INTERNATIONAL STANDARD

ISO 11476

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Paper and board — Determination of CIE whiteness, C/2° (indoor illumination conditions)

Papier et carton — Détermination du degré de blanc CIE, C/2° (éclairage intérieur)

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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 Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 11476 was prepared by Technical Committee ISO/TC 6, *Paper, board and pulps*. It is based on the CIE-whiteness formula, published in CIE Publication 15.2-1986, *Colorimetry*.

Annexes A and B form a normative part of this International Standard.

Paper and board — Determination of CIE whiteness, C/2° (indoor illumination conditions)

1 Scope

This International Standard specifies the procedure to be used for determining the whiteness of papers and boards, in order to obtain values which correspond to the visual appearance of white papers and boards, with or without fluorescent whitening agents, when they are viewed indoors. It is based on radiance factor data obtained over the full visible spectral range (VIS) in contrast to the measurement of ISO brightness, which is limited to the blue region of VIS.

In addition, it specifies a method for adjustment of the UV-content to correspond to the CIE illuminant C [1] [2], since the results obtained when fluorescent whitening agents are present are dependent upon the UV-content of the radiation falling upon the sample. The CIE illumination C is taken to be representative of indoor illumination conditions because it contains a suitable proportion of UV-radiation [3] [4]. This method is not applicable to coloured papers containing fluorescent dyes. It is specific for the situation where the fluorescence occurs in the blue region of the visible spectral range.

This International Standard should be read in conjunction with ISO 2469.

NOTE 1 It is recognized that the CIE-whiteness equation was developed in the context of the CIE standard illuminant D65 [10], but the similarity between the relative spectral power curves for the C and D65 illuminants within the visible region and the closeness of their correlated colour temperatures (6 770 K and 6 500 K respectively) is taken as a justification for the use of the analogous whiteness equation with the CIE illuminant C.

NOTE 2 A related International Standard, ISO 11475 [13] specifies the procedure for obtaining values corresponding to the appearance of papers viewed under the CIE illuminant D65.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 186:1994, *Paper and board — Sampling to determine average quality.*

ISO 2469, *Paper, board and pulps — Measurement of diffuse reflectance factor.*

ISO 2470, *Paper, board and pulps — Measurement of diffuse blue reflectance factor (ISO brightness).*

3 Terms and definitions

For the purposes of this International Standard, the following terms and definitions apply.

3.1
reflectance factor
R
ratio of the radiation reflected by a body to that reflected by the perfect reflecting diffuser under the same conditions

NOTE The ratio is usually expressed as a percentage.

3.2
intrinsic reflectance factor
reflectivity
R_∞
reflectance factor of a layer or pad of the material thick enough to be opaque, i.e. such that increasing the thickness of the pad by doubling the number of sheets results in no change in the measured reflectance factor

3.3
radiance factor
β
ratio of the radiance of a body to that of the perfect reflecting diffuser under the same conditions of illumination and viewing

NOTE For fluorescent (luminescent) materials, the total radiance factor, β, is the sum of two portions, the reflected radiance factor, β_S, and the luminescent radiance factor, β_L, so that

$$\beta = \beta_S + \beta_L$$

For non-fluorescent materials, the reflected radiance factor, β_S is simply the reflectance factor, R.

3.4
intrinsic radiance factor
β_∞
radiance factor of a layer or pad of the material thick enough to be opaque, i.e. such that increasing the thickness of the pad by doubling the number of sheets results in no change in the measured radiance factor

NOTE For fluorescent (luminescent) materials, the intrinsic total radiance factor β_∞, is the sum of two portions, the intrinsic reflected radiance factor, $\beta_{\infty,S}$, and the intrinsic luminescent radiance factor, $\beta_{\infty,L}$, so that

$$\beta_\infty = \beta_{\infty,S} + \beta_{\infty,L}$$

For non-fluorescent materials, the intrinsic reflected radiance factor, $\beta_{\infty,S}$, is simply the intrinsic reflectance factor R_∞.

3.5
CIE whiteness
W
measure of whiteness derived from the CIE tristimulus values determined under the conditions specified in this International Standard, and expressed as whiteness units

3.6
green/red tint
T_W
measure of the deviation from whiteness of the test material towards the green or red region, and expressed as tint units

NOTE A positive value of T_W indicates a greenish tint and a negative value indicates a reddish tint.

3.7
fluorescence component
W_F
measure of the extent to which the whiteness of the material is affected by excitation of the added fluorescent whitening agent (FWA) under the conditions specified in this International Standard

4 Principle

The diffuse radiance factor of the material is determined under standardized conditions after adjustment of the instrument so that the relative UV-content of the illumination corresponds to that of the CIE illuminant C, and the CIE whiteness and tint are calculated. The fluorescence component of the whiteness is calculated from the difference between this diffuse-radiance-factor value and the value obtained when the fluorescence emission from the material is eliminated, for instance by the introduction into the light beams of a sharp cut-off UV-absorbing filter.

5 Apparatus and equipment

5.1 Reflectometer or **spectrophotometer,** having the geometric, spectral and photometric characteristics described in ISO 2469, calibrated in accordance with the provisions of ISO 2469, and equipped with a radiation source having an adequate UV-content and a means of adjusting the relative UV-content so that the measured ISO-brightness value agrees with the ISO-brightness value assigned to a fluorescent reference standard (5.2.2) and corresponding to the CIE illuminant C [2][5][6]. If a filter (the UV-adjustment filter) is used to make this adjustment, it shall have a cut-off value of 395 nm so that it absorbs UV-radiation but does not at the same time alter the visible spectrum within the sphere.

NOTE 1 In the 1994 edition of ISO 2469, the reflectometer characteristics are described in annex A and the calibration service is described in annex B. When ISO 2469 is revised, the numbering may change; users of editions subsequent to 1994 should therefore determine which elements of text specify these characteristics and this service.

NOTE 2 In order to achieve concordance between the conditions for measuring both ISO brightness and CIE whiteness (C/2°), an adjustment based on a reference standard having an assigned ISO-brightness value is preferred.

For the measurement of reflectance factors with the fluorescence effect eliminated, the instrument shall be equipped with a sharp-cut-off, UV-absorbing filter (the UV-cut-off filter) having a transmittance not exceeding 5,0 % at and below a wavelength of 410 nm and not exceeding 50 % at a wavelength of 420 nm. The cut-off filter shall have characteristics such that a reliable reflectance-factor value is obtained at 420 nm. The reflectance-factor value obtained at 420 nm shall then be considered for computational purposes to be the value, which applies at all lower wavelengths, at which it is not possible to make any measurement.

For the measurement of fluorescent papers, photometric linearity up to a scale reading of at least 200 % is necessary in the wavelength region corresponding to the fluorescent emission.

5.1.1 In the case of a filter reflectometer, pairs of filters giving the photoelectric detectors of the reflectometer responses equivalent to the CIE tristimulus values X, Y, Z of the test piece [7], evaluated for the CIE illuminant C [6] and CIE 1931 (2°) observer [8].

5.1.2 In the case of an abridged spectrophotometer, a means of calculating the weighted means according to the requirements of the CIE illuminant C and CIE 1931 (2°) observer using the weighting functions given in annex A.

5.2 Reference standards for calibration of the instrument and working standards

5.2.1 Non-fluorescent reference standard for calibration, fulfilling the requirements for ISO reference standards of level 3 as prescribed in ISO 2469.

5.2.2 Fluorescent reference standard for use in adjusting the UV-content of the radiation incident upon the sample, having an assigned ISO-brightness value as specified in annex B and fulfilling the requirements for ISO reference standards of level 3.

Use new reference standards sufficiently frequently to ensure satisfactory calibration and UV-adjustment.

5.3 Working standards

5.3.1 Two plates of flat opal glass or ceramic material, cleaned as described in ISO 2469.

5.3.2 A stable plastic or other tablet incorporating a fluorescent whitening agent.

5.4 Black cavity, having a reflectance factor which does not differ from its nominal value by more than 0,2 %, at all wavelengths. The black cavity should be stored upside down in a dust-free environment or with a protective cover.

NOTE The condition of the black cavity should be checked by reference to the instrument maker.

6 Calibration

6.1 Using the values assigned to the non-fluorescent reference standard (5.2.1), calibrate the instrument with the UV-cut-off filters removed from the radiation beams. The setting of the UV-adjustment filter is not important at this stage.

6.2 Using the appropriate measurement procedure, measure the reflectance of the fluorescent reference standard (5.2.2), determine the ISO-brightness value as described in ISO 2470 and compare the value obtained with that assigned to the fluorescent reference standard.

A measured ISO-brightness value higher than the assigned value indicates that the relative UV-content of the illumination is too high and a lower value indicates that the relative UV-content is too low.

6.3 Using the UV-adjustment filter or other adjustment device, adjust the UV-content of the illumination until measurement gives the correct ISO-brightness value.

6.4 Repeat the calibration as described in 6.1 using the non-fluorescent standard (5.2.1) with the UV-adjustment in the position which gave the correct ISO-brightness value for the fluorescent reference standard. Repeat the measurement of the brightness of the fluorescent standard (5.2.2) as described in 6.2. If the ISO-brightness value obtained does not agree with the assigned value, adjust the position of the UV-adjustment filter until measurement gives the correct ISO-brightness value as described in 6.3.

6.5 Repeat 6.4 until the correct value for the ISO brightness of the fluorescent standard is obtained with the instrument correctly calibrated to the non-fluorescent standard. The UV-content is now correctly adjusted with respect to brightness to a relative UV-content equivalent to the CIE illuminant C. Record the setting of the UV-adjustment.

NOTE 1 This setting means that the illumination in the instrument corresponds to the CIE illuminant C for ISO-brightness measurement and it will give acceptable agreement for CIE whiteness (C/2°). Variations in the green/red tint value may still arise and it cannot be assumed that the tristimulus values and other parameters will also be exactly those applicable to the illuminant C.

NOTE 2 In some instruments, the procedure indicated in subclauses 6.2 to 6.5 is performed automatically.

6.6 Calibrate the fluorescent tablet (5.3.2) as a working standard by measuring it and assigning an ISO-brightness value.

This working standard shall only be used in the specific instrument in which it is calibrated and shall only be used to monitor changes in the lamps and sphere conditions. It shall be recalibrated against a fluorescent reference standard of level 3 (5.2.2) if the lamps are changed.

6.7 Calibrate the opal glass or ceramic plates (5.3.1) as working standards as described in ISO 2469.

6.8 After adjustment of the UV-content as in 6.1 to 6.5, insert the UV-cut-off filter and calibrate the instrument in this position, using the non-fluorescent standard (5.2.1), with the UV-adjustment unchanged.

7 Sampling

Sampling is not included in this International Standard. If the mean quality of a lot is to be determined, sampling shall be in accordance with ISO 186. If the tests are made on another type of sample, make sure that the test pieces taken are representative of the sample received.

8 Preparation of test pieces

Avoiding watermarks, dirt and obvious defects, cut rectangular test pieces approximately 75 mm × 150 mm. Assemble at least ten of the test pieces in a pad with their top sides uppermost; the number should be such that doubling the number of test pieces does not alter the radiance factor. Protect the pad by placing an additional sheet on both top and bottom of the pad. Avoid contamination and unnecessary exposure to light or heat.

Mark the top test piece in one corner to identify the sample and its top side.

If the top side can be distinguished from the wire side, it shall be uppermost. If the distinction is not possible, as may be the case for papers manufactured on twin-wire machines or those coated on both sides, ensure that the same side of each test piece is uppermost so that the CIE whiteness can be determined separately for each side of the paper or board.

NOTE Pulp sheets made in accordance with ISO 3688 [9] may be measured in the same way, but whiteness is not normally considered to be a pulp property.

9 Procedure

9.1 Remove the UV-cut-off-filter from the light beam. Operate the reflectometer or spectrophotometer as described in ISO 2469.

9.2 Remove the protecting sheets from the pad of test pieces and measure the intrinsic total radiance factors of the top test piece.

9.3 Move the measured test piece to the bottom of the pad. Repeat 9.2 until 10 test pieces have been measured. Repeat on the reverse side of the paper or board.

9.4 If an assessment of the fluorescence component is required, place the UV-cut-off-filter in the light beam. Operating the reflectometer or spectrophotometer as described in ISO 2469, measure the intrinsic radiance factors of the top test piece without fluorescence excitation, i.e. the intrinsic reflected radiance factors.

9.5 Move the measured test piece to the bottom of the pad. Repeat 9.4 until 10 test pieces have been measured. Repeat on the reverse side of the paper or board.

NOTE Normally the CIE-whiteness and tint values will be automatically calculated for each test piece at the time of measurement. In some instruments, it may be more convenient to measure the whiteness with and without fluorescence excitation on each test piece before proceeding to the next test piece.

10 Calculation and expression of results

10.1 Calculate the whiteness, W, and tint, T, values for each test piece, according to the following equations:

$$W = Y + 800\,(x_n - x) + 1700\,(y_n - y) \qquad (1)$$

$$T = 1000\,(x_n - x) - 650\,(y_n - y) \qquad (2)$$

where

x and y are the chromaticity coordinates of the test piece, calculated as

$$x = \frac{X}{X + Y + Z}$$

$$y = \frac{Y}{X + Y + Z}$$

X, Y and Z are the tristímulus values of the test piece for C/2° conditions;

x_n and y_n are the chromaticity coordinates of the perfect reflecting diffuser for the illuminant and observer specified (x_n = 0,310 06, y_n = 0,316 15 for C/2°).

10.2 The limiting values for a sample to be considered white are given by

$$40 < W < (5Y - 280) \quad (3)$$

$$-3 < T_W < 3 \quad (4)$$

NOTE As stated in the scope, it is recognized that the CIE-whiteness equation was originally developed for the D65 illuminant, but it is here assumed that the use of the equation and its limits can be justified because of the similarity of the spectral power distributions of the C and D65 illuminants in the visible region.

10.3 Where relevant, calculate the whiteness without fluorescence excitation, W_0, i.e. with the UV-cut-off filter (see 5.1) in the light beam. Calculate the fluorescence component, W_F, of the CIE whiteness (C/2°) as the difference between the two whiteness values measured with and without fluorescence excitation.

$$W_F = W - W_0 \quad (5)$$

where

W is the whiteness determined when the illumination has the desired UV-content corresponding to the C illuminant;

W_0 is the whiteness determined when the radiation which excites fluorescence has been eliminated by a sharp cut-off UV-absorbing filter.

NOTE A cut-off filter which eliminates only the UV-component below 400 nm does not eliminate all the fluorescence effect.

10.4 Calculate the mean values and report the mean CIE whiteness (C/2°) separately for both sides to the nearest integer, and the tint value with one decimal. If either W or T_W falls outside the limits given in 10.2, report that the sample is "not white according to CIE". If W_0 falls outside the limits given in 10.2, it is not necessary to report this fact. Report the fluorescence component as the whiteness difference to the nearest integer.

11 Precision

Preliminary tests have shown a between-laboratory standard deviation of the order of ± 1 whiteness unit.

12 Test report

The test report shall include the following information:

a) date and place of testing;

b) precise identification of the sample;

c) a reference to this International Standard;

d) the CIE-whiteness value, the tint value and the fluorescence component of the whiteness for the two sides separately;

e) the type of apparatus used;

f) any departure from this International Standard or any other circumstances that may have affected the results.

Annex A
(normative)

Spectral characteristics of reflectometers for determining tristimulus values

A.1 Filter reflectometers

The required spectral characteristics of the reflectometer are arrived at by a combination of lamps, integrating sphere, glass optics, filters and photoelectric cells. The filters shall be such that they, together with the optical characteristics of the instrument, give overall responses equivalent to the CIE tristimulus values X, Y, Z of the CIE 1931 (2°) standard colorimetric system of the test piece evaluated for the CIE illuminant C.

A.2 Abridged spectrophotometers

The desired tristimulus values are obtained by summing the products of the spectral reflectance factors and the weighting functions given in ASTM E 308-95 [11] for the C illuminant and CIE 1931 (2°) observer.

Use Tables A.1 and A.2[1)], which have been prepared to apply a correction for spectral bandpass dependence built into the calculation of the tristimulus values, using data for which the bandpass is approximately equal to the measurement interval.

"Check sum" and "White point" data are given at the bottom of each column in Tables A.1 and A.2. The "check sum" is the algebraic sum of the entries. It provides, as a convenience, a check value to ensure that the tables have been copied correctly should copying be required. These check sums may not be identical to the "White point" data located below them because of roundoff. Each value in a column has been rounded to three decimal digits. It is these "White point" data, and no others, that must be used as X_n Y_n Z_n when converting tristimulus values calculated by use of these tables to CIELAB or CIELUV coordinates or for any other purpose requiring the ratio of the tristimulus value of the specimen to that of the "White point".

Apply the following instructions, given in ASTM E 308-95 [11], section 7.3.2.2, when the values are not available at the top or at the bottom of the range:

Wavelength range less than 360 nm to 780 nm. When data for $R(\lambda)$ are not available for the full wavelength range, add the weights at the wavelengths for which data are not available to the weights at the shortest or longest wavelength for which spectral data are available, i.e.:

a) add the weights for all wavelengths (360 nm, ...) for which measured data are not available to the next higher weight for which such data are available;

b) add the weights for all wavelengths (... 780 nm) for which measured data are not available to the next lower weight for which such data are available.

1) Tables taken from ASTM E 308-95 [11] (tables 6.5 and 6.6).

Table A.1 — Weighting functions for instruments measuring at 10 nm intervals

Wavelength nm	W_X	W_Y	W_Z
360	0,000	0,000	0,000
370	0,001	0,000	0,003
380	0,004	0,000	0,017
390	0,015	0,000	0,069
400	0,074	0,002	0,350
410	0,261	0,007	1,241
420	1,170	0,032	5,605
430	3,074	0,118	14,967
440	4,066	0,259	20,346
450	3,951	0,437	20,769
460	3,421	0,684	19,624
470	2,292	1,042	15,153
480	1,066	1,600	9,294
490	0,325	2,332	5,115
500	0,025	3,375	2,788
510	0,052	4,823	1,481
520	0,535	6,468	0,669
530	1,496	7,951	0,381
540	2,766	9,193	0,187
550	4,274	9,889	0,081
560	5,891	9,898	0,036
570	7,353	9,186	0,019
580	8,459	8,008	0,015
590	9,036	6,621	0,010
600	9,005	5,302	0,007
610	8,380	4,168	0,003
620	7,111	3,147	0,001
630	5,300	2,174	0,000
640	3,669	1,427	0,000
650	2,320	0,873	0,000
660	1,333	0,492	0,000
670	0,683	0,250	0,000
680	0,356	0,129	0,000
690	0,162	0,059	0,000
700	0,077	0,028	0,000
710	0,038	0,014	0,000
720	0,018	0,006	0,000
730	0,008	0,003	0,000
740	0,004	0,001	0,000
750	0,002	0,001	0,000
760	0,001	0,000	0,000
770	0,000	0,000	0,000
780	0,000	0,000	0,000
Check sum	**98,074**	**99,999**	**118,231**
White point	**98,074**	**100,000**	**118,232**

Table A.2 — Weighting functions for instruments measuring at 20 nm intervals

Wavelength nm	W_X	W_Y	W_Z
360	0,000	0,000	0,000
380	0,066	0,000	0,311
400	-0,164	0,001	-0,777
420	2,373	0,044	11,296
440	8,595	0,491	42,561
460	6,939	1,308	39,899
480	2,045	3,062	18,451
500	-0,217	6,596	4,728
520	0,881	12,925	1,341
540	5,406	18,650	0,319
560	11,842	20,143	0,059
580	17,169	16,095	0,028
600	18,383	10,537	0,013
620	14,348	6,211	0,002
640	7,148	2,743	0,000
660	2,484	0,911	0,000
680	0,600	0,218	0,000
700	0,136	0,049	0,000
720	0,031	0,011	0,000
740	0,006	0,002	0,000
760	0,002	0,001	0,000
780	0,000	0,000	0,000
Check sum	**98,073**	**99,998**	**118,231**
White point	**98,074**	**100,000**	**118,232**