
**Paper and board — Determination of
colour by diffuse reflectance —**

**Part 1:
Indoor daylight conditions (C/2°)**

*Papier et carton — Détermination de la couleur par réflectance
diffuse —*

Partie 1: Conditions d'éclairage intérieur de jour (C/2°)

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: 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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

The committee responsible for this document is ISO/TC 6, *Paper, board and pulps*.

This third edition cancels and replaces the second edition (ISO 5631-1:2015), of which it constitutes a minor revision. The changes are as follows:

- update of the CIE and joint ISO/CIE Normative and Bibliographic references to current versions.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The colour of an object can be uniquely characterized by means of a triplet of colour coordinates such as the CIE tristimulus values or the CIELAB 1976 L^* , a^* , b^* coordinates for a specified CIE illuminant and CIE standard observer.

Apart from the optical properties of the sample, the values of such coordinates depend upon the conditions of measurement, particularly the spectral and geometric characteristics of the instrument used. This document should therefore be read in conjunction with ISO 2469.

This document describes the measurement and description of colour in terms of the CIE illuminant C and the CIE 1931 (2°) standard observer. The other parts of the ISO 5631 series describe measurements and calculations carried out in an analogous manner using either the CIE standard illuminant D65 and the CIE 1964 (10°) standard observer or the CIE illuminant D50 and the CIE 1931 (2°) standard observer.

The choice of illuminant conditions is important when determining the colour coordinates of white papers containing a fluorescent whitening agent. In ISO 5631-2, the UV content of the illumination is much higher, approximating UV levels encountered in outdoor viewing conditions.

ISO 5631-3 describes the measurement and description of colour in terms of the CIE illuminant D50 and the CIE 1931 (2°) standard observer. This method is especially applicable to graphic arts situations since these illuminant/observer conditions are used within the graphic arts industry.

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Paper and board — Determination of colour by diffuse reflectance —

Part 1: Indoor daylight conditions (C/2°)

1 Scope

This document specifies a method for measuring the colour of paper and board by the diffuse reflectance method with the elimination of specular gloss.

This document is not applicable to coloured papers or boards which incorporate fluorescent dyes or pigments. It may be used to determine the colour of papers or boards which contain fluorescent whitening agents provided the UV content of the illumination on the test piece has been adjusted to conform to that in the CIE illuminant C, using a fluorescent reference standard that fulfils the requirements for international fluorescent reference standards of level 3 (IR3) as prescribed by ISO 2469 with an assigned ISO brightness value provided by an authorized laboratory, as described in ISO 2470-1.

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.

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

ISO 2469, *Paper, board and pulps — Measurement of diffuse radiance factor (diffuse reflectance factor)*

ISO 2470-1, *Paper, board and pulps — Measurement of diffuse blue reflectance factor — Part 1: Indoor daylight conditions (ISO brightness)*

ASTM E308, *Standard Practice for Computing the Colors of Objects by Using the CIE System*

CIE Publication 015:2018, *Colorimetry*, 4th ed.

3 Terms and definitions

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

**3.1
radiance factor**

β

ratio of the radiance of a surface element of a body in the direction delimited by a given cone, with its apex at the surface element, to that of the perfect reflecting diffuser under the same conditions of illumination

Note 1 to entry: For fluorescent (luminescent) materials, the total radiance factor, β , is the sum of two portions, the reflected radiance factor, β_R , and the luminescent radiance factor, β_L , so that $\beta = \beta_R + \beta_L$.

For non-fluorescent materials, the reflected radiance factor, β_R , is numerically equal to the reflectance factor, R .

**3.2
intrinsic radiance factor**

β_∞

radiance factor (3.1) of a layer or pad of material thick enough to be opaque, such that increasing the thickness of the pad by doubling the number of sheets results in no change in the measured radiance factor

Note 1 to entry: The intrinsic radiance factor is often expressed as a percentage.

**3.3
reflectance factor**

R

ratio of the radiation reflected by a surface element of a body in the direction delimited by a given cone, with its apex at the surface element to that of the perfect reflecting diffuser under the same conditions of illumination

Note 1 to entry: The ratio is often expressed as a percentage.

Note 2 to entry: The reflectance factor is influenced by the backing if the body is translucent.

**3.4
intrinsic reflectance factor**

R_∞

reflectance factor (3.3) of a layer or pad of material thick enough to be opaque, such that increasing the thickness of the pad by doubling the number of sheets results in no change in the measured reflectance factor

Note 1 to entry: The reflectance factor of a non-opaque sheet is dependent on the background and is not a material property.

**3.5
tristimulus values**

X, Y, Z

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

Note 1 to entry: In this document, the CIE illuminant C and the CIE 1931 (2°) standard observer are used to define the trichromatic system.

Note 2 to entry: No subscript is applied to conform to the CIE convention that tristimulus values have no subscript when the CIE 1931 (2°) standard observer is used [the subscript 10 is applied for tristimulus values that are obtained using the CIE 1964 (10°) standard observer].

3.6

CIELAB colour space

three-dimensional, approximately uniform colour space, produced by plotting, in rectangular coordinates L^* , a^* , b^* , quantities defined by the formulae given in [Clause 9](#)

Note 1 to entry: The quantity, L^* , is a measure of the lightness of the test piece, where $L^* = 0$ corresponds to black and $L^* = 100$ is defined by the perfect reflecting diffuser. Visually, the quantities a^* and b^* represent respectively the red-green and yellow-blue axes in colour space, such that

- + a^* is a measure of the degree of redness of the test piece,
- a^* is a measure of the degree of greenness of the test piece,
- + b^* is a measure of the degree of yellowness of the test piece, and
- b^* is a measure of the degree of blueness of the test piece.

If both a^* and b^* are equal to zero, the test piece is achromatic.

4 Principle

The light reflected from a sample under specified conditions is analysed either by a tristimulus-filter colorimeter or by an abridged spectrophotometer, and the colour coordinates are then calculated for $C/2^\circ$ conditions.

5 Apparatus

5.1 Reflectometer

5.1.1 Reflectometer, having the geometric, spectral and photometric characteristics described in ISO 2469, and calibrated in accordance with the provisions of ISO 2469.

If materials containing fluorescent whitening agents are to be measured, the reflectometer shall be equipped with a radiation source having an adequate UV content control, adjusted to a UV condition corresponding to the C illuminant by the use of a reference standard, as described in ISO 2470-1.

5.1.2 In the case of a filter reflectometer, a set of filters that, in conjunction with the optical characteristics of the basic instrument, give overall responses equivalent to the CIE tristimulus values X, Y and Z of the CIE 1931 standard colorimetric system of the test piece evaluated for the CIE illuminant C.

In the case of a filter reflectometer, the radiation falling upon the test piece shall have a UV content corresponding to that of the CIE illuminant C.

5.1.3 In the case of an abridged spectrophotometer, the instrument shall have a function that permits calculation of the CIE tristimulus values X, Y and Z of the CIE 1931 standard colorimetric system of the test piece evaluated for the CIE illuminant C using the weighting functions given in [Annex A](#) where the [Tables A.1](#) and [A.2](#) are used for instruments without bandpass correction and [Tables A.3](#) and [A.4](#) are used for instruments with bandpass correction.

In the case of an abridged spectrophotometer, the instrument shall have an adjustable filter with a cut-off wavelength of 395 nm or some other equivalent system, and this filter shall be adjusted or the system shall be calibrated with the help of the fluorescent reference standard ([5.2.2](#)), so that the UV content of the illumination falling upon the sample corresponds to that of the CIE illuminant C.

5.2 Reference standards

Reference standards, for calibration of the instrument and the working standards, and used frequently enough to ensure satisfactory calibration and UV adjustment.

5.2.1 Non-fluorescent reference standard, for photometric calibration, issued by an authorized laboratory in accordance with the provisions of ISO 2469.

5.2.2 Fluorescent reference standard, for use in adjusting the UV content of the radiation incident upon the sample, having an ISO brightness value assigned by an authorized laboratory, as prescribed in ISO 2470-1.

5.3 Working standards

Working standards, calibrated frequently enough to ensure that satisfactory calibration is maintained.

5.3.1 Two plates of flat opal glass, made of ceramic or other suitable material, cleaned and calibrated as described in ISO 2469.

NOTE In some instruments, the function of the primary working standard can be taken over by a built-in internal standard.

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 1 The reflectance level of the black cavity can be checked by reference to the instrument manufacturer.

NOTE 2 The nominal value is given by the manufacturer.

6 Sampling and conditioning

If the tests are being made to evaluate a lot of paper or board, the sample shall be selected 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.

Conditioning according to ISO 187 is recommended but not required but preconditioning with elevated temperatures should not be applied since it might change the optical properties.

7 Preparation of test pieces

Avoiding watermarks, dirt and obvious defects, cut rectangular test pieces approximately 75 mm × 150 mm. Assemble at least 10 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 of paper or board on both the 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, or to distinguish between the two sides.

If the top side can be distinguished from the wire side, it shall be uppermost; if not, as may be the case for papers manufactured on twin-wire machines, ensure that the same side of the sheet is uppermost.

8 Procedure

8.1 Ensure that calibration has been performed as described in ISO 2470-1 according to the instrument manufacturer's instructions.

8.2 Remove the protective sheets from the top and the bottom of the test piece pad. Without touching the test area, use the procedure appropriate to the instrument to obtain the three CIE tristimulus values of the first test piece (or CIELAB values if the instrument is designed to report directly in this colour space). Read and record the tristimulus values to the nearest 0,01 unit.

8.3 Move the uppermost test piece to the bottom of the pad and determine the values for succeeding test pieces until at least 10 test pieces have been evaluated. If required, repeat the procedure for the other side of the test pieces.

9 Calculation

9.1 CIE tristimulus values

If the instrument has a bandpass of 5 nm or narrower, calculate the CIE tristimulus values in accordance with CIE Publication 015:2018, 4th ed. In all other cases, calculate the tristimulus values using the appropriate weighting functions given in ASTM E308. If the instrument does not provide the CIE tristimulus values directly, obtain them by calculation using the tables provided in [Annex A](#).

9.2 CIELAB coordinates

Calculate the CIELAB coordinates from the tristimulus values X , Y , Z , by means of [Formulae \(1\)](#), [\(2\)](#) and [\(3\)](#):

$$L^* = 116(Y/Y_n)^{1/3} - 16 \quad (1)$$

$$a^* = 500 \left[(X/X_n)^{1/3} - (Y/Y_n)^{1/3} \right] \quad (2)$$

$$b^* = 200 \left[(Y/Y_n)^{1/3} - (Z/Z_n)^{1/3} \right] \quad (3)$$

where X_n , Y_n , Z_n are the tristimulus values of the perfect reflecting diffuser under C/2° conditions. These are given as the "white point" values in [Annex A](#).

Alternative equations shall, however, be used if any of the ratios X/X_n , Y/Y_n , $Z/Z_n \leq (24/116)^3$ are satisfied as follows.

- If $(X/X_n) \leq (24/116)^3$, replace the term $(X/X_n)^{1/3}$ in [Formula \(2\)](#) by the expression $(841/108) (X/X_n) + 16/116$.
- If $(Y/Y_n) \leq (24/116)^3$, replace the term $(Y/Y_n)^{1/3}$ in [Formulae \(1\)](#), [\(2\)](#) and [\(3\)](#) by the expression $(841/108) (Y/Y_n) + 16/116$.
- If $(Z/Z_n) \leq (24/116)^3$, replace the term $(Z/Z_n)^{1/3}$ in [Formula \(3\)](#) by the expression $(841/108) (Z/Z_n) + 16/116$.

NOTE 1 The term $(24/116)^3$ is approximately equal to 0,008 856.

NOTE 2 The term $(841/108)$ is approximately equal to 7,787.

NOTE 3 [Formula \(1\)](#) transforms to $L^* = 903,3(Y/Y_n)$ when $(Y/Y_n) \leq (24/116)^3$.

9.3 Dispersion of the results

Since the three-dimensional statistical calculations are extremely complicated, the following simple procedure for assessing the dispersion is recommended.

Calculate the mean values $\langle L^* \rangle$, $\langle a^* \rangle$ and $\langle b^* \rangle$ of the L^* , a^* and b^* values.

Calculate, for each test piece, the deviation ΔE_{ab}^* from the mean according to [Formula \(4\)](#):

$$\Delta E_{ab}^* = \sqrt{[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]} \quad (4)$$

where ΔL^* , Δa^* and Δb^* are the differences between the L^* , a^* and b^* values of the test piece and the corresponding mean values $\langle L^* \rangle$, $\langle a^* \rangle$, $\langle b^* \rangle$.

Calculate the mean $\langle \Delta E_{ab}^* \rangle$ value. This is known as the Mean Colour Difference from the Mean (MCDM) value and defines the dispersion in terms of a sphere of radius $\langle \Delta E_{ab}^* \rangle$ about the mean point in CIELAB space.

NOTE This calculation uses the expression for the colour difference between two samples which can be calculated in these coordinates as:

$$\Delta E_{ab}^* = \sqrt{[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]} \quad (5)$$

where ΔL^* , Δa^* and Δb^* are the differences between the L^* , a^* and b^* values of the two samples.

The calculation of colour differences is not, however, included in this document.

10 Expression of results

Report the L^* , a^* and b^* values to three significant figures and the dispersion as the MCDM value to two significant figures.

NOTE Information about the nature of the variations can be obtained by calculating the mean ΔL^* , Δa^* and Δb^* as defined in [Formula \(4\)](#), but this is not included in this document.

11 Precision

Information relating to the precision of the method is not yet available. It should be noted, however, that, when white or near white samples containing a fluorescent whitening agent are measured, the reproducibility between instruments will be reduced, since the adjustment of the UV content to match that of the CIE illuminant C is limited to a single-point adjustment based on the ISO brightness value of a fluorescent reference standard.

12 Test report

The test report shall include the following information:

- a) a reference to this document, i.e. ISO 5631-1;
- b) the date and place of testing;
- c) the precise identification of the sample and the side or sides tested;
- d) whether the test pieces were conditioned and, if so, the conditioning atmosphere used;
- e) the average colour coordinates and the mean colour difference from the mean (see [9.3](#)) for the required side(s) of the sample;

- f) the type of instrument used;
- g) any departure from this document which may have affected the results.

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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 photodetectors. 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 for the test piece evaluated for the CIE illuminant C.

A.2 Abridged spectrophotometers

A.2.1 General

The desired tristimulus values are obtained by summing the products of the spectral reflectance factors and the weighting functions given in ASTM E308¹⁾ for the C illuminant and CIE 1931 (2°) observer.

“Checksum” and “white point” data are given at the bottom of each column in [Tables A.1, A.2, A.3](#) and [A.4](#). The “checksum” is the algebraic sum of the entries. It provides, for convenience, a check value to ensure that the tables have been copied correctly, should copying be required. These checksums may not be identical with 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 other, that shall 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 E308, 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 $\beta(\lambda)$ 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.

In the absence of fluorescence, the spectral radiance factor can be replaced by, or referred to as, the spectral reflectance factor, $R(\lambda)$.

A.2.2 Procedure for using data without bandpass correction

Use [Tables A.1](#) and [A.2](#) when the spectral data have not been corrected for bandpass dependence and for which the bandpass is approximately equal to the measurement interval; [Table A.1](#) is to be used

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when the data have been obtained at 10 nm measurement intervals; [Table A.2](#) is to be used when the data have been obtained at 20 nm measurement intervals. [Tables A.1](#) and [A.2](#) apply a correction for spectral bandpass dependence built into the calculation of the tristimulus values.

A.2.3 Procedure for using data with bandpass correction

Use [Tables A.3](#) and [A.4](#) when the spectral data have been already corrected for bandpass dependence (e.g. by the instrument manufacturer) and for which the bandpass is approximately equal to the measurement interval; [Table A.3](#) is to be used when the data have been obtained at 10 nm measurement intervals; [Table A.4](#) is to be used when the data have been obtained at 20 nm measurement intervals.

NOTE 1 [Tables A.3](#) and [A.4](#) were added to this document to allow for calculation using instrumentation that does not require bandpass correction, i.e. has already been built into the instrument and applied to the reported raw data.

NOTE 2 Raw reflectance data will differ from instruments, depending upon whether or not they have built-in bandpass correction. However, after the appropriate weighting table is used, the resulting colorimetric values will be nearly identical.

Table A.1 — Weighting functions (C/2°) for instruments without bandpass correction and measuring at 10 nm intervals (Source: ASTM E308)

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

Table A.1 (continued)

Wavelength nm	W_X	W_Y	W_Z
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 (C/2°) for instruments without bandpass correction and measuring at 20 nm intervals (Source: ASTM E308)

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