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

Part 3:

Indoor illumination conditions (D50/2°)

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

Partie 3: Conditions d'éclairage intérieur (D50/2°)

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Published in Switzerland

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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 2.

The main task of technical committees is to prepare International Standards. 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 document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 5631-3 was prepared by Technical Committee ISO/TC 6, *Paper, board and pulps*.

ISO 5631 consists of the following parts, under the general title *Paper and board — Determination of colour by diffuse reflectance*:

- *Part 1: Indoor daylight conditions (C/2°)*
- *Part 2: Outdoor daylight conditions (D65/10°)*
- *Part 3: Indoor illumination conditions (D50/2°)*

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.

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 part of ISO 5631 should therefore be read in conjunction with ISO 2469.

This part of ISO 5631 describes the measurement and description of colour in terms of the CIE illuminant D50 and the CIE 1931 (2°) standard observer. The method is especially applicable to graphic arts situations since these illuminant/observer conditions are used within the graphic arts industry. It is, however, emphasized that this is only a partial approach to the graphic arts conditions, since ISO 13655 also specifies measurement with a 45:0 or 0:45 geometry of a single sheet over a specified black backing. It is intended particularly for use in situations where papers are to be compared in a light booth adjusted to match the CIE illuminant D50.

The other parts of this International Standard describe measurements and calculations carried out in an analogous manner using either the CIE illuminant C and the CIE 1931 (2°) standard observer (ISO 5631-1) or the CIE standard illuminant D65 and the CIE 1964 (10°) standard observer (ISO 5631-2). 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.

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Paper and board — Determination of colour by diffuse reflectance —

Part 3: Indoor illumination conditions (D50/2°)

1 Scope

This part of ISO 5631 specifies a method for measuring the colour of paper and board by the diffuse reflectance method with the elimination of specular gloss.

This part of ISO 5631 is primarily intended for measuring the colour of paper and board to be used in the graphic arts industry where that industry specifies the measurement of colour under D50/2° conditions in accordance with ISO 13655.

The method may be used to determine the colour of papers or boards that 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 provided by an authorized laboratory, as described in ISO 2470-1.

This part of ISO 5631 is not applicable to coloured papers or boards that incorporate fluorescent dyes or pigments.

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 2469, *Paper, board and pulps — Measurement of diffuse radiance factor*

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

CIE Publication 15:2004, *Colorimetry*, 3rd ed.

ASTM E 308-06, *Standard Practice for Computing the Colors of Objects by Using the CIE System*

3 Terms and definitions

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

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 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 numerically equal to the reflectance factor, R .

**3.2
intrinsic radiance factor**

R_∞
radiance factor 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 The ratio 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 The ratio is often expressed as a percentage.

NOTE 2 The reflectance factor is influenced by the backing if the body is translucent.

**3.4
intrinsic reflectance factor**

R_∞
reflectance factor 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 The reflectance factor of a non-opaque sheet is dependent on the background and is not a material property.

**3.5
tristimulus values**

X_2, Y_2, Z_2
amounts of the three reference colour stimuli, in a given chromatic system, required to match the stimulus considered

NOTE 1 In this part of ISO 5631, the CIE illuminant D50 and the CIE 1931 standard observer are used to define the trichromatic system.

NOTE 2 The subscript 2 is applied to conform to the CIE convention that tristimulus values have the subscript 2 when the CIE 1931 (2°) standard observer is used.

**3.6
CIELAB colour space**

three-dimensional, approximately uniform colour space, produced by plotting, in rectangular coordinates L^*, a^*, b^* , quantities defined by the equations given in Clause 9

NOTE 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,
- 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 grey.

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 D50/2° 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 D50.

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 D50, using the weighting functions given in Annex A.

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, 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 ISO/TC 6 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 ISO/TC 6 authorized laboratory, as prescribed in ISO 2470-1.

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

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

NOTE In some instruments, the function of the primary working standard may 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 condition of the black cavity can be checked by reference to the instrument maker.

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 should 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, though 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 reflectance 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 maker'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 subsequent 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 15:2004, 3rd ed. In all other cases, calculate the tristimulus values using the appropriate weighting functions given in ASTM E 308-06. 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_2 , Y_2 , Z_2 by means of the following equations:

$$L^* = 116(Y_2/Y_{2,n})^{1/3} - 16 \quad (1)$$

$$a^* = 500 \left[(X_2/X_{2,n})^{1/3} - (Y_2/Y_{2,n})^{1/3} \right] \quad (2)$$

$$b^* = 200 \left[(Y_2/Y_{2,n})^{1/3} - (Z_2/Z_{2,n})^{1/3} \right] \quad (3)$$

where $X_{2,n}$, $Y_{2,n}$, $Z_{2,n}$ are the tristimulus values of the perfect reflecting diffuser under D50/2° conditions. These are given as the “white point” values in Annex A.

Alternative equations shall however be used if any of the ratios $X_2/X_{2,n}$, $Y_2/Y_{2,n}$, $Z_2/Z_{2,n} \leq (24/116)^3$ are satisfied as follows:

- If $(X_2/X_{2,n}) \leq (24/116)^3$, replace the term $(X_2/X_{2,n})^{1/3}$ in Equation (2) by the expression $(841/108) (X_2/X_{2,n}) + 16/116$.
- If $(Y_2/Y_{2,n}) \leq (24/116)^3$, replace the term $(Y_2/Y_{2,n})^{1/3}$ in Equations (1), (2) and (3) by the expression $(841/108) (Y_2/Y_{2,n}) + 16/116$.
- If $(Z_2/Z_{2,n}) \leq (24/116)^3$, replace the term $(Z_2/Z_{2,n})^{1/3}$ in Equation (3) by the expression $(841/108) (Z_2/Z_{2,n}) + 16/116$.

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 Equation (1) transforms to $L^* = 903,3(Y_2/Y_{2,n})$ when $(Y_2/Y_{2,n}) \leq (24/116)^3$.

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 the following equation:

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

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

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 may 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, however, not covered by this part of ISO 5631.

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 Equation (4), but this is not covered by this part of ISO 5631.

11 Precision

Information relating to the precision of the method is not yet available.

12 Test report

The test report shall include the following information:

- a) a reference to this part of ISO 5631;
- 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 part of ISO 5631 which may have affected the results.

Annex A (normative)

Calculation of tristimulus values

The desired tristimulus values are obtained by summing the products of the spectral reflectance factors and the weighting factors (see Tables A.1 and A.2) given as tables 6.9 and 6.10 in ASTM E 308-06¹⁾ for the CIE 1931 (2°) Standard Observer and the CIE illuminant D50.

ASTM E 308-06 presents two sets of tables. The tables given in this Annex are the tables which should normally be used. They 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.

The figure labelled “check sum” at the bottom of each column of the tables given in this Annex 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 are not identical to the “white point” data located below them in most cases because of roundoff. These “white point” data shall be used as $X_{2,n}$, $Y_{2,n}$, $Z_{2,n}$ when converting tristimulus values, calculated using these tables, to CIELAB coordinates.

The following instructions, given in ASTM E 308-06, section 7.3.2.2, should be applied when the values are not available at the top or at the bottom of the range.

When data for $\beta(\lambda)$ are not available for the full wavelength range from 360 nm to 780 nm, 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 may be replaced by, or referred to as, the spectral reflectance factor, $R(\lambda)$.

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Table A.1 — Weighting factors, W , for instruments measuring at 10 nm intervals

Wavelength nm	$W_{2,X}$	$W_{2,Y}$	$W_{2,Z}$
360	0,000	0,000	0,000
370	0,001	0,000	0,005
380	0,003	0,000	0,014
390	0,008	0,000	0,039
400	0,058	0,002	0,277
410	0,191	0,005	0,906
420	0,751	0,021	3,603
430	1,592	0,060	7,747
440	2,519	0,158	12,593
450	2,824	0,310	14,834
460	2,556	0,511	14,659
470	1,717	0,776	11,344
480	0,832	1,246	7,240
490	0,250	1,783	3,934
500	0,025	2,892	2,447
510	0,047	4,610	1,432
520	0,538	6,586	0,688
530	1,590	8,435	0,403
540	2,770	9,185	0,186
550	4,210	9,733	0,080
560	5,662	9,503	0,035
570	7,092	8,882	0,019
580	8,681	8,225	0,016
590	9,175	6,728	0,010
600	9,966	5,884	0,008
610	9,556	4,752	0,003
620	8,099	3,584	0,002
630	5,835	2,392	0,000
640	4,199	1,633	0,000
650	2,539	0,954	0,000
660	1,517	0,560	0,000
670	0,831	0,304	0,000
680	0,423	0,153	0,000
690	0,178	0,064	0,000
700	0,096	0,035	0,000
710	0,049	0,018	0,000
720	0,020	0,007	0,000
730	0,012	0,004	0,000
740	0,006	0,002	0,000
750	0,002	0,001	0,000
760	0,001	0,000	0,000
770	0,001	0,000	0,000
780	0,000	0,000	0,000
Check sum	96,422	99,998	82,524
White point	96,422	100,000	82,521