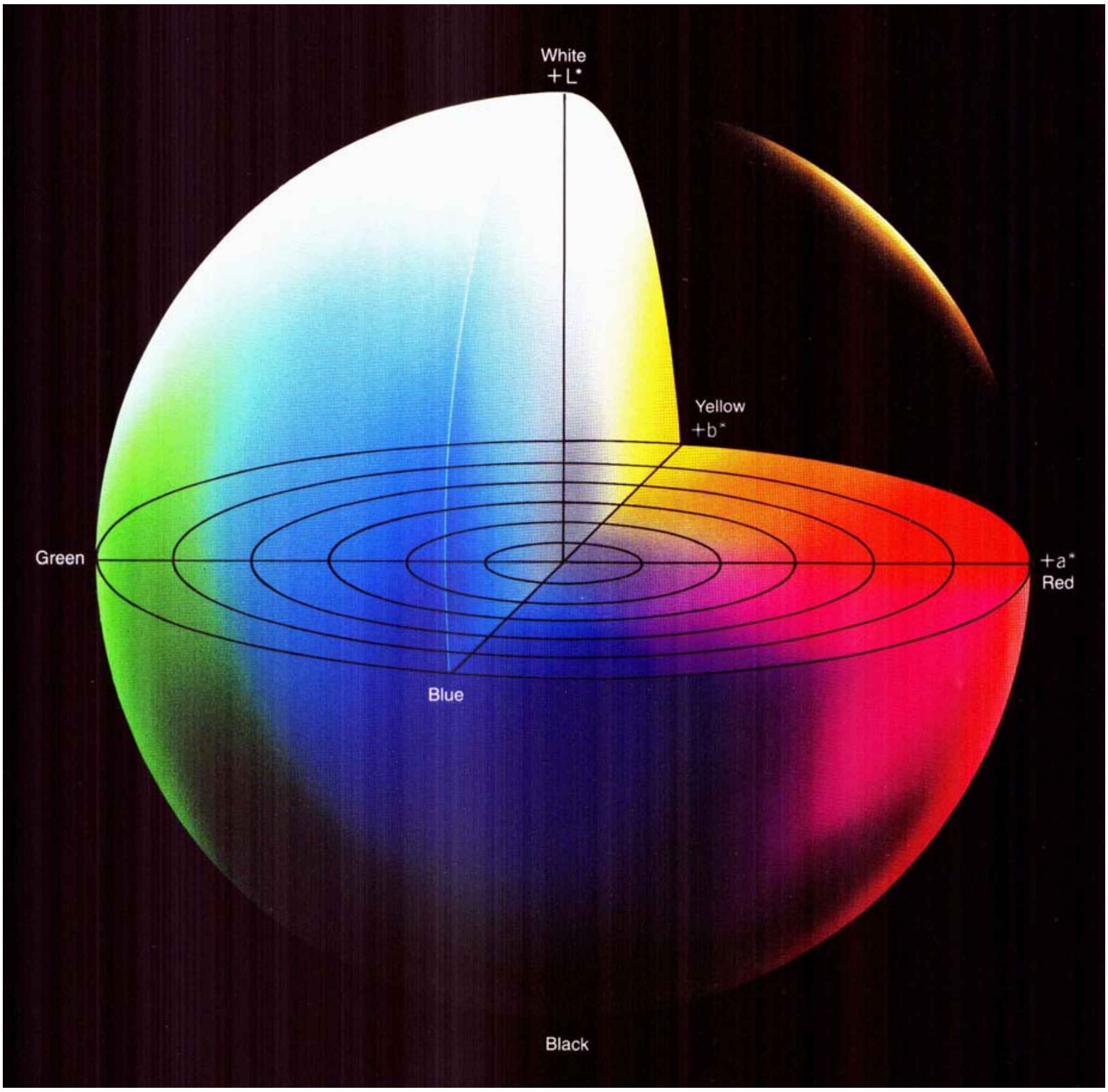
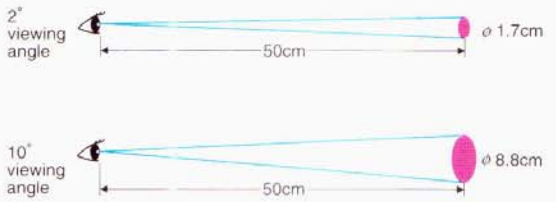

White
+L*
Yellow
+b*
Green
+a*
Red
Blue
Black

2° Standard Observer and 10° Supplementary Standard Observer

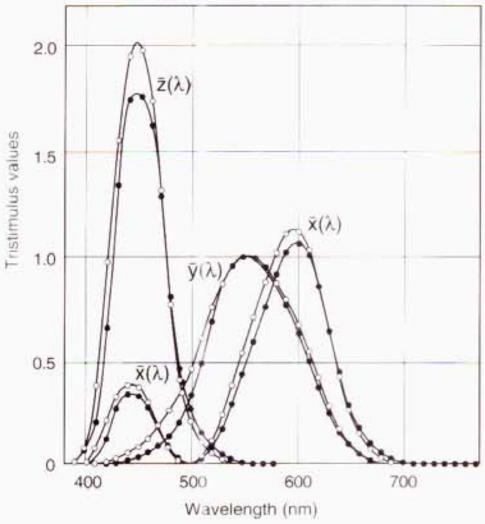
The color sensitivity of the eye changes according to the angle of view (object size). The CIE originally defined the standard observer in 1931 using a 2° field of view, hence the name 2° Standard Observer. In 1964, the CIE defined an additional standard observer, this time based upon a 10° field of view; this is referred to as the 10° Supplementary Standard Observer. To give an idea of what a 2° field of view is like compared to a 10° field of view, at a viewing distance of 50cm a 2° field of view would be a ϕ1.7cm circle while a 10° field of view at the same distance would be a ϕ8.8cm circle. Most of the information in this booklet is based on the 2° Standard Observer. The 2° Standard Observer should be used for viewing angles of 1° to 4°; the 10° Supplementary Standard Observer should be used for viewing angles of more than 4°.



Color-Matching Functions

The color-matching functions are the tristimulus values of the equal-energy spectrum as a function of wavelength. These functions are intended to correspond to the sensitivity of the human eye. Separate sets of three color-matching functions are specified for the 2° Standard Observer and 10° Supplementary Standard Observer.

Color-matching functions



● 2° Standard Observer
○ 10° Supplementary Standard Observer

XYZ Tristimulus Values (CIE 1931)

Tristimulus values determined based on the color-matching functions $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, and $\bar{z}(\lambda)$ defined in 1931 by CIE; also referred to as 2° XYZ tristimulus values. They are suitable for a viewing angle of 4° or less and are defined for reflecting objects by the following formulas:

$$X = K\int_{380}^{780} S(\lambda)\,\bar{x}(\lambda)R(\lambda)d\lambda$$

$$Y = K\int_{380}^{780} S(\lambda)\,\bar{y}(\lambda)R(\lambda)d\lambda$$

$$Z = K\int_{380}^{780} S(\lambda)\,\bar{z}(\lambda)R(\lambda)d\lambda$$

$$K = \frac{100}{\int_{380}^{780} S(\lambda)\,\bar{y}(\lambda)\,d\lambda}$$

where

$S(\lambda)$: Relative spectral power distribution of the illuminant

$\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$: Color-matching functions for CIE 2° Standard Observer (1931)

$R(\lambda)$: Spectral reflectance of specimen

X_{10} Y_{10} Z_{10} Tristimulus Values (CIE 1964)

Tristimulus values determined based on the color-matching functions $\bar{x}_{10}(\lambda)$, $\bar{y}_{10}(\lambda)$,and $\bar{z}_{10}(\lambda)$ defined in 1964 by CIE; also referred to as 10° XYZ tristimulus values. They are suitable for a viewing angle of more than 4° and are defined for reflecting objects by the following formulas:

$$X_{10} = K\int_{380}^{780} S(\lambda)\,\bar{x}_{10}(\lambda)R(\lambda)d\lambda$$

$$Y_{10} = K\int_{380}^{780} S(\lambda)\,\bar{y}_{10}(\lambda)R(\lambda)d\lambda$$

$$Z_{10} = K\int_{380}^{780} S(\lambda)\,\bar{z}_{10}(\lambda)R(\lambda)d\lambda$$

$$K = \frac{100}{\int_{380}^{780} S(\lambda)\,\bar{y}_{10}(\lambda)\,d\lambda}$$

where

$S(\lambda)$: Relative spectral power distribution of the illuminant

$\bar{x}_{10}(\lambda)$, $\bar{y}_{10}(\lambda)$, $\bar{z}_{10}(\lambda)$: Color-matching functions for CIE 10° Supplementary Standard Observer (1964)

$R(\lambda)$: Spectral reflectance of specimen

xyz Chromaticity Coordinates

The xyz chromaticity coordinates are calculated from the XYZ tristimulus values according to the following formulas:

$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z}$$

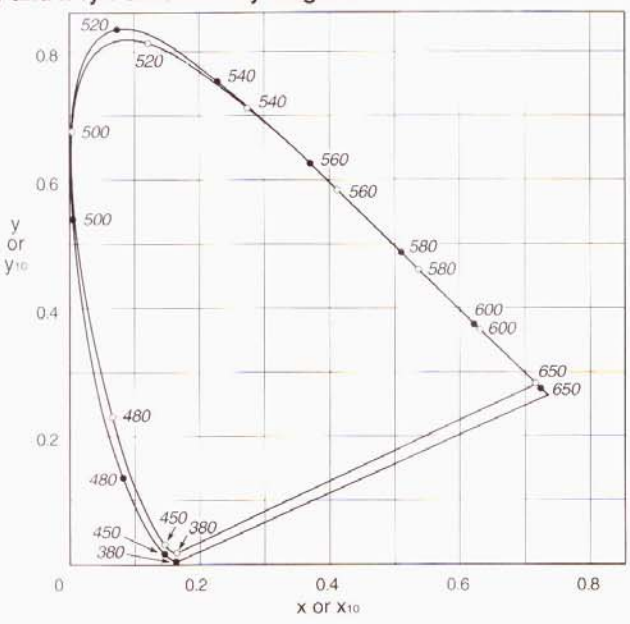
$$z = \frac{Z}{X+Y+Z} = 1 - x - y$$

If the above formulas are used with the X_{10} Y_{10} Z_{10} tristimulus values, the chromaticity coordinates would be x_{10} y_{10} z_{10}.

xy and x_{10} y_{10} Chromaticity Diagram

Two-dimension diagram on which the xy or $x_{10}y_{10}$ chromaticity coordinates can be plotted.

xy and $x_{10}y_{10}$ chromaticity diagram



● For 2° Standard Observer (CIE 1931)
○ For 10° Supplementary Standard Observer (CIE 1964)

L*a*b* Color Space

The L*a*b* color space (also referred to as the CIELAB space) is one of the uniform color spaces defined by the CIE in 1976. The values of L*, a*, and b* are calculated according to the formulas below:

Lightness variable L*:

$$L^* = 116\left(\frac{Y}{Y_n}\right)^{1/3} - 16$$

Chromaticity coordinates a* and b*:

$$a^* = 500\left[\left(\frac{X}{X_n}\right)^{1/3} - \left(\frac{Y}{Y_n}\right)^{1/3}\right]$$

$$b^* = 200\left[\left(\frac{Y}{Y_n}\right)^{1/3} - \left(\frac{Z}{Z_n}\right)^{1/3}\right]$$

where

X, Y, Z: Tristimulus values XYZ (for 2° Standard Observer) or $X_{10}Y_{10}Z_{10}$ (for 10° Supplementary Standard Observer) of the specimen

X_n, Y_n, Z_n: Tristimulus values XYZ (for 2° Standard Observer) or $X_{10}Y_{10}Z_{10}$ (for 10° Supplementary Standard Observer) of a perfect reflecting diffuser.

If X/Xn, Y/Yn, or Z/Zn is less than 0.008856, the above equations are changed as described below:

$\left(\frac{X}{X_n}\right)^{1/3}$ is replaced by $7.787\left(\frac{X}{X_n}\right) + \frac{16}{116}$

$\left(\frac{Y}{Y_n}\right)^{1/3}$ is replaced by $7.787\left(\frac{Y}{Y_n}\right) + \frac{16}{116}$

$\left(\frac{Z}{Z_n}\right)^{1/3}$ is replaced by $7.787\left(\frac{Z}{Z_n}\right) + \frac{16}{116}$

Color difference ΔE^*_{ab} in the L*a*b* color space, which indicates the degree of color difference but not the direction, is defined by the following equation:

$$\Delta E^*_{ab} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

where

ΔL^*, Δa^*, Δb^*: Difference in L*, a*, and b* values between the specimen color and the target color.