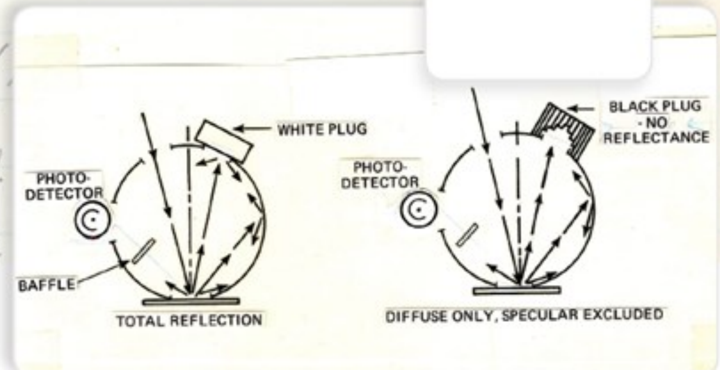
Applications Note

AN 1120



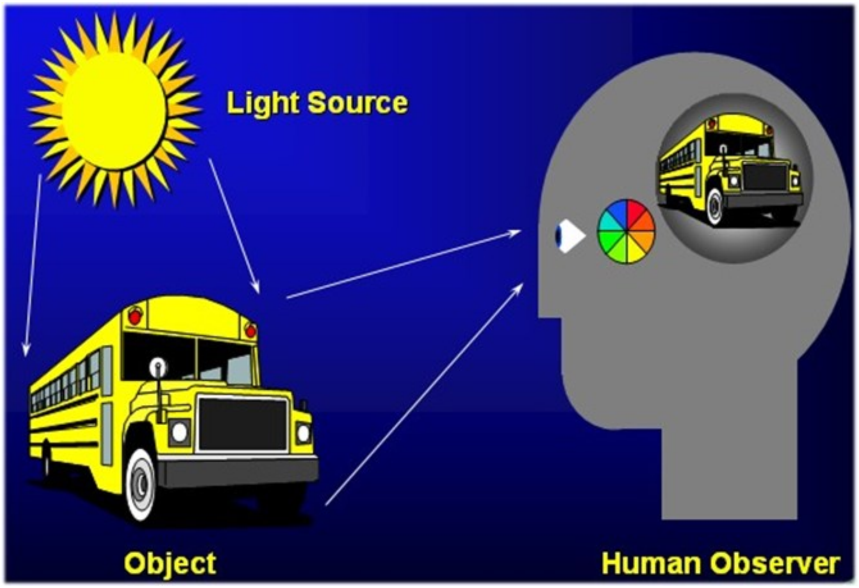
CIE Standard Observer

The 10° Standard Observer is currently believed to best represent the average spectral response of human observers . . .

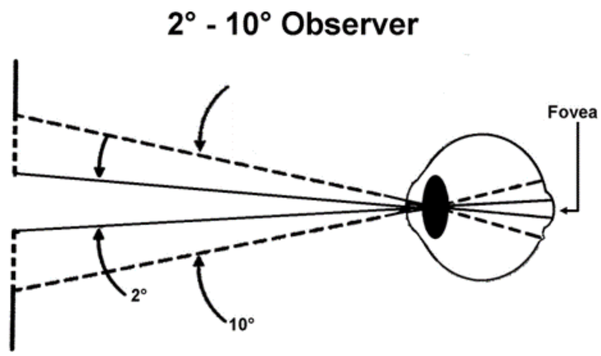
Abstract

Since different humans perceive color and appearance in different ways, subjectively, attempts have been made to “standardize” the human observer as a numerical representation of what the “average person” sees. This standard observer could then be used in lieu of a human observer when assessments are made instrumentally.

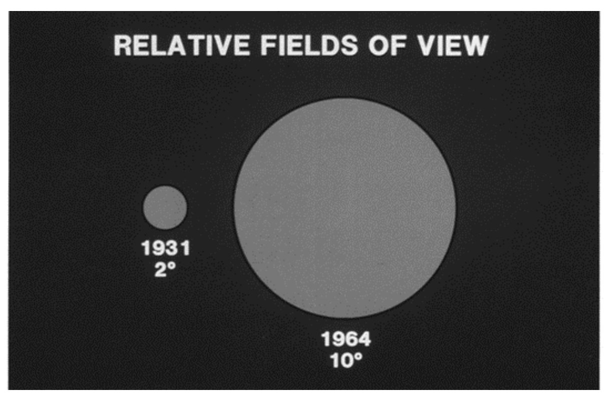
In the visual observing situation, the observer is the human eye that receives the light reflected from or transmitted through an object, and the brain which perceives the vision.



Visual Observing Situation

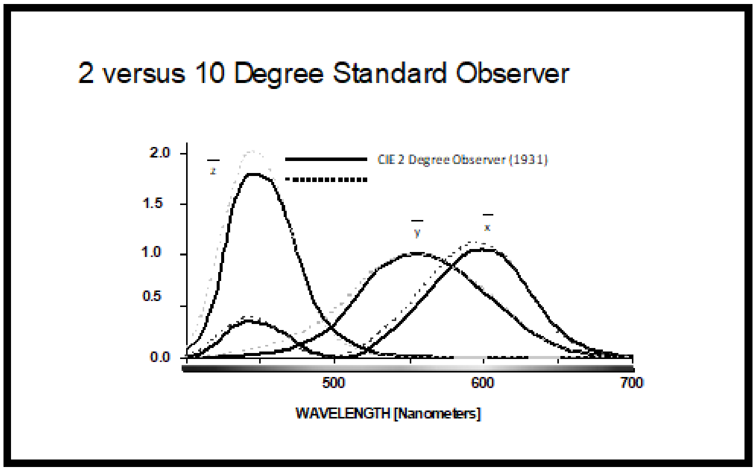


Wright and Guild performed experiments using human volunteers to assess their color vision and develop an average, or standard, observer. In 1931 they published the 2° CIE Standard Observer function based on their research. The function is called 2° because their experiments involved having the subjects judge colors while looking through a hole that allowed them a 2° field of view. In 1931, it was believed that all the color-sensing cones of the eye were located within a 2° arc of the fovea. Thus the 2° field of view was chosen and used in establishing the standard observer.



By the 1960s, it was realized that cones were present in a larger area of the eye than previously believed, and so in 1964, the 10° Standard Observer was developed. The 10° Standard Observer is currently believed to best represent the average spectral response of human observers, although the 2° Standard Observer still has its place for measurement of objects that will be viewed at a distance, such as road signs. The relative sizes of the two fields of view are shown in the diagrams.

The standard observers, in the form of mathematical functions of the human response to each wavelength of light, are used in color calculations. The observers can be graphed as shown on the next page.



The CIE Tristimulus XYZ color scale, for instance, is calculated as follows:

$$X = \int (R \text{ or } T) * \text{illuminant factor} * x \text{ factor of standard observer}$$

$$Y = \int (R \text{ or } T) * \text{illuminant factor} * y \text{ factor of standard observer}$$

$$Z = \int (R \text{ or } T) * \text{illuminant factor} * z \text{ factor of standard observer}$$

Where, R = % reflectance
T = % transmittance
Sums are across the spectral range for which the instrument reads.

Note that X, Y, and Z include factors for the mathematical standard observer in their formulas. All other tristimulus color scales (such as Hunter L, a, b and CIEL*a*b*) may then be calculated from XYZ.

Color Scales

The formulas for the **Hunter L, a, b** and **$R_d$ab** color scales (shown below) reference X_n, Y_n, and Z_n tristimulus values for the illuminant used, as well as K_a and K_b chromaticity coefficients for the illuminant used. These factors depend on the illuminant (and observer) being used for the display of the measurements in your software. Tables containing these factors for all the possible illuminant/observer combinations are given later in this *Applications Note* for your reference in case you wish to perform any manual calculations of the Hunter L, a, b or $R_d$ab color scales.

Hunter L, a, b:

$$L = 100\sqrt{\frac{Y}{Y_n}}$$

$$a = K_a \frac{X/X_n - Y/Y_n}{\sqrt{Y/Y_n}}$$

$$b = K_b \frac{Y/Y_n - Z/Z_n}{\sqrt{Y/Y_n}}$$

where:

X, Y, and Z are the CIE tristimulus values obtained for the sample.

Rdab:

$$R_d = Y$$

$$a_{Rd} = K_a f(Y)\left(\frac{X}{X_n} - \frac{Y}{Y_n}\right)$$

$$b_{Rd} = K_b f(Y)\left(\frac{Y}{Y_n} - \frac{Z}{Z_n}\right)$$

where

$$f(Y) = 0.51\,\frac{21 + 0.2Y}{1 + 0.2Y}$$

X, Y, and Z are the CIE tristimulus values obtained for the sample.

X_n, Y_n, and Z_n are the tristimulus values of the standard illuminant with Y_n always equal to 100.00 (normalized).

K_a and K_b are the chromaticity coefficients for the illuminant used.

The Illuminant Factors

The factors used in EasyMatch QC for the various illuminant/observer combinations are given in the tables below. Beneath the tables are brief explanations of how these factors are calculated. Note that the factors vary according to the type of illuminant (ASTM E308) and, for the the type of instrument used.

ASTM E308 Illuminant Factors for All Instruments					
Illuminant/Observer Combination	X_n	Y_n	Z_n	K_a	K_b
A(ASTM)/2°	109.850	100.000	35.585	185.2379	38.42191
A(ASTM)/10°	111.144	100.000	35.200	186.3257	38.21350
C(ASTM)/2°	98.074	100.000	118.232	175.0277	70.03466
C(ASTM)/10°	97.285	100.000	116.145	174.3222	69.41379
D50(ASTM)/2°	96.422	100.000	82.521	173.5473	58.50968
D50(ASTM)/10°	96.720	100.000	81.427	173.8153	58.12055
D55(ASTM)/2°	95.682	100.000	92.149	172.8800	61.82880
D55(ASTM)/10°	95.799	100.000	90.926	172.9857	61.41714
D65(ASTM)/2°	95.047	100.000	108.883	172.3054	67.20871
D65(ASTM)/10°	94.811	100.000	107.304	172.0914	66.71961
D75(ASTM)/2°	94.972	100.000	122.638	172.2374	71.32767
D75(ASTM)/10°	94.416	100.000	120.641	171.7325	70.74455
F02(ASTM)/2°	99.186	100.000	67.393	176.0171	52.87531
F02(ASTM)/10°	103.279	100.000	69.027	179.6122	53.51247
F07(ASTM)/2°	95.041	100.000	108.747	172.3000	67.16672
F07(ASTM)/10°	95.792	100.000	107.686	172.9794	66.83826
F11(ASTM)/2°	100.962	100.000	64.350	177.586	51.66778
F11(ASTM)/10°	103.863	100.000	65.607	180.1193	52.16997

The ASTM E308 illuminant factors are either obtained directly or are calculated from the values given in Table 5 of ASTM Method E308. The 10-nm version of this table is the one of interest, and the line of interest is the very bottom one containing the White Point data. For each illuminant/observer combination:

X_n = White point in the W_x column = WP_x

Z_n = White point in the W_z column = WP_z

Y_n always $\sqrt{\frac{WP_x}{98.043}} = 100$

$Ka = \sqrt{\frac{WP_z}{118.115}} = 175$

Kb = 70

For EasyMatch QC users, these illuminant and observer files are contained in the "Ezmatch" folder. If you open these files using Notepad or another text viewer, you will see that the ASTM tables (including the white point values) are listed there. The files in this folder are named as follows: ILNob10a.dat, where

ILN = illuminant name

ob = standard observer year (i.e., "31" is 2° and "64" is 10°)

10 = 10-nm data table used (true for all illuminant/observer combinations)

a = E308 Table 5 used [as opposed to Table 6] (true for all illuminant/observer combinations)

For example, the file named "D503110a.dat" contains the data for the D50 illuminant and 2° (1931) observer using ASTM E308's 10-nm version of Table 5. The equations listed above for the calculation of K_a and K_b values apply to data obtained from these files just as they do the data found in ASTM E308 Table 5.

References

ASTM Method E308, "Standard Practice for Computing the Colors of Objects by Using the CIE System," American Society of Testing and Materials, 2001.

About HunterLab

HunterLab is the technology leader in color measurement solutions, providing instruments, software, knowledge and service to a wide variety of industries.
With over 5 decades of experience in more than 65 countries, HunterLab applies our leading edge technology to your products helping you measure and communicate color simply and effectively.

The world's true measure of color
HunterLab