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CIE standard colorimetric observers

Observateurs de référence colorimétriques CIE

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ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

ISO 10527 was prepared as Standard CIE S 014-1/E by the International Commission on Illumination, which has been recognized by the ISO Council as an international standardizing body. It was adopted by ISO under a special procedure which requires approval by at least 75 % of the member bodes casting a vote, and is published as a joint ISO/CIE edition.

The International Commission on Illumination (abbreviated as CIE from its French title) is an organization devoted to international cooperation and exchange of information among its member countries on all matters relating to the science and art of lighting.

ISO 10527 was prepared by CIE Division 2 *Physical measurement of light and radiation.*

ISO 10527 cancels and replaces ISO/CIE 10527:1991.

In particular, the values in the tables of the colour matching functions are chromaticity coordinates of the CIE 1931 and 1964 standard colorimetric observers are identical with the previous standard, but it has now been clarified that they apply for standard air.

CIE S 014-1/E:2006

COMMISSION INTERNATIONALE DE L'ÉCLAIRAGE
INTERNATIONAL COMMISSION ON ILLUMINATION
INTERNATIONALE BELEUCHTUNGSKOMMISSION

Standard

Colorimetry -
Part 1: CIE Standard Colorimetric Observers

Colorimétrie - Partie 1: Observateurs de référence colorimétriques CIE

Farbmessung - Teil 1: CIE farbmetrische Normalbeobachter

CIE Central Bureau, Vienna
Kegelgasse 27, A-1030 Vienna, Austria

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CIE Central Bureau
Kegelgasse 27
A-1030 Vienna
Austria
Tel.: +43 1 714 3187 0
Fax: +43 1 714 3187 18
e-mail: ciecb@ping.at
Web: www.cie.co.at/

FOREWORD

Standards produced by the Commission Internationale de l'Eclairage (CIE) are a concise documentation of data defining aspects of light and lighting, for which international harmony requires such unique definition. CIE Standards are therefore a primary source of internationally accepted and agreed data, which can be taken, essentially unaltered, into universal standard systems.

This CIE Standard replaces ISO/CIE 10527:1991 and was approved by the CIE Board of Administration and the National Committees of the CIE. This CIE Standard has been prepared by CIE Division 2 "Physical measurement of light and radiation".

This standard contains only minor changes from the previous standard, in particular the values in the tables of the colour matching functions and chromaticity coordinates of the CIE 1931 and 1964 standard colorimetric observers are identical with the previous standard, but it has now been clarified that they apply for standard air.

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COLORIMETRY - PART 1: CIE STANDARD COLORIMETRIC OBSERVERS

INTRODUCTION

Colours with different spectral compositions can look alike. An important function of colorimetry is to determine whether a pair of such metameric colours will look alike. The use of visual colorimeters for this purpose is handicapped by variations in the colour matches made amongst observers classified as having normal colour vision. Visual colorimetry also tends to be time-consuming. For these reasons, it has long been the practice in colorimetry to make use of sets of colour-matching functions to calculate tristimulus values for colours: equality of tristimulus values for a pair of colours indicates that the colour appearances of the two colours match, when they are viewed in the same conditions by an observer for whom the colour-matching functions apply. The use of standard sets of colour-matching functions makes the comparison of tristimulus values obtained at different times and locations possible.

1. SCOPE

This International Standard specifies colour-matching functions for use in colorimetry. Two sets of colour-matching functions are specified.

a) Colour-matching functions for the CIE 1931 standard colorimetric observer

This set of colour-matching functions is representative of the colour-matching properties of observers with normal colour vision for visual field sizes of angular subtense from about 1° to about 4°, for vision at photopic levels of adaptation.

b) Colour-matching functions for the CIE 1964 standard colorimetric observer

This set of colour-matching functions is representative of the colour-matching properties of observers with normal colour vision for visual field sizes of angular subtense greater than about 4°, for vision at sufficiently high photopic levels and with spectral power distributions such that no participation of the rod receptors of the retina is to be expected.

2. NORMATIVE REFERENCES

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

CIE 15:2004. *Colorimetry, 3rd edition*.

CIE 17.4-1987. *International lighting vocabulary* (ILV) - Joint publication IEC/CIE.

3. DEFINITIONS

For the purposes of this International Standard, the following definitions apply. These definitions are taken from CIE 17.4-1987, where other relevant terms will also be found.

3.1 colour stimulus function, $\varphi_\lambda(\lambda)$ (see ILV 845-03-03)

description of a colour stimulus by the spectral concentration of a radiometric quantity (such as radiance or radiant power) as a function of wavelength

3.2 relative colour stimulus function, $\varphi(\lambda)$ (see ILV 845-03-04)

relative spectral power distribution of the colour stimulus function

3.3 metameric colour stimuli; metamers (see ILV 845-03-05)

spectrally different colour stimuli that have the same tristimulus values

3.4 monochromatic stimulus: spectral stimulus (see ILV 845-03-08)

stimulus consisting of a monochromatic radiation

3.5 equi-energy spectrum (see ILV 845-03-14)

spectrum of a radiation whose spectral concentration of a radiometric quantity as a function of wavelength is constant throughout the visible region

3.6 additive mixture of colour stimuli (see ILV 845-03-15)

method of stimulation that combines on the retina the actions of various stimuli in such a manner that they cannot be perceived individually

3.7 colour matching (see ILV 845-03-16)

action of making a colour stimulus appear the same in colour as a given colour stimulus

3.8 trichromatic system (see ILV 845-03-20)

system for specifying colour stimuli in terms of tristimulus values based on matching colours by additive mixture of three suitably chosen reference colour stimuli

3.9 reference colour stimuli, [R], [G], [B]; [X], [Y], [Z]; [X_{10}], [Y_{10}], [Z_{10}]; etc. (see ILV 845-03-21)

set of three colour stimuli on which a trichromatic system is based

3.10 tristimulus values, R, G, B; X, Y, Z; X_{10}, Y_{10}, Z_{10}; etc. (see ILV 845-03-22)

amounts of three reference colour stimuli, in a given trichromatic system, required to match the colour of the stimulus considered

3.11 colour-matching functions, $\bar{r}(\lambda), \bar{g}(\lambda), \bar{b}(\lambda)$; $\bar{x}(\lambda), \bar{y}(\lambda), \bar{z}(\lambda)$; $\bar{x}_{10}(\lambda), \bar{y}_{10}(\lambda), \bar{z}_{10}(\lambda)$; etc. (see ILV 845-03-23)

tristimulus values of monochromatic stimuli of equal radiant power

3.12 CIE 1931 standard colorimetric system (X, Y, Z) (see ILV 845-03-28)

system for determining the tristimulus values of any spectral power distribution using the set of reference colour stimuli [X], [Y], [Z], and the three CIE colour-matching functions $\bar{x}(\lambda), \bar{y}(\lambda), \bar{z}(\lambda)$ adopted by the CIE in 1931 and defined in this standard

3.13 CIE 1964 standard colorimetric system (X_{10}, Y_{10}, Z_{10}) (see ILV 845-03-29)

system for determining the tristimulus values of any spectral power distribution using the set of reference colour stimuli [X_{10}], [Y_{10}], [Z_{10}], and the three CIE colour-matching functions $\bar{x}_{10}(\lambda), \bar{y}_{10}(\lambda), \bar{z}_{10}(\lambda)$ adopted by the CIE in 1964 and defined in this standard

3.14 CIE colour-matching functions (see ILV 845-03-30)

functions $\bar{x}(\lambda), \bar{y}(\lambda), \bar{z}(\lambda)$ in the CIE 1931 standard colorimetric system and $\bar{x}_{10}(\lambda), \bar{y}_{10}(\lambda), \bar{z}_{10}(\lambda)$ in the CIE 1964 standard colorimetric system

3.15 CIE 1931 standard colorimetric observer (see ILV 845-03-31)

ideal observer whose colour-matching properties correspond to the CIE colour-matching functions $\bar{x}(\lambda), \bar{y}(\lambda), \bar{z}(\lambda)$

3.16 CIE 1964 standard colorimetric observer (see ILV 845-03-32)

ideal observer whose colour-matching properties correspond to the CIE colour-matching functions $\bar{x}_{10}(\lambda), \bar{y}_{10}(\lambda), \bar{z}_{10}(\lambda)$

3.17 chromaticity coordinates, r, g, b; x, y, z; x_{10}, y_{10}, z_{10}; etc. (see ILV 845-03-33)
ratio of each of a set of three tristimulus values to their sum

3.18 spectral chromaticity coordinates, $r(\lambda)$, $g(\lambda)$, $b(\lambda)$; $x(\lambda)$, $y(\lambda)$, $z(\lambda)$; $x_{10}(\lambda)$, $y_{10}(\lambda)$, $z_{10}(\lambda)$; etc. (see ILV 845-03-36)
chromaticity coordinates of monochromatic stimuli

3.19 spectral luminous efficiency, $V(\lambda)$ (see ILV 845-01-22)
ratio of the radiant flux at wavelength λ_m to that at wavelength λ, such that both radiations produce an equal visual response under specified photometric conditions and λ_m is chosen so that the maximum value of this ratio is equal to 1

3.20 perfect reflecting diffuser (see ILV 845-04-54)
ideal isotropic diffuser with a reflectance equal to unity

4. SPECIFICATIONS

4.1 Colour-matching functions

The colour-matching functions $\bar{x}(\lambda), \bar{y}(\lambda), \bar{z}(\lambda)$ of the CIE 1931 standard colorimetric observer are defined by the values given in Table 1, and those $\bar{x}_{10}(\lambda), \bar{y}_{10}(\lambda), \bar{z}_{10}(\lambda)$ of the CIE 1964 standard colorimetric observer are defined by the values given in Table 2. The values are given at 1 nm wavelength intervals from 360 nm to 830 nm. If values are required at closer wavelength intervals than 1 nm, they should be derived by linear interpolation.

4.2 Spectral chromaticity coordinates

Tables 1 and 2 also give values for the spectral chromaticity coordinates, $x(\lambda)$, $y(\lambda)$, $z(\lambda)$; $x_{10}(\lambda)$, $y_{10}(\lambda)$, $z_{10}(\lambda)$; these have been derived from the appropriate colour-matching functions by forming the ratios:

$$x(\lambda)=\frac{\bar{x}(\lambda)}{\bar{x}(\lambda)+\bar{y}(\lambda)+\bar{z}(\lambda)}, \quad y(\lambda)=\frac{\bar{y}(\lambda)}{\bar{x}(\lambda)+\bar{y}(\lambda)+\bar{z}(\lambda)} \quad \text{and} \quad z(\lambda)=\frac{\bar{z}(\lambda)}{\bar{x}(\lambda)+\bar{y}(\lambda)+\bar{z}(\lambda)}$$

$$x_{10}(\lambda)=\frac{\bar{x}_{10}(\lambda)}{\bar{x}_{10}(\lambda)+\bar{y}_{10}(\lambda)+\bar{z}_{10}(\lambda)}, \quad y_{10}(\lambda)=\frac{\bar{y}_{10}(\lambda)}{\bar{x}_{10}(\lambda)+\bar{y}_{10}(\lambda)+\bar{z}_{10}(\lambda)} \quad \text{and}$$

$$z_{10}(\lambda)=\frac{\bar{z}_{10}(\lambda)}{\bar{x}_{10}(\lambda)+\bar{y}_{10}(\lambda)+\bar{z}_{10}(\lambda)}$$

Note: All wavelengths are for standard air.

5. DERIVATION OF THE COLOUR-MATCHING FUNCTIONS FOR THE CIE 1931 STANDARD COLORIMETRIC OBSERVER

5.1 Experimental basis

The CIE 1931 colour-matching functions, $\bar{x}(\lambda), \bar{y}(\lambda), \bar{z}(\lambda)$ were derived from experimental work carried out by Wright (1928-1930) and by Guild (1931) in which a total of 17 observers matched the monochromatic stimuli of the spectrum, over the range of about 400 nm to 700 nm, with additive mixtures of red, green and blue lights, using observing fields of 2° angular subtense.

5.2 Transformation procedures

The experimental results were converted into those that would have been obtained if the matching had been carried out using, as reference colour stimuli, monochromatic radiations of wavelengths 700 nm for the red [R], 546,1 nm for the green [G] and 435,8 nm for the blue [B], measured in units such that equal quantities of [R], [G] and [B] were required to match the equi-energy spectrum.

The results for the 17 observers were averaged and then slightly adjusted so that by adding together suitable proportions of the [R], [G], [B] colour-matching functions $\bar{r}(\lambda), \bar{g}(\lambda), \bar{b}(\lambda)$ it was possible to obtain a function identical to that of the CIE spectral luminous efficiency, $V(\lambda)$; the proportions used were in the ratios of 1,000 0 to 4,590 7 to 0,060 1, and these were then the relative luminances of unit quantities of [R], [G] and [B]. The CIE 1931 colour-matching functions were then determined by the following equations:

$$\bar{x}(\lambda) = \left[0{,}49\bar{r}(\lambda) + 0{,}31\bar{g}(\lambda) + 0{,}20\bar{b}(\lambda)\right]n$$
$$\bar{y}(\lambda) = \left[0{,}176\,97\bar{r}(\lambda) + 0{,}812\,40\bar{g}(\lambda) + 0{,}010\,63\bar{b}(\lambda)\right]n$$
$$\bar{z}(\lambda) = \left[0{,}00\bar{r}(\lambda) + 0{,}01\bar{g}(\lambda) + 0{,}99\bar{b}(\lambda)\right]n$$

where n is a normalising constant given by

$$n = \frac{V(\lambda)}{0{,}176\,97\bar{r}(\lambda) + 0{,}812\,40\bar{g}(\lambda) + 0{,}010\,63\bar{b}(\lambda)}$$

n is a constant, not a function of wavelength, because the coefficients 0,176 97, 0,812 40, and 0,010 63 are in the same ratios to one another as the ratio of 1,000 0 to 4,590 7 to 0,060 1; n is equal to

$$\frac{1{,}000\,0 + 4{,}590\,7 + 0{,}060\,1}{0{,}176\,97 + 0{,}812\,40 + 0{,}010\,63} = 5{,}650\,8$$

The values of $\bar{x}(\lambda), \bar{y}(\lambda), \bar{z}(\lambda)$ given in Table 1 from 360 nm to 400 nm and from 700 nm to 830 nm are extrapolations.

5.3 Transformation properties

The transformation given in the above equations was chosen to achieve the following objectives. First, the $\bar{y}(\lambda)$ function is identical to the $V(\lambda)$ function. Second, the values of $\bar{x}(\lambda), \bar{y}(\lambda), \bar{z}(\lambda)$ are all positive for all wavelengths of the spectrum (unlike $\bar{r}(\lambda), \bar{g}(\lambda), \bar{b}(\lambda)$ one of which is negative at most wavelengths because of the need to desaturate spectral stimuli when matching them with red, green, and blue reference stimuli). Third, the values of $\bar{z}(\lambda)$ are zero for wavelengths longer than 650 nm. Fourth, the values of $\bar{x}(\lambda)$ are nearly zero at wavelengths around 505 nm. Fifth, the values of $\bar{x}(\lambda)$ and $\bar{y}(\lambda)$ are small at the short-wavelength end of the spectrum. Sixth, the equi-energy spectrum is specified by equal amounts of X, Y and Z.

Because the $\bar{y}(\lambda)$ function is identical to the $V(\lambda)$ function, the Y tristimulus value is proportional to luminance.

5.4 Comparison with earlier data

The values of $\bar{x}(\lambda), \bar{y}(\lambda), \bar{z}(\lambda)$ given in Table 1 for the spectral range of 380 nm to 780 nm at 5 nm intervals, when rounded to four decimal places, agree closely with those originally published in 1931. There are only three minor differences: at λ = 775 nm the new value of $\bar{x}(\lambda)$ is 0,000 1 instead of 0,000 0; at λ = 555 nm, $\bar{y}(\lambda)$ = 1,000 0 instead of 1,000 2 and at λ = 740 nm, $\bar{y}(\lambda)$ = 0,000 2 instead of 0,000 3. These changes are considered insignificant in most colorimetric computations.

When the relative luminances of unit quantities of [R], [G] and [B] are deduced from the data of Tabie 1, the values obtained are 1,000 0 to 4,588 8 to 0,060 3 instead of 1,000 0 to