of the HSV hexcone (Fig. 15-16). In the hexcone, saturation is measured along a horizontal axis, and value is along a vertical axis through the center of the hexcone.

Hue is represented as an angle about the vertical axis, ranging from 0° at red through 360°. Vertices of the hexagon are separated by 60° intervals. Yellow is at 60°, green at 120°, and cyan opposite red at $H = 180°$. Complementary colors are 180° apart.

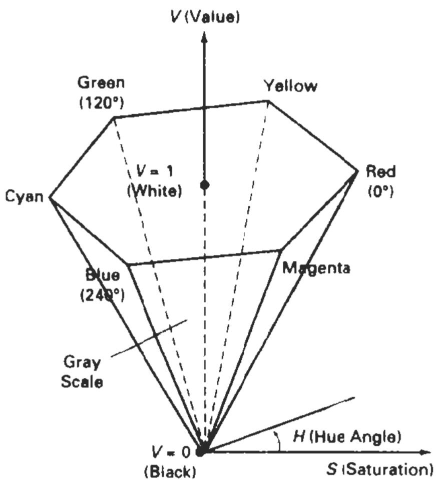

Figure 15-16
The HSV hexcone.

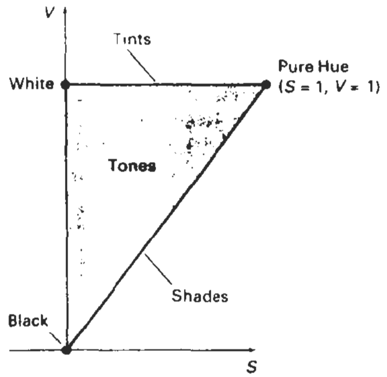

Figure 15-17
Cross section of the HSV hexcone, showing regions for shades, tints, and tones.

Saturation S varies from 0 to 1. It is represented in this model as the ratio of the purity of a selected hue to its maximum purity at $S = 1$. A selected hue is said to be one-quarter pure at the value $S = 0.25$. At $S = 0$, we have the gray scale.

Value V varies from 0 at the apex of the hexcone to 1 at the top. The apex represents black. At the top of the hexcone, colors have their maximum intensity. When $V = 1$ and $S = 1$, we have the "pure" hues. White is the point at $V = 1$ and $S = 0$.

This is a more intuitive model for most users. Starting with a selection for a pure hue, which specifies the hue angle H and sets $V = S = 1$, we describe the color we want in terms of adding either white or black to the pure hue. Adding black decreases the setting for V while S is held constant. To get a dark blue, V could be set to 0.4 with $S = 1$ and $H = 240°$. Similarly, when white is to be added to the hue selected, parameter S is decreased while keeping V constant. A light blue could be designated with $S = 0.3$ while $V = 1$ and $H = 240°$. By adding some black and some white, we decrease both V and S. An interface for this model typically presents the HSV parameter choices in a color palette.

Color concepts associated with the terms shades, tints, and tones are represented in a cross-sectional plane of the HSV hexcone (Fig. 15-17). Adding black to a pure hue decreases V down the side of the hexcone. Thus, various shades are represented with values $S = 1$ and $0 \le V \le 1$. Adding white to a pure tone produces different tints across the top plane of the hexcone, where parameter values are $V = 1$ and $0 \le S \le 1$. Various tones are specified by adding both black and white, producing color points within the triangular cross-sectional area of the hexcone.

The human eye can distinguish about 128 different hues and about 130 different tints (saturation levels). For each of these, a number of shades (value settings) can be detected, depending on the hue selected. About 23 shades are discernible with yellow colors, and about 16 different shades can be seen at the blue end of the spectrum. This means that we can distinguish about $128 \times 130 \times 23 = 82{,}720$ different colors. For most graphics applications, 128 hues, 8 saturation levels, and 15 value settings are sufficient. With this range of parameters in the HSV color model, 16,384 colors would be available to a user, and the system would need 14 bits of color storage per pixel. Color lookup tables could be used to reduce the storage requirements per pixel and to increase the number of available colors.