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CIE standard illuminants for colorimetry

Illuminants colorimétriques normalisés CIE

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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.

International Standard ISO 10526 was prepared as Standard CIE S 005 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 bodies 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.

International Standard ISO 10526 was prepared by Technical Committee 2-33 (Rationalisation of CIE Standard Illuminants A and D65) of the CIE.

This second edition cancels and replaces the first edition (ISO 10526:1991), of which it constitutes a technical revision.

Standard

CIE Standard Illuminants for Colorimetry

Illuminants colorimétriques normalisés CIE
CIE Normlichtarten für Farbmessung

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

S 005/E-1998

UDC: 535.65:006
535.643.2

Descriptor: Standardisation of colour measurement
Standard colorimetric system

Foreword

This CIE Standard has been prepared by CIE Technical Committee 2-33, "Rationalisation of CIE Standard Illuminants A and D65"*), and was approved by the CIE Board of Administration and the National Committees of the CIE.

The numerical values of the relative spectral distributions of standard illuminants A and D65 defined by this Standard are the same, within an accuracy of six significant digits, as those defined in earlier versions of these illuminants.

Standards produced by the CIE are concise documentation of data, defining aspects of light and lighting for which international harmony requires a unique definition. As such, CIE Standards are a primary source of internationally accepted and agreed data that can be taken, essentially unaltered, into universal standard systems.

CIE Standard Illuminants for Colorimetry

Contents

*) Chairman of this TC was K. D. Mielenz (US), members were: J. J. Hsia (US), J. R. Moore (GB), A. R. Robertson (CA), H. Terstiege (DE), J. F. Verrill (GB).

1. Scope

This International Standard specifies two illuminants for use in colorimetry. The illuminants, which are defined in clauses 4 and 5 of this International Standard, are as follows:

a) CIE standard illuminant A

This is intended to represent typical, domestic, tungsten-filament lighting. Its relative spectral power distribution is that of a Planckian radiator at a temperature of approximately 2 856 K. CIE standard illuminant A should be used in all applications of colorimetry involving the use of incandescent lighting, unless there are specific reasons for using a different illuminant.

b) CIE standard illuminant D65

This is intended to represent average daylight and has a correlated colour temperature of approximately 6 500 K. CIE standard illuminant D65 should be used in all colorimetric calculations requiring representative daylight, unless there are specific reasons for using a different illuminant. Variations in the relative spectral power distribution of daylight are known to occur, particularly in the ultraviolet spectral region, as a function of season, time of day, and geographic location. However, CIE standard illuminant D65 should be used pending the availability of additional information on these variations.

Values for the relative spectral power distribution of CIE standard illuminants A and D65 are given in Table 1 of this International Standard. Values are given at 1 nm intervals from 300 nm to 830 nm.

The term "illuminant" refers to a defined spectral power distribution, not necessarily realizable or provided by a source. Illuminants are used in colorimetry to compute the tristimulus values of reflected or transmitted object colours under specified conditions of illumination. The CIE has also defined illuminant C and other illuminants D. These illuminants are described in Publication CIE 15.2-1986 [1], but they do not have the status of primary CIE standards accorded to the CIE standard illuminants A and D65 described in this International Standard. It is recommended that one of the two CIE standard illuminants defined in this International Standard be used wherever possible. This will greatly facilitate the comparison of published results.

It is noted that in the fields of graphic arts and photography extensive use is also made of CIE illuminant D50, for example ISO 3644 [2] and ISO 13655 [3].

In most practical applications of colorimetry, it is sufficient to use the values of CIE standard illuminants A and D65 at less frequent wavelength intervals or in a narrower spectral region than defined in this Standard. Data and guidelines that facilitate such practice are provided in Publication CIE 15.2 [1], together with other recommended procedures for practical colorimetry.

The term "source" refers to a physical emitter of light, such as a lamp or the sky. In certain cases, the CIE recommends laboratory sources that approximate the spectral power distributions of CIE illuminants. In all cases, however, the definition of a CIE recommended source is secondary to the definition of the corresponding CIE illuminant, because of the possibility that, from time to time, new developments will lead to improved sources that represent a particular illuminant more accurately or are more suitable for laboratory use.

Subclause 6.1 of this International Standard describes CIE source A, which is recommended for laboratory realizations of CIE standard illuminant A. At present, there is no CIE recommended source representing CIE standard illuminant D65.

2. Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this Standard are encouraged to investigate the possibility of applying most recent editions of the standards indicated below. Members of CIE, the International Electrotechnical Commission (IEC) and the International Organization for Standardization (ISO) maintain registers of currently valid international standards.

CIE 15.2-1986: *Colorimetry*

CIE 17.4-1987: *International Lighting Vocabulary* - equivalent to IEC 50(845)

CIE 51-1981: *A method for assessing the quality of daylight simulators for colorimetry*

ISO/CIE 10527-1991: *CIE standard colorimetric observers*

3. Definitions

For the purposes of this International Standard, the following definitions apply. These definitions are taken from Publication CIE 17.4-1987 [4], where other relevant terms will also be found.

3.1 chromaticity co-ordinates

Ratio of each of a set of three tristimulus values to their sum.

NOTE1 As the sum of the three chromaticity co-ordinates equals 1, two of them are sufficient to define a chromaticity.

NOTE2 In the CIE standard colorimetric systems, the chromaticity co-ordinates are represented by the symbols x, y, z and x_{10}, y_{10}, z_{10}.

3.2 chromaticity diagram

A plane diagram in which points specified by chromaticity co-ordinates represent the chromaticities of colour stimuli.

3.3 CIE standard illuminants

The illuminants A and D65 defined by the CIE in terms of relative spectral power distributions.

3.4 CIE standard sources

Artificial sources, specified by the CIE, whose relative spectral power distributions are approximately the same as those of CIE standard illuminants*.

3.5 CIE 1976 uniform-chromaticity-scale diagram; CIE 1976 UCS diagram

The uniform-chromaticity-scale diagram produced by plotting in rectangular co-ordinates *v'* against *u'*, quantities defined by the equations

$$u' = 4X/(X + 15Y + 3Z) = 4x/(-2x + 12y + 3)$$
$$v' = 9Y/(X + 15Y + 3Z) = 9y/(-2x + 12y + 3)$$

X, Y, Z are the tristimulus values in the CIE 1931 or 1964 standard colorimetric systems, and x, y are the corresponding chromaticity co-ordinates of the colour stimulus considered.

3.6 colour temperature *Tc*

The temperature of a Planckian radiator whose radiation has the same chromaticity as that of a given stimulus.

* This definition is a revision of the definition given in CIE 17.4-1987.

3.7 correlated colour temperature T_{cp}

The temperature of the Planckian radiator whose perceived colour most closely resembles that of a given stimulus at the same brightness and under specified viewing conditions.

NOTE The recommended method of calculating the correlated colour temperature of a stimulus is to determine, on a chromaticity diagram, the temperature corresponding to the point on the Planckian locus that is intersected by the agreed isotemperature line containing the point representing the stimulus (see Publication CIE 15.2 [1]).

3.8 daylight illuminant

Illuminant having the same, or nearly the same, relative spectral power distribution as a phase of daylight.

3.9 illuminant

Radiation with a relative spectral power distribution defined over the wavelength range that influences object colour perception.

3.10 Planckian radiator; black-body

Ideal thermal radiator that absorbs completely all incident radiation, whatever the wavelength, the direction of incidence or the polarization. This radiator has, for any wavelength and any direction, the maximum spectral concentration of radiance for a thermal radiator in thermal equilibrium at a given temperature.

3.11 Planckian locus

The locus of points in a chromaticity diagram that represents chromaticities of the radiation of Planckian radiators at different temperatures.

3.12 primary light source

Surface or object emitting light produced by a transformation of energy.

3.13 secondary light source

Surface or object which is not self-emitting but receives light and re-directs it, at least in part, by reflection or transmission.

3.14 tristimulus values (of a colour stimulus)

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

NOTE In the CIE standard colorimetric systems, the tristimulus values are represented by the symbols X, Y, Z and X_{10}, Y_{10}, Z_{10}.

4. CIE standard illuminant A

4.1 Definition

The relative spectral power distribution $S^{A}(\lambda)$ of CIE standard illuminant A is defined by the equation

$$S^{A}(\lambda) = 100\left(\frac{0{,}56}{\lambda}\right)^{5} \times \frac{\exp\dfrac{1\,435\,000}{159\,488} - 1}{\exp\dfrac{14\,350}{2\,848\,\lambda} - 1} \qquad (1)$$

where

λ is the vacuum wavelength in micrometres and the numerical constants in the two exponential terms are integers.

This spectral power distribution is normalized to the value 100 (exactly) at the vacuum wavelength 0,56 µm (exactly)[*] .

CIE standard illuminant A is defined over the 300 nm to 830 nm spectral region.

NOTE Table 1 provides the relative spectral power distribution of CIE standard illuminant A between 300 nm and 830 nm at one nm intervals. For all practical purposes it suffices to use these tabulated values instead of the values calculated from equation 1.

4.2 Theoretical basis

Equation 1 is equivalent to and can be derived from the expression

$$S(\lambda) = 100\ M_{e,\lambda}(\lambda, T)\ /\ M_{e,\lambda}(\ 0{,}56\ T\ ), \qquad (2)$$

where

$$M_{e,\lambda}(\ \lambda, T\ ) = c_1\ \lambda^{-5}\ [\exp(c_2\ /\lambda T) - 1]^{-1}, \quad \text{[Units of W·m}^{-2}\text{·µm}^{-1}\text{]}, \qquad (3)$$

is the spectral radiant exitance of a Planckian radiator of temperature T, c_1 and c_2 are the first and second radiation constants and the ratio $c_2\ /T$ is given by

$$c_2\ /T = 14\ 350\ /\ 2\ 848\ \text{µm}. \qquad (4)$$

Since the numerical value of c_1 is of no importance in calculating the relative spectral power distribution of an illuminant, the definition of CIE standard illuminant A involves no assumptions about the numerical values of c_1, c_2, and T other than the ratio defined in equation 4.

4.3 Supplementary notes

CIE standard illuminant A was originally defined in 1931 [5] as the relative spectral power distribution of a Planckian radiator of temperature

$$T_{\text{CIE 1931}} = 2\ 848\ \text{K}, \qquad (5)$$

the value of the second radiation constant c_2 then being taken as

$$c_{2,\ \text{CIE 1931}} = 14\ 350\ \text{µm·K}. \qquad (6)$$

This form of definition as given in Equ. 1 was carefully chosen to ensure that CIE standard illuminant A was defined as a relative spectral power distribution and not as a function of temperature. As explained in 4.2 above, the definition of the relative spectral power distribution has not changed since 1931 and equation 1 simply expresses it in a general form.

What has changed is the temperature assigned to this distribution. The value of c_2 given in equation 6 and used by the CIE in 1931 is different from the respective values, $c_{2,\ \text{ITS-27}}$ = 14 320 µm·K, $c_{2,\text{IPTS-48}}$ = 14 380 µm·K, and $c_{2,\text{IPTS-68}}$ = $c_{2,\text{ITS-90}}$ = 14 388 µm·K, that were assigned to this constant in the International Temperature Scales of 1927, 1948, 1968 and 1990. Although this has had no effect on the relative spectral power distribution of CIE standard illuminant A, the correlated colour temperatures of sources recommended for laboratory realizations have been different, over the years, depending on the values of c_2 used.

[*] The value of 2 848 x 0,56 is 1 594,88; to avoid decimal figures, both nominator and denominator in the exponential term in the nominator of equation 1 were multiplied by 100.

As may be seen from equation 4, the colour temperatures associated with CIE standard illuminant A on the various international temperature scales referred to above were T_{27} = 2 842 K, T_{48} = 2 854 K, and T_{68} = T_{90} = 2 856 K, respectively (see 6.1).

It is implicit in the 1931 definition of CIE standard illuminant A that the term λ in equation 1 denotes a vacuum wavelength. The use of air, instead of vacuum, wavelengths will cause the following, insignificantly small, errors of the relative spectral distribution of CIE standard illuminant A: - 0,2 % at 300 nm, -0,1 % at 400 nm, - 0,03 % at 500 nm, + 0,02 % at 600 nm, + 0,05 % at 700 nm and + 0,08 % at 800 nm.

5. CIE standard illuminant D65

5.1 Definition

The relative spectral power distribution $S^{D65}(\lambda)$ of CIE standard illuminant D65 is defined by the values given in table 1 which are presented at 1 nm intervals over the wavelength range from 300 nm to 830 nm. If required, other intermediate values may be derived by linear interpolation from the published values*.

5.2 Experimental basis

The relative spectral power distribution of CIE standard illuminant D65 is based on experimental measurements of daylight in the wavelength range 330 nm to 700 nm, with extrapolations to 300 nm and 830 nm, as reported by Judd, MacAdam, and Wyszecki [6]. The extrapolated values are believed to be sufficiently accurate for conventional colorimetric purposes, but are not recommended for non-colorimetric use.

5.3 Correlated colour temperature

CIE standard illuminant D65 has a nominal correlated colour temperature of 6 500 K. The exact value depends on the convention used to assign a correlated colour temperature to a stimulus whose chromaticity, as in this case, does not fall precisely on the Planckian locus.

NOTE: Using the value of c_2 = 14 388 µm·K specified in the International Temperature Scale of 1990 and the recommended convention that lines of constant correlated colour temperature are normal to the Planckian locus in a chromaticity diagram in which $2v'/3$ is plotted against u', where u', v' are the co-ordinates used in the CIE 1976 uniform-chromaticity-scale diagram, the correlated colour temperature of CIE standard illuminant D65 was found to be within 4 K of 6 500 K. This difference from the nominal temperature of the CIE standard illuminant was judged to be insignificantly small.

6. CIE sources for producing CIE standard illuminants

6.1 CIE source A

CIE standard illuminant A can be realized by CIE source A, defined as a gas-filled, tungsten-filament lamp operating at a correlated colour temperature

$$T = \frac{2848\, c_2}{14350}\ \text{K} \qquad (7)$$

on a radiation temperature scale specified by a given value of the second radiation constant c_2. A lamp with a fused-quartz envelope or window is recommended if the spectral power distribution of the ultraviolet radiation of CIE standard illuminant A is to be realized more accurately.

* Information on the procedure used to derive D65 values is given in Publication CIE 15.2 [1].