APPENDIX B

CIE Color Measurement System

To determine a standard observer, a set of red, green, and blue lamps is used by a number of representative subjects to match all the pure colors of the spectrum. The result is called a set of *color-matching functions*. The set of color-matching functions for the Commission Internationale de l'Éclairage (CIE) standard observer is illustrated in Figure B.1. They were obtained with red, green, and blue pure spectral hues at 700, 546, and 436 nanometers, respectively, using a number of trained observers. Notice that there are negative values in these functions. These exist for the reasons discussed in Chapter 4. It is not possible to match directly all spectral lights with these, or any other, primaries.

For a number of reasons, the CIE chose not to use the standard-observer color-matching functions directly as the color standard, although it would have been perfectly legitimate to do so. Instead, they chose a set of abstract primaries called the *XYZ tristimulus values* and transformed the original color-matching functions into this new coordinate system. The process is the transformation from one coordinate system to another, as described in Appendix A. The transformed color-matching functions are illustrated in Figure B.2.

The CIE *XYZ* tristimulus values have the following properties:

1. All tristimulus values are positive for all colors. To achieve this, it was necessary to create primaries that do not correspond to any real lights. The *XYZ* primary axes are purely abstract concepts. However, this model has the advantage that all perceivable colors fall within the CIE gamut. They are, in effect, a set of virtual primaries.

2. The X and Z tristimulus values have zero luminance. Only the Y tristimulus value contains luminance information, and the color-matching function ($\bar{y}$) is the same as the $V(\lambda)$ function, discussed in Chapter 3.

To determine the *XYZ* tristimulus values for a given patch of light, we integrate the energy distribution with the three $\bar{x},\bar{y},\bar{z}$ color-matching functions that define the CIE standard. Note that

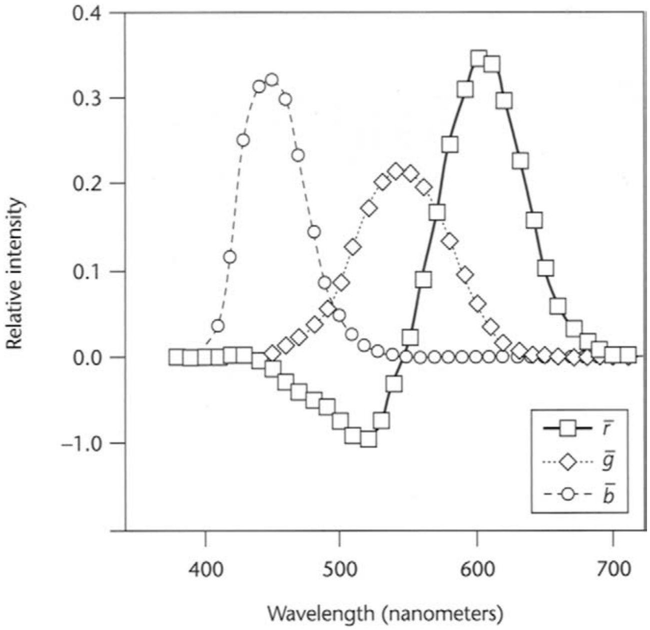

Figure B.1 The color-matching functions that define the CIE 1931 standard observer. To obtain these, each pure spectral wavelength was matched by a mixture of three primary lights.

this is a generalization of the process of obtaining luminance described in Chapter 3—only here, we obtain three values to fully specify a color:

$$
\begin{aligned}
X &= K_m \int_\lambda E(\lambda)\bar{x}_\lambda d\lambda \\
Y &= K_m \int_\lambda E(\lambda)\bar{y}_\lambda d\lambda \\
Z &= K_m \int_\lambda E(\lambda)\bar{z}_\lambda d\lambda
\end{aligned}
\tag{B1.1}
$$

If K_m = 680 lumens/watt and $E(\lambda)$ is measured in watts per unit area solid angle (steradians), then Y gives luminance.

This appendix provides only a very brief introduction to the complex and technical subject of colorimetry. Many important issues have been neglected that must be taken into account in serious color measurement. One issue is whether the light to be measured is an extended source,

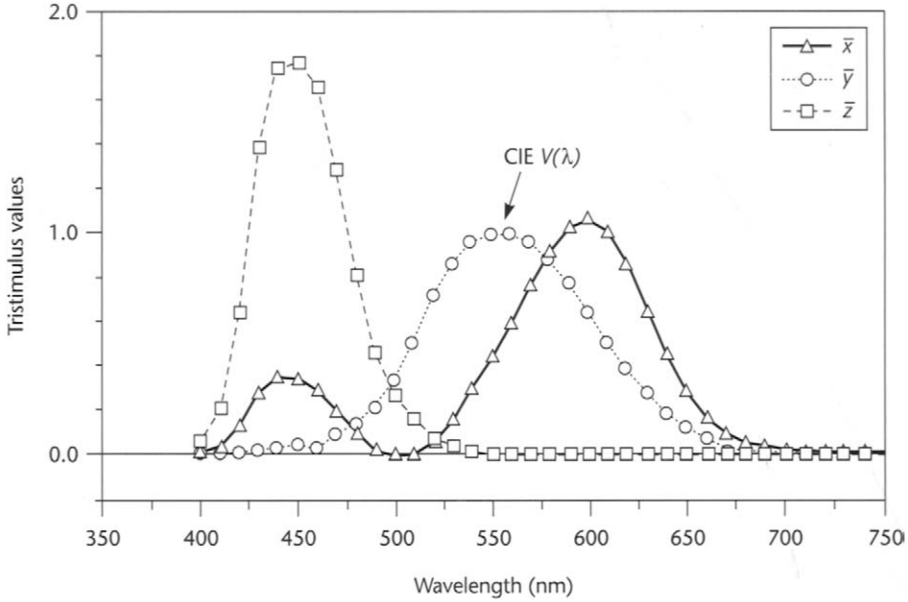

Figure B.2 The CIE tristimulus functions used to define the color of a light in *XYZ* tristimulus coordinates.

such as a monitor, in which case we measure in light emitted per unit area (candelas per square meter), or a lamp, in which case we measure total light output in all directions.

The subject becomes still more complex when we consider the measurement of surface colors; the color of the illuminating source must be taken into account, and we can no longer use a trichromatic system. Fortunately, computer monitors, because they emit light, do allow us to use a trichromatic system. The reader who intends to get involved in serious color measurement should obtain one of the standard textbooks, such as Wyszecki and Stiles (1982) or Judd and Wyszecki (1975).