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CIE standard colorimetric illuminants

Illuminants colorimétriques normalisés CIE

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Contents

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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.

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.

The objectives of the CIE are

a) to provide an international forum for the discussion of all matters relating to science, technology and art in the fields of light and lighting and for the interchange of information between countries in these fields;

b) to develop basic standards and procedures of metrology in the fields of light and lighting;

c) to provide guidance on the application of principles and procedures in the development of International Standards and national standards in the fields of light and lighting;

d) to prepare and publish standards, reports and other publications concerned with all matters relating to science, technology and art in the fields of light and lighting;

e) to maintain liaison and technical interaction with other international organizations concerned with matters relating to science, technology, standardization and art in the fields of light and lighting.

Within these objectives, light and lighting embrace fundamental subjects such as vision, photometry and colorimetry, involving natural and man-made radiations in the ultraviolet, visible and infrared regions of the spectrum, and also applications covering all uses of light, indoors and out, including environmental and aesthetic effects, and also means for the production and control of light and radiation.

The technical activities of the CIE are covered by seven divisions, each being responsible for a major subject area of interest to the CIE. Technical Committees consisting of small groups of experts are established in each division to work on separate subjects. The text of this International Standard was prepared by Division 1: *Vision and Colour.* The ratification of a CIE Standard requires the approval of the division members, the Council and national member bodies of the CIE.

Standards produced by the CIE are a concise documentation of data defining aspects of light and lighting, for which international harmony requires a 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.

International Standard ISO/CIE 10526 was prepared as Standard CIE S001 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.

International Standard ISO/CIE 10526 was prepared by Technical Committee CIE/TC 1.3, *Colorimetry*.

Annex A of this International Standard is for information only.

Introduction

Illuminants are radiations defined by their relative spectral power distributions, and they are widely used in colorimetry in calculations of tristimulus values of reflecting and transmitting object colours. The calculation of tristimulus values for a particular situation requires spectroradiometric evaluation of the illuminant *in situ*. This is often difficult to do. In addition, the use of many different illuminants makes comparisons of data for different situations difficult. For these reasons, it has long been the practice in colorimetry to use only a few standard illuminants. The purpose of this Internationai Standard is to specify two illuminants as CIE standard illuminants.

CIE standard colorimetric illuminants

1 Scope

This International Standard specifies relative spectral power distributions of illuminants for use in colorimetry. Two illuminants are specified as follows.

a) CIE standard illuminant A

This is representative of domestic, tungsten-filament lighting. Its relative spectral power distribution is an expression of that from a Planckian radiator at a temperature of approximately 2 856 K. This illuminant should be used in all applications of colorimetry requiring the use of representative, domestic, tungsten lighting, unless there are specific reasons for using a different illuminant.

b) CIE standard illuminant D_{65}

This is representative of average daylight. It has a correlated colour temperature of approximately 6 500 K. This illuminant should be used in all colorimetric calculations requiring the use of representative daylight, unless there are specific reasons for using a different illuminant. Seasonal variations in the relative spectral power distribution of daylight are known to occur, particularly in the spectral region of wavelengths corresponding to ultraviolet radiation, but this standard illuminant should be used pending the availability of additional information on these variations.

The CIE has also defined standard illuminant C and other illuminants D. These illuminants are described in CIE Publication No. 15.2, but they do not have the status of primary CIE standards accorded to CIE standard illuminants A and D_{65} described in this International Standard.

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 International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

CIE Publication 15.2 : 1986, *Colorimetry*.

CIE Publication 17.4 : 1987, *International lighting vocabulary* (IEC/CIE joint publication).

CIE Publication 51 : 1981, *A method for assessing the quality of daylight simulators for colorimetry.*

3 Definitions

For the purposes of this International Standard, the following definitions apply. These definitions are from the CIE International Lighting Vocabulary (4th edition), where other relevant terms will be found.

3.1 illuminant: Radiation with a relative spectral power distribution defined over the range of wavelengths that influences object-colour perception.

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

3.3 CIE standard illuminants: The illuminants A and D_{65}, defined by the CIE in terms of relative spectral power distribution.

3.4 CIE standard sources: Artificial sources, specified by the CIE, whose radiations approximate CIE standard illuminants.

3.5 primary light source: Surface or object emitting light produced by a transformation of energy.

3.6 secondary light source: Surface or object that is not self-emitting but receives light and redirects it, at least in part, by reflection or transmission.

3.7 tristimulus values, X, Y, Z; X_{10}, Y_{10}, Z_{10}; etc.: Amounts of the three reference colour stimuli, in a given trichromatic system, required to match the colour of the stimulus considered.

3.8 chromaticity coordinates, x, y, z; x_{10}, y_{10}, z_{10}; etc.: Ratio of each of a set of three tristimulus values to their sum.

3.9 chromaticity diagram: A plane diagram in which points specified by chromaticity coordinates represent the chromaticities of colour stimuli.

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

3.11 colour temperature, T_c: The temperature of a Planckian radiator whose radiation has the same chromaticity as that of a given stimulus.

3.12 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.

3.13 CIE 1976 uniform-chromaticity-scale diagram: The uniform-chromaticity-scale diagram produced by plotting in rectangular coordinates v' against u', quantities defined by the following equations:

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

for the CIE 1931 standard colorimetric system, or v'_{10} against u'_{10}, quantities defined by the following equations

$$u'_{10} = 4X_{10}/(X_{10} + 15Y_{10} + 3Z_{10}) = 4x_{10}/(-2x_{10} + 12y_{10} + 3)$$
$$v'_{10} = 9Y_{10}/(X_{10} + 15Y_{10} + 3Z_{10}) = 9y_{10}/(-2x_{10} + 12y_{10} + 3)$$

for the CIE 1964 supplementary standard colorimetric system.

4 Specifications

CIE standard illuminants A and D_{65} are specified by the relative spectral power distributions (see table 1). The values are given at 1 nm wavelength intervals from 300 nm to 830 nm. If values are required at closer wavelength intervals than 1 nm, they should be derived by linear interpolation.

NOTE — All wavelengths are for a vacuum.

5 Derivation of CIE standard illuminant A

5.1 Basis of calculation

The relative spectral power distribution of CIE standard illuminant A has been calculated in accordance with Planck's radiation law. This law gives the spectral concentration, in watts per cubic metre, of radiant exitance M_e, in watts per square metre per wavelength interval, as a function of wavelength, λ, in metres, and temperature, T, in kelvins, by the following equation:

$$M_{e,\lambda}(\lambda, T) = c_1 \lambda^{-5} (e^{c_2/\lambda T} - 1)^{-1}$$

where

$$c_1 = 3{,}741\,774\,9 \times 10^{-16}\ \mathrm{W \cdot m^2}$$
$$c_2 = 1{,}438\,8 \times 10^{-2}\ \mathrm{m \cdot K}$$

$$T = \frac{1{,}438\,8}{1{,}435\,0} \times 2\,848\ \mathrm{K}$$

The choice of this temperature assured a relative spectral power distribution identical to the one adopted by the CIE in 1931 for illuminant A when c_2 was equal to $1{,}435\,0 \times 10^{-2}$ m·K and T was set to 2 848 K. The value of $c_2 = 1{,}438\,8 \times 10^{-2}$ m·K, is that given by the "International Practical Temperature Scale, 1968" issued by the Comité international des poids et mesures. The values given in table 1 were normalized by computing the relative spectral power distribution.

$$S(\lambda) = 100 M_{e,\lambda}/M_{e,560}$$

Thus $S(\lambda)$ is exactly equal to 100 for $\lambda = 560 \times 10^{-9}$ m = 560 nm. The numerical value of c_1 is of no importance in the calculation of these relative spectral power distributions.

5.2 Comparison with earlier data

The values $S(\lambda)$ for standard illuminant A, given in table 1, show small discrepancies, in several instances, from those originally adopted by the CIE in 1931. These discrepancies are of no significance in practical colorimetry. The values given in table 1, which are the same as those given in CIE Publication No. 15 (1971), supersede those given in earlier CIE publications.

6 Derivation of CIE standard illuminant D_{65}

6.1 Experimental basis

The relative spectral power distribution of CIE standard illuminant D_{65} is based on experimental measurements of daylight, as reported by Judd, MacAdam and Wyszecki[6], over the range of wavelengths from 330 nm to 700 nm and on extrapolation in the ranges of 300 nm to 330 nm and 700 nm to 830 nm. The extrapolated values are believed to be accurate enough for ordinary colorimetric purposes but should not be used for other purposes if high accuracy is required in these spectral regions.

6.2 Comparison with earlier data

The values of $S(\lambda)$ for standard illuminant D_{65} given in table 1 are the same as those given in CIE Publication No. 15 (1971).

NOTE — The procedure for calculating these values is given in CIE Publication No. 15.2.

6.3 Correlated colour temperature

CIE standard illuminant D_{65} has a correlated colour temperature of approximately 6 500 K. The exact value depends on the value

adopted for the constant c_2 in Planck's radiation law, and on the convention used for assigning correlated colour temperature to stimuli whose chromaticities do not lie exactly on the Planckian locus. Using the 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', the correlated colour temperature was equal to 6 500 K when $c_2 = 1{,}438\,0 \times 10^{-2}$ m·K; with $c_2 = 1{,}438\,8 \times 10^{-2}$ m·K, it is equal to 6 500 (1,438 8/1,435 0) K.

(u' and v' are the coordinates used in the CIE 1976 uniform-chromaticity-scale diagram).

7 Practical applications of CIE standard illuminants

For most practical applications of colorimetry, it is sufficient to use values of relative spectral power distributions at less frequent intervals of wavelength than every 1 nm, covering a more restricted range of wavelengths than from 300 nm to 830 nm, and using fewer decimal places than are given in table 1. Data and guidelines that facilitate such practice are provided in CIE Publication No. 15.2 together with various other recommended procedures for practical colorimetry.

8 Sources for producing CIE standard illuminants

8.1 Source for CIE standard illuminant A

CIE standard illuminant A can be realized by means of CIE standard source A, which is defined as follows.

A gas-filled tungsten-filament lamp operating at a correlated colour temperature of 2 848 (1,438 8/1,435 0) K, which is approximately equal to 2 856 K. A lamp with a fused-quartz envelope or window is recommended if the relative spectral power distribution of CIE standard illuminant A is to be realized accurately.[1)]

8.2 Source for CIE standard illuminant D_{65}

At present, no source is recommended for realizing CIE standard illuminant D_{65}. Practical sources intended for this purpose can be assessed by a method described in CIE Publication No. 51.

1) The International Temperature Scale (ITS) was redefined in 1990 (ITS-90). The changes do not influence the temperature of the blackbody defining CIE standard illuminant A (2 856 K). During the realization, however, the following discrepancy may be observed.

The pyrometer reading for a lamp set to standard illuminant A would read 2 856 K on the International Practical Temperature Scale 1968 (IPTS-68). With unchanged lamp settings, a pyrometer calibrated in accordance with ITS-90 would then read approximately 2 855 K, a difference too small to be taken into account with state of the art measuring technology.

Table 1 — Relative spectral power distribution of CIE standard colorimetric illuminants

Wavelength, λ nm	Relative spectral power distribution, $S(\lambda)$ Standard illuminant A	Standard illuminant D_{65}	Wavelength, λ nm	Relative spectral power distribution, $S(\lambda)$ Standard illuminant A	Standard illuminant D_{65}
300	0.930 483	0.034 100 0	355	5.410 70	45.775 0
301	0.967 643	0.360 140	356	5.552 13	45.947 7
302	1.005 97	0.686 180	357	5.696 22	46.120 3
303	1.045 49	1.012 22	358	5.842. 98	46.293 0
304	1.086 23	1.338 26	359	5.992 44	46.465 6
305	1.128 21	1.664 30	360	6.144 62	46.638 3
306	1.171 47	1.990 34	361	6.299 55	47.183 4
307	1.216 02	2.316 38	362	6.457 24	47.728 5
308	1.261 88	2.642 42	363	6.617 74	48.273 5
309	1.309 10	2.968 46	364	6.781 05	48.818 6
310	1.357 69	3.294 50	365	6.947 20	49.363 7
311	1.407 68	4.988 65	366	7.116 21	49.908 8
312	1.459 10	6.682 80	367	7.288 11	50.453 9
313	1.511 98	8.376 95	368	7.462 92	50.998 9
314	1.566 33	10.071 1	369	7.640 66	51.544 0
315	1.622 19	11.765 2	370	7.821 35	52.089 1
316	1.679 59	13.459 4	371	8.005 01	51.877 7
317	1.738 55	15.153 5	372	8.191 67	51.666 4
318	1.799 10	16.847 7	373	8.381 34	51.455 0
319	1.861 27	18.541 8	374	8.574 04	51.243 7
320	1.925 08	20.236 0	375	8.769 80	51.032 3
321	1.990 57	21.917 7	376	8.968 64	50.820 9
322	2.057 76	23.599 5	377	9.170 56	50.609 6
323	2.126 67	25.281 3	378	9.375 61	50.398 2
324	2.197 34	26.963 0	379	9.583 78	50.186 9
325	2.269 80	28.644 7	380	9.795 10	49.975 5
326	2.344 06	30.326 5	381	10.009 6	50.442 8
327	2.420 17	32.008 2	382	10.227 3	50.910 0
328	2.498 14	33.690 0	383	10.448 1	51.377 3
329	2.578 01	35.371 7	384	10.672 2	51.844 6
330	2.659 81	37.053 5	385	10.899 6	52.311 8
331	2.743 55	37.343 0	386	11.130 2	52.779 1
332	2.829 28	37.632 6	387	11.364 0	53.246 4
333	2.917 01	37.922 1	388	11.601 2	53.713 7
334	3.006 78	38.211 6	389	11.841 6	54.180 9
335	3.098 61	38.501 1	390	12.085 3	54.648 2
336	3.192 53	38.790 7	391	12.332 4	57.458 9
337	3.288 57	39.080 2	392	12.582 8	60.269 5
338	3.386 76	39.369 7	393	12.836 6	63.080 2
339	3.487 12	39.659 3	394	13.093 8	65.890 9
340	3.589 68	39.948 8	395	13.354 3	68.701 5
341	3.694 47	40.445 1	396	13.618 2	71.512 2
342	3.801 52	40.941 4	397	13.885 5	74.322 9
343	3.910 85	41.437 7	398	14.156 3	77.133 6
344	4.022 50	41.934 0	399	14.430 4	79.944 2
345	4.136 48	42.430 2	400	14.708 0	82.754 9
346	4.252 82	42.926 5	401	14.989 1	83.628 0
347	4.371 56	43.422 8	402	15.273 6	84.501 1
348	4.492 72	43.919 1	403	15.561 6	85.374 2
349	4.616 31	44.415 4	404	15.853 0	86.247 3
350	4.742 38	44.911 7	405	16.148 0	87.120 4
351	4.870 95	45.084 4	406	16.446 4	87.993 6
352	5.002 04	45.257 0	407	16.748 4	88.866 7
353	5.135 68	45.429 7	408	17.053 8	89.739 8
354	5.271 89	45.602 3	409	17.362 8	90.612 9