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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

$$c_1 = 3{,}741\,774\,9 \times 10^{-16}\ \text{W·m}^2$$

$$c_2 = 1{,}438\,8 \times 10^{-2}\ \text{m·K}$$

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

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 × 10^{-2} m·K and T was set to 2 848 K. The value of c_2 = 1,438 8 × 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 λ = 560 × 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 × 10^{-2} m·K; with c_2 = 1,438 8 × 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

Wave-length, λ nm	Relative spectral power distribution, $S(\lambda)$ Standard illuminant A	Relative spectral power distribution, $S(\lambda)$ Standard illuminant D_{65}	Wave-length, λ nm	Relative spectral power distribution, $S(\lambda)$ Standard illuminant A	Relative spectral power distribution, $S(\lambda)$ 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

Table 1 — *(continued)*

Wavelength, λ nm	Relative spectral power distribution, $S(\lambda)$ Standard illuminant A	Relative spectral power distribution, $S(\lambda)$ Standard illuminant D_{65}	Wavelength, λ nm	Relative spectral power distribution, $S(\lambda)$ Standard illuminant A	Relative spectral power distribution, $S(\lambda)$ Standard illuminant D_{65}
410	17.675 3	91.486 0	465	40.300 2	116.337
411	17.991 3	91.680 6	466	40.807 6	116.041
412	18.310 8	91.875 2	467	41.318 2	115.746
413	18.633 9	92.069 7	468	41.832 0	115.451
414	18.960 5	92.264 3	469	42.349 1	115.156
415	19.290 7	92.458 9	470	42.869 3	114.861
416	19.624 4	92.653 5	471	43.392 6	114.967
417	19.961 7	92.848 1	472	43.919 2	115.073
418	20.302 6	93.042 6	473	44.448 8	115.179
419	20.647 0	93.237 2	474	44.981 6	115.286
420	20.995 0	93.431 8	475	45.517 4	115.392
421	21.346 5	92.756 8	476	46.056 3	115.498
422	21.701 6	92.081 9	477	46.598 3	115.604
423	22.060 3	91.406 9	478	47.143 3	115.710
424	22.422 5	90.732 0	479	47.691 3	115.817
425	22.788 3	90.057 0	480	48.242 3	115.923
426	23.157 7	89.382 1	481	48.796 3	115.212
427	23.530 7	88.707 1	482	49.353 3	114.500
428	23.907 2	88.032 2	483	49.913 2	113.789
429	24.287 3	87.357 2	484	50.476 0	113.078
430	24.670 9	86.682 3	485	51.041 8	112.367
431	25.058 1	88.500 6	486	51.610 4	111.656
432	25.448 9	90.318 8	487	52.181 8	110.944
433	25.843 2	92.137 1	488	52.756 1	110.233
434	26.241 1	93.955 3	489	53.333 2	109.522
435	26.642 5	95.773 6	490	53.913 2	108.811
436	27.047 5	97.591 9	491	54.495 8	108.865
437	27.456 0	99.410 1	492	55.081 3	108.919
438	27.868 1	101.228	493	55.669 4	108.974
439	28.283 6	103.047	494	56.260 3	109.028
440	28.702 7	104.865	495	56.853 9	109.083
441	29.125 3	106.079	496	57.450 1	109.137
442	29.551 5	107.293	497	58.048 9	109.191
443	29.981 1	108.508	498	58.650 4	109.246
444	30.414 2	109.722	499	59.254 5	109.300
445	30.850 8	110.936	500	59.861 1	109.354
446	31.290 9	112.151	501	60.470 3	109.199
447	31.734 5	113.365	502	61.082 0	109.044
448	32.181 5	114.579	503	61.696 2	108.889
449	32.632 0	115.793	504	62.312 8	108.733
450	33.085 9	117.008	505	62.932 0	108.578
451	33.543 2	117.088	506	63.553 5	108.423
452	34.004 0	117.169	507	64.177 5	108.268
453	34.468 2	117.249	508	64.803 8	108.112
454	34.935 8	117.329	509	65.432 5	107.957
455	35.406 8	117.410	510	66.063 5	107.802
456	35.881 1	117.490	511	66.696 8	107.501
457	36.358 8	117.571	512	67.332 4	107.199
458	36.839 9	117.651	513	67.970 2	106.898
459	37.324 3	117.732	514	68.610 2	106.597
460	37.812 1	117.812	515	69.252 5	106.296
461	38.303 1	117.517	516	69.896 9	105.995
462	38.797 5	117.222	517	70.543 5	105.693
463	39.295 1	116.927	518	71.192 2	105.392
464	39.796 0	116.632	519	71.843 0	105.091

Table 1 — (continued)

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}
520	72.495 9	104.790	575	110.803	96.061 1
521	73.150 8	105.080	576	111.529	96.006 5
522	73.807 7	105.370	577	112.255	95.951 9
523	74.466 6	105.660	578	112.982	95.897 2
524	75.127 5	105.950	579	113.709	95.842 6
525	75.790 3	106.240	580	114.436	95.788 0
526	76.455 1	106.530	581	115.164	95.077 8
527	77.121 7	106.820	582	115.893	94.367 5
528	77.790 2	107.110	583	116.622	93.657 3
529	78.460 5	107.400	584	117.351	92.947 0
530	79.132 6	107.689	585	118.080	92.236 8
531	79.806 5	107.361	586	118.810	91.526 6
532	80.482 1	107.033	587	119.540	90.816 3
533	81.159 5	106.704	588	120.270	90.106 1
534	81.838 6	106.376	589	121.001	89.395 8
535	82.519 3	106.047	590	121.731	88.685 6
536	83.201 7	105.719	591	122.462	88.817 7
537	83.885 6	105.391	592	123.193	88.949 7
538	84.571 2	105.062	593	123.924	89.081 8
539	85.258 4	104.734	594	124.655	89.213 8
540	85.947 0	104.405	595	125.386	89.345 9
541	86.637 2	104.370	596	126.118	89.478 0
542	87.328 8	104.334	597	126.849	89.610 0
543	88.021 9	104.298	598	127.580	89.742 1
544	88.716 5	104.262	599	128.312	89.874 1
545	89.412 4	104.226	600	129.043	90.006 2
546	90.109 7	104.190	601	129.774	89.965 5
547	90.808 3	104.154	602	130.505	89.924 8
548	91.508 2	104.118	603	131.236	89.884 1
549	92.209 5	104.082	604	131.966	89.843 4
550	92.912 0	104.046	605	132.697	89.802 6
551	93.615 7	103.642	606	133.427	89.761 9
552	94.320 6	103.237	607	134.157	89.721 2
553	95.026 7	102.832	608	134.887	89.680 5
554	95.733 9	102.428	609	135.617	89.639 8
555	96.442 3	102.023	610	136.346	89.599 1
556	97.151 8	101.618	611	137.075	89.409 1
557	97.862 3	101.214	612	137.804	89.219 0
558	98.573 9	100.809	613	138.532	89.029 0
559	99.286 4	100.405	614	139.260	88.838 9
560	100.000	100.000	615	139.988	88.648 9
561	100.715	99.633 4	616	140.715	88.458 9
562	101.430	99.266 8	617	141.441	88.268 8
563	102.146	98.900 3	618	142.167	88.078 8
564	102.864	98.533 7	619	142.893	87.888 7
565	103.582	98.167 1	620	143.618	87.698 7
566	104.301	97.800 5	621	144.343	87.257 7
567	105.020	97.433 9	622	145.067	86.816 7
568	105.741	97.067 4	623	145.790	86.375 7
569	106.462	96.700 8	624	146.513	85.934 7
570	107.184	96.334 2	625	147.235	85.493 6
571	107.906	96.279 6	626	147.957	85.052 6
572	108.630	96.225 0	627	148.678	84.611 6
573	109.354	96.170 3	628	149.398	84.170 6
574	110.078	96.115 7	629	150.117	83.729 6