International Standard

ISO 2469

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

Papier, carton et pâtes — Mesurage du facteur de luminance énergétique diffuse (facteur de réflectance diffuse)

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Foreword

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This document was prepared by Technical Committee ISO/TC 6, *Paper, board and pulps*.

This sixth edition cancels and replaces the fifth edition (ISO 2469:2014), which has been technically revised.

The main changes are as follows:

— introduction of the method for calibrating to the CIE illuminant C and to the CIE standard illuminant D65, in addition to the procedure for calibration of the non-fluorescent part of the spectrum;

— addition of limit values for brightness and whiteness to check the performance of the calibration (as it is reported for non-fluorescence calibration);

— addition of effective residual ink concentration (ERIC number) to the list of optical properties based on reflectance and radiance measurements in the introduction;

— update of Annex C in order to reflect the revised version of ISO 4094;

— update of bibliography;

— editorial revision.

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.

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Introduction

The radiance factor depends on the conditions of measurement, particularly the spectral and geometric characteristics of the instrument used. The diffuse radiance factor as defined by this document is determined using instruments having the characteristics given in Annex A and calibrated with standards delivered in the framework of the organisation described in Annex B.

The diffuse radiance factor is the sum of the reflected radiance factor and the luminescent radiance factor, and the luminescent radiance factor of a luminescent (fluorescent) object is dependent on the spectral power distribution of the illumination. If adequately accurate measurements are carried out on fluorescent objects, the UV-content of the instrument illumination is adjusted to produce the same amount of fluorescence for a fluorescent reference standard as the selected CIE illuminant. The preparation of fluorescent reference standards to enable this adjustment to be made is described in Annex C. The use of these fluorescent reference standards is described in detail in the International Standards describing the measurement of the properties of the materials containing fluorescent whitening agents.

The spectral diffuse radiance factor or the weighted diffuse radiance factor applicable to one or several specified wavelength bands is often used to characterize the properties of pulp, paper and board. Examples of diffuse radiance factors associated with specified wavelength bands are the ISO brightness (diffuse blue radiance factor) and the luminance factor.

The diffuse radiance factor or diffuse reflectance factor is also used as the basis for calculating optical properties, such as opacity, colour, whiteness, effective residual ink concentration (ERIC number) and the Kubelka-Munk scattering and absorption coefficients. These various properties are described in detail in specific International Standards.

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

1 Scope

This document describes the general procedure for measuring the diffuse radiance factor of all types of pulp, paper and board. More particularly, it specifies in detail the procedures to be used for calibrating the equipment, and in Annex A, the characteristics of the equipment to be used for such measurements.

This document can be used to measure the diffuse radiance factors and related properties of materials containing fluorescent whitening agents, provided that the UV-content of the instrument illumination has been adjusted to give the same level of fluorescence as a fluorescent reference standard for a selected CIE illuminant, according to the International Standard describing the measurement of the property in question.

Annex C describes the preparation of fluorescent reference standards.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 4094, *Paper, board and pulps — General requirements for the competence of laboratories authorized for the issue of optical reference transfer standards of level 3*

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 luminescent (fluorescent) 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, defined in 3.3.

Note 2 to entry: The radiance is expressed in $W \cdot m^{-2} \cdot sr^{-1}$.

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3.2
diffuse radiance factor
ratio of the radiation reflected and emitted from a body to that reflected from the perfect reflecting diffuser under the same conditions of diffuse illumination and normal detection

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

Note 2 to entry: This document prescribes diffuse illumination and normal detection in an instrument constructed and calibrated in accordance with the provisions of this document. The term “diffuse radiance factor” is used here both for bidirectional and sphere geometries.

3.3
reflectance factor
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 reflected by 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: This term may be used only when it is known that the test material exhibits no luminescence (fluorescence).

Note 3 to entry: In this document, it has been considered advisable to introduce the term radiance factor rather than reflectance factor into the title, because the increasing use of fluorescent whitening agents in papermaking means that the measurement is seldom limited to reflectance. From a single measurement the instrument cannot distinguish between the two factors.

3.4
diffuse reflectance factor
R
ratio of the reflection from a body to that from the perfect reflecting diffuser under the same conditions of diffuse illumination and normal detection

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

Note 2 to entry: This document specifies diffuse illumination and normal detection in an instrument constructed and calibrated in accordance with the provisions of this document.

3.5
international reference standard level 1
IR1
primary optical reference standard, the perfect reflecting diffuser, the ideal diffuser exhibiting isotropic diffuse reflection with a reflectance equal to 1, used for calibration of optical transfer standards

Note 1 to entry: Reflectance is defined as the ratio of the reflected to the incident radiation.

[SOURCE: ISO 4094:2017, 3.4]

3.6
international reference standard level 2
IR2
secondary optical reference transfer standard for the certification of level 3 *(IR3)* (3.7) standards or for the calibration of instruments, consisting of a material certified against an *international reference standard of level 1* (3.5) by a standardizing laboratory, as specified in the relevant International Standard

Note 1 to entry: This document refers to two types of IR2: a non-fluorescent IR2, whose spectral reflectance factors have been determined by a standardizing Laboratory in relation to the IR1; and a fluorescent IR2, whose total spectral radiance factors corresponding to a specified CIE illuminant have been determined by a standardizing laboratory. A non-fluorescent IR2 is used to calibrate the photometric scale of an authorized laboratory’s reference instrument, and a fluorescent IR2 standard is used to adjust the UV level of an authorized laboratory’s reference instrument.

[SOURCE: ISO 4094:2017, 3.5]

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3.7
international reference standard level 3
IR3
tertiary optical reference transfer standard consisting of a material certified against an *international reference standard of level 2* (3.6) by an authorized laboratory, as specified in the relevant International Standard, and used by a testing laboratory for the calibration of instruments

Note 1 to entry: This document refers to two types of IR3: a non-fluorescent IR3, whose spectral reflectance factors have been determined by an authorized laboratory in relation to the non-fluorescent IR2; and a fluorescent IR3, whose calibration values have been determined by an authorized laboratory in relation to the fluorescent IR2. A non-fluorescent IR3 is used to calibrate the photometric scale of a testing laboratory's instrument. A testing laboratory uses a fluorescent IR3 to adjust the UV level of the testing laboratory's instrument.

[SOURCE: ISO 4094:2017, 3.6]

3.8
working standard
physical standard whose radiance (reflectance) factors have been determined by calibration with a suitable international reference standard (IR3) for subsequent use on a single instrument that conforms to specific requirements

Note 1 to entry: The specific requirements are given in this document.

3.9
primary working standard
working standard that is used routinely to validate and check a given measuring instrument for its intended use

Note 1 to entry: The assigned radiance (reflectance) factors of the primary working standard may not be transferred to a different instrument, even of the same type (see 3.8). However, it is possible to use a primary working standard for validation purposes only on instruments of the same type.

3.10
control plate
secondary working standard
working standard that is used on an infrequent basis to monitor and validate the performance of a given primary working standard

Note 1 to entry: When one or more control plates give anomalous results on a given instrument, it can be necessary to re-calibrate the primary working standard used with that instrument with an appropriate international reference standard (IR3).

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4 Principle

A test piece is irradiated diffusely in a standard instrument and the light reflected (and emitted as a result of fluorescence) in a direction normal to the surface is passed to a detection system. This detection system may consist either of a defined optical filter and photodetector or of an array of photodetectors where each detector responds to a specific effective wavelength. The desired radiance factors are determined directly from the output from the photodetector in the former case or by calculation from the detector array outputs using appropriate weighting functions in the latter case.

5 Apparatus

5.1 Reflectometer

Reflectometer having the geometric, spectral and photometric characteristics in accordance with Annex A.

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5.2 Reference standards

For photometric calibration of the instrument and its working standards, use a non-fluorescent reference standard issued by an authorized laboratory (AL), as defined in Annex B, and fulfilling the requirements for an IR3, in accordance with Annex B.

Use reference standards sufficiently frequently to ensure satisfactory calibration.

NOTE If fluorescent materials are measured, a fluorescent reference standard issued by an authorized laboratory is needed to enable the UV-content of the instrument illumination to be adjusted to produce the same amount of fluorescence as the selected CIE illuminant. This UV adjustment procedure is described in detail in Annex C. The use of these fluorescent reference standards is described in the International Standards for the determination of specific optical properties.

5.3 Working standards

For measurements on non-fluorescent materials, two working standards of opal glass, ceramic or other suitable material with flat surfaces.

NOTE In some instruments, the function of the primary working standard (see 6.4) can be fulfilled by a built-in internal standard.

For measurements on white fluorescent materials, stable fluorescent working standards of plastic or other material incorporating a fluorescent whitening agent are required. These working standards are described in the relevant International Standards.

5.4 Black cavity

For calibration or validation of the low end of the photometric scale. This black cavity shall have a radiance factor which does not differ from its nominal value by more than 0,2 percentage points at all wavelengths. The black cavity shall be stored upside-down in a dust-free environment or with a protective cover. During calibration, the instrument shall be adjusted to the nominal value of the black cavity.

It is not yet possible to institute a system of reference standards to enable testing laboratories to check the reflectance factor of the black cavity. At the time of delivery, the level should be guaranteed by the instrument maker. Questions concerning the use and condition of the black cavity should be resolved by contacting the instrument maker.

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6 Calibration of the instrument and its working standards

6.1 General

Handle each IR3 carefully and protect the test area from contamination. Store it in darkness when not in use. It is recommended to store IR3s in temperature conditions not exceeding 24 °C, and preferably below 10 °C for long term storage in airtight packages.

Before use, condition the unopened packages in the laboratory atmosphere to reach temperature equilibrium. Then, unpack and condition the IR3s in the laboratory atmosphere.

6.2 Photometric calibration of the instrument and UV setting

6.2.1 Step 1

Using the procedure appropriate to the instrument, calibrate the photometric scale of the instrument with a non-fluorescent IR3. Using the values assigned to the non-fluorescent reference standard (5.2), 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.

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6.2.2 Step 2

When the measurements are made on fluorescent materials, carry out also a UV-calibration with a fluorescent IR3. Using the appropriate measurement procedure, measure the diffuse radiance factors of the fluorescent IR3, calculate the brightness/whiteness value and compare the value obtained with that assigned to the fluorescent reference standard.

NOTE Brightness measurement is used to perform UV C setting and whiteness measurement for UV D65 setting.

A measured brightness/whiteness value higher than the assigned value indicates that the relative UV-content is too high and vice versa.

6.2.3 Step 3

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

NOTE If the UV-content is too low, it can be necessary to replace the UV-adjustment filter with a filter which raises rather than lowers the relative UV-content.

6.2.4 Step 4

Repeat the calibration as described in 6.2.1 using the non-fluorescent IR3 with the UV-adjustment filter in the position which gave the correct brightness/whiteness value. Repeat the measurement of the brightness/whiteness of the fluorescent IR3 as described in 6.2.2. If the brightness whiteness value obtained does not agree with the assigned value, adjust the position of the UV-adjustment filter until measurement gives the correct brightness/whiteness value as described in 6.2.3.

6.2.5 Step 5

Repeat 6.2.4 until the correct value for the brightness/whiteness of the fluorescent reference standard is obtained with the instrument correctly calibrated to the non-fluorescent IR3. The deviation between the measured and the assigned brightness of the non-fluorescent IR3 used for the primary calibration shall not exceed 0,05. The deviation between the measured and the assigned ISO brightness of the fluorescent IR3 used for the primary calibration shall not exceed 0,3. The deviation between the measured and the assigned CIE whiteness of the fluorescent IR3 used for the primary calibration shall not exceed 0,5. The relative UV-content is now correctly adjusted with respect to brightness so that the setting gives the ISO brightness value equivalent to the CIE illuminant C and CIE 1931 (2°) observer, and to whiteness so that the setting gives the CIE whiteness value equivalent to the CIE standard illuminant D65 and CIE 1964 (10°) observer. Record the settings of the UV-adjustments.

NOTE 1 Variations in the green/red tint value can still arise and it cannot be assumed that the tristimulus values and other parameters will also be exactly applicable to the D65 illuminant.

NOTE 2 In most instruments available on the market at the time of publication, the procedure indicated in 6.2.2 to 6.2.5 is performed automatically.

All calibrations are thus related to the IR1 through a calibration chain comprising an IR2 and an IR3 to which absolute values have been assigned respectively by a standardizing laboratory and by an authorized laboratory using an instrument conforming to this document.

6.3 Value assignment to the working standards for their intended use

Clean the working standards (see 6.5) and measure their radiance factors using an instrument previously calibrated with a set of IR3s and read off and record the values to the nearest 0,01 percentage point. This value assignment of the working standard is instrument-specific, for given conditions of measurement.

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The working standard shall only be used for subsequent control on the same instrument and for the same instrument conditions in which it was originally measured.

NOTE In order to achieve agreement with the reference instrument, a working standard can be assigned multiple control values, depending on the working level and the purpose of the measurement. This applies, for example, if the working standard is translucent or glossy and if the linearity of the instrument scale is poor so, in this case, the control is both sample and instrument specific.

6.4 Use of the working standards

Use one plate as a primary working standard for checking a given instrument, and use the other much less frequently as a control plate for checking the primary working standard. The frequency with which the instrument needs to be calibrated depends on the type of instrument. Frequent calibration of the instrument tends to introduce undesirable fluctuations in the instrument, and the instrument shall be recalibrated only when a check with the primary working standard indicates that calibration is necessary. Check the primary working standard periodically against the control plate. If any significant change in the radiance factor is noticed, clean the primary working standard by the procedure described in 6.5. If the change persists, clean and recalibrate both working standards against an appropriate IR3.

The primary working standard should be checked against the control plate sufficiently often to ensure that any change in the primary working standard is discovered before an error is introduced into the control.

NOTE A significant change can be 0,2 for R_x and R_y; 0,3 for R_z and ISO brightness on non-fluorescent standards, and 0,5 for ISO Brightness and 1,0 for CIE whiteness on fluorescent standards.

6.5 Cleaning the working standards

Handle with care. If cleaning is necessary, follow the manufacturer's instructions. In the case of working standards of opal glass or ceramic material, rinse with distilled water and detergent free from fluorescent ingredients while rubbing with a soft brush. Rinse thoroughly in distilled water and dry in the air in a dust-free environment without allowing anything to touch the surface. Leave them in a desiccator until they are optically stable.

NOTE Ceramic material standards can require days of drying in a dessicator to avoid getting water onto the back of the material, and to restore the optical properties, as the backing of a ceramic is very porous.

7 Sampling

If the tests are being made to evaluate a lot, the sample shall be selected in accordance with ISO 186[1]. 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 the test pieces

For the determination of optical properties based on the measurement of radiance factors and defined by another International Standard, prepare the test pieces in accordance with the instructions given in the relevant International Standard.

If only radiance factors must be measured, rather than some other optical property defined by another International Standard, use the following procedure.

Avoiding watermarks, dirt and obvious defects, cut rectangular test pieces approximately 75 mm × 150 mm, taking care to avoid touching the future test area.

Assemble test pieces in a pad with their top sides uppermost; the number shall 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 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.

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

If sufficient sheets are not available or if it is desired to measure a background-dependent radiance factor, select a suitable background and include a description of this background in the report.

9 Procedure

9.1 General

For the determination of optical properties based on the measurement of radiance factors, follow the procedure described in the relevant International Standard.

If it is desired to measure the radiance factors only, follow the procedure described in 9.2 and 9.3.

9.2 Verification of calibration

Check the calibration of the instrument using a non-fluorescent working standard calibrated in relation to an IR3 (5.3). Recalibrate the instrument if necessary.

If the instrument is of the spectrophotometer type, and if the material to be measured contains or can contain a fluorescent component, the UV content of the illumination shall be adjusted to match the fluorescence produced by the selected CIE illuminant using the fluorescent (5.2) and non-fluorescent (5.2) international level 3 reference standards in an iterative procedure. More details on the procedure for UV-adjustment to match the CIE standard illuminant D65 are given in ISO 11475 and for UV-adjustment to match the CIE illuminant C in ISO 2470-1.

9.3 Measurement

Remove the protecting sheets from the test piece pad. Without touching the test area, use the procedure appropriate to the instrument, and the working standard, to measure the desired radiance factors. Read and record the value to the nearest 0,01 percentage point.

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10 Calculation and expression of results

Express the radiance factor results in per cent with 2 decimal numbers.

Calculate the results as required in the relevant International Standard for the determination of radiance factors or optical properties based on the measurement of radiance factors, e.g. ISO 2470-1[2], ISO 2470-2[3], ISO 2471[4], ISO 5631-1[5], ISO 5631-2[6], ISO 5631-3[7], ISO 9416[8], ISO 11475[9], ISO 11476[10], ISO 22754 [11].

NOTE Comments on the definition and calculation of the measurement uncertainty are given in Annex D.

11 Precision

Data relating to the precision of results obtained in accordance with the procedure described in this document are given in the relevant test method for the determination of radiance factors or optical properties based on the measurement of radiance factors. (See also Annex D).

12 Test report

The test report shall include the following details:

a) date and place of testing;

b) precise identification of the sample;

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c) a reference to this document, i.e. ISO 2469:2024;

d) the type of instrument used;

e) the wavelength range, pitch and bandwidth if a spectrophotometer is used, or the type of filter if a filter instrument is used;

f) the illuminant to which the UV-content of the illumination of the instrument is adjusted;

g) the number of test pieces and the procedure adopted to calculate the reported results;

h) the test results;

i) any departure from this document or any circumstances or influences that could have affected the results.

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Annex A
(normative)

Instruments for the measurement of radiance factor

A.1 Geometric characteristics

A.1.1 The test piece and reference area shall be subjected to diffuse illumination which is achieved by means of an integrating sphere (see ISO 11664-2:2007, 845.05.24[14]) with an internal spectrally non-selective white diffusing surface and an internal diameter of (150 ± 3) mm.

A.1.2 The sphere shall be constructed as a dual-beam instrument so that a measurement can be made on a test piece, and a reference measurement can be made simultaneously on a reference region of the inner surface of the sphere.

A.1.3 The sphere shall be constructed or equipped with screens (baffles) to ensure that neither the test piece nor the reference region is directly illuminated by the light source.

A.1.4 The total area of the apertures and other non-reflecting areas in the sphere shall not exceed 13 % of the area of the inner surface of the sphere.

A.1.5 The receptor aperture shall be surrounded by a black annulus subtending a half-angle of (15,8 ± 0,8)° at the centre of the test piece aperture. This black annulus serves as a “gloss trap” so that specularly reflected light from the test piece does not reach the receptor. The black annulus shall be matt and shall have a radiance factor of less than 4 %, at all wavelengths within the visible region.

A.1.6 The test piece aperture shall be designed so that the test piece itself is essentially a continuation of the internal wall of the sphere. The rim of the test piece aperture shall have a thickness of (1,0 ± 0,5) mm including the thickness of the internal coating.

A.1.7 The measured test area on the test piece shall be circular with a diameter of (28 ± 3) mm.

NOTE It is expected that the use of the smaller area aperture will eliminate edge effects, which can lead to a pseudo-nonlinearity, and that this will lead to a higher reproducibility between instruments.

A.1.8 The diameter of the aperture shall be larger than that of the test area (34,0 ± 0,5) mm, to ensure that no light reflected from the rim of the test piece aperture or from the test piece within a distance of 1 mm from the rim of the aperture can reach the detector.

A.1.9 The test piece shall be viewed normally, i.e. at an angle of (0 ± 1)° to the normal. Only reflected rays within a cone, the vertex of which is centred in the test piece aperture and the half-angle of which is not greater than 4°, shall fall on the receptor.

A.2 Photometric linearity

The photometric accuracy of the instrument shall be such that the residual departure from photometric linearity after calibration does not give rise to systematic errors exceeding 0,3 % radiance factor.

For the measurement of fluorescent papers, photometric linearity up to a total radiance factor value of at least 200 % is necessary in the wavelength region corresponding to the fluorescence emission.

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A.3 Spectral characteristics

There are two main types of instrument that conform to this document, known respectively as filter colorimeters and abridged spectrophotometers.

In the case of filter colorimeters, the spectral characteristics are determined by the filters inserted into the light beams in combination with the characteristics of the receptor, the sphere lining, the lamps and other optical parts of the instrument, or by a set of individual optical filters with different specific wavelengths. The filters shall be chosen so that the overall characteristics of the instrument agree with the spectral functions specified in the test methods relating to the determination of specific optical properties. The CIE recommended methods for characterizing these filter colorimeters are given in CIE Publication 179:2007[12].

In the case of abridged spectrophotometers, the spectral characteristics are determined by the accuracy to which the individual receptors represent the nominal wavelengths assigned to them, the bandwidth associated with each receptor, and the values given to the mathematical functions used in the subsequent calculations. For colorimetry, the instrument shall incorporate not less than 16 receptors uniformly spaced over at least the range from 400 to 700 nm.

In instruments providing spectral data, the manufacturer shall indicate the optical bandpass of the instrument. Ideally the colorimetric data shall be computed only from spectral data measured at wavelength intervals equal to the instrument's optical bandwidth. The centroid wavelength of each band shall not differ from its nominal wavelength by more than ±0,5 nm. However, in practical applications, it may be necessary to carry out the calculations using predicted rather than measured data at a wavelength interval of 10 nm or 20 nm, depending on the nominal instrument bandpass.

The spectral characteristics can be checked using suitable coloured reference standards.

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A.4 Computational procedures

A.4.1 General

To calculate tristimulus values as specified by the CIE illuminant and standard observer functions (1931 or 1964), the appropriate tables of weighting factors presented in Tables A.1 to A.8 and in the relevant test methods for determining specific optical properties for measurement at e.g. 10 nm or 20 nm intervals, shall be used. The tristimulus values shall be calculated by direct summation using these tabulated values with no attempt at interpolation using, e.g. a cubic spline function.

The tables to be used are those which assume that the spectral bandpass of the instrument used to obtain the data is equal to the measurement interval and is triangular in shape. These tables shall be used together with the data for which the manufacturer has identified the instrument bandpass as previously mentioned.

The following instructions shall be followed with regard to the summation of the tabulated values below 400 nm or above 700 nm if the measurement data do not cover the full extent of the tables.

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.

If data are from an instrument with a triangular lineshape [15] operating with a bandwidth of 5 nm, this 5-nm data shall be convolved with a 10-nm or 20-nm triangular bandpass function to give data at 10-nm or 20-nm, respectively. If data from an instrument operating with a bandwidth of 10 nm are presented and used at 20 nm intervals, the 10 nm data shall not be converted merely by taking the 10 nm data at 20 nm

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intervals. If the original data are from an instrument with a triangular lineshape, the convolved data should preferably be calculated using a 3-point equation, as shown in Formula (A.1)

$$R_{20}(\lambda_i) = \frac{1}{4} R_{10}(\lambda_i - \Delta\lambda) + \frac{1}{2} R_{10}(\lambda_i) + \frac{1}{4} R_{10}(\lambda_i + \Delta\lambda) \quad \text{(A.1)}$$

where $\Delta\lambda$ = 10 nm.

It should be noted that such a computation can still be only approximate.

NOTE If data are from an instrument that does not have a triangular lineshape, then a 3-point convolution equation is not necessarily a good choice. For example, for data from an instrument using a two-monochromator method for the measurement of fluorescent IR2 standards, the instrument lineshape is nearly Gaussian and a 5-point equation can give better inter-instrument agreement.

A.4.2 Procedure for using data without bandpass correction

Use Tables A.1, A.2, A.3 and A.4 when the spectral data have not been corrected for bandpass dependence and for which the bandpass is approximately equal to the measurement interval.

With C illuminant, Table A.1 is to be used when the data have been obtained at 10 nm measurement intervals; Table A.2 is to be used when the data has been obtained at 20 nm measurement intervals.

With D65 illuminant, 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 has been obtained at 20 nm measurement intervals.

These tables apply a correction for spectral bandpass dependence built into the calculation of the tristimulus values.

A.4.3 Procedure for using data with bandpass correction

Use Tables A.5, A.6, A.7 and A.8 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;

With C illuminant, Table A.5 is to be used when the data have been obtained at 10 nm measurement intervals; Table A.6 is to be used when the data have been obtained at 20 nm measurement intervals.

With D65 illuminant, Table A.7 is to be used when the data have been obtained at 10 nm measurement intervals; Table A.8 is to be used when the data have been obtained at 20 nm measurement intervals.

NOTE Raw reflectance data will differ for instruments with built-in bandpass correction from those without. However, after the appropriate weighting table is used, the resulting colourimetric values will be nearly identical.

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Table A.1 — Weighting functions (C/2°) for instruments without bandpass correction and 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

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Table A.1 *(continued)*

Wavelength nm	W_X	W_Y	W_Z
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

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Table A.2 — Weighting functions (C/2°) for instruments without bandpass correction and 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

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Table A.3 — Weighting functions (D65/10°) for instruments without bandpass correction and measuring at 10 nm intervals

Wavelength nm	$W_{10.X}$	$W_{10.Y}$	$W_{10.Z}$
360	0,000	0,000	0,000
370	0,000	0,000	−0,001
380	0,001	0,000	0,004
390	0,005	0,000	0,020
400	0,097	0,010	0,436
410	0,616	0,064	2,808
420	1,660	0,171	7,868
430	2,377	0,283	11,703
440	3,512	0,549	17,958
450	3,789	0,888	20,358
460	3,103	1,277	17,861

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Table A.3 *(continued)*

Wavelength nm	$W_{10.X}$	$W_{10.Y}$	$W_{10.Z}$
470	1,937	1,817	13,085
480	0,747	2,545	7,510
490	0,110	3,164	3,743
500	0,007	4,309	2,003
510	0,314	5,631	1,004
520	1,027	6,896	0,529
530	2,174	8,136	0,271
540	3,380	8,684	0,116
550	4,735	8,903	0,030
560	6,081	8,614	−0,003
570	7,310	7,950	0,001
580	8,393	7,164	0,000
590	8,603	5,945	0,000
600	8,771	5,110	0,000
610	7,996	4,067	0,000
620	6,476	2,990	0,000
630	4,635	2,020	0,000
640	3,074	1,275	0,000
650	1,814	0,724	0,000
660	1,031	0,407	0,000
670	0,557	0,218	0,000
680	0,261	0,102	0,000
690	0,114	0,044	0,000
700	0,057	0,022	0,000
710	0,028	0,011	0,000
720	0,011	0,004	0,000
730	0,006	0,002	0,000
740	0,003	0,001	0,000
750	0,001	0,000	0,000
760	0,000	0,000	0,000
770	0,000	0,000	0,000
780	0,000	0,000	0,000
Check sum	**94,813**	**99,997**	**107,304**
White point	**94,811**	**100,000**	**107,304**

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Table A.4 — Weighting functions (D65/10°) for instruments without bandpass correction and measuring at 20 nm intervals

Wavelength nm	$W_{10.X}$	$W_{10.Y}$	$W_{10.Z}$
360	0,000	0,000	0,000
380	0,003	−0,001	0,025
400	0,056	0,013	0,199
420	2,951	0,280	13,768
440	7,227	1,042	36,808
460	6,578	2,534	37,827
480	1,278	4,872	14,226
500	−0,259	8,438	3,254
520	1,951	14,030	1,025
540	6,751	17,715	0,184
560	12,223	17,407	−0,013
580	16,779	14,210	0,004
600	17,793	10,121	−0,001
620	13,135	5,971	0,000
640	5,859	2,399	0,000
660	1,901	0,741	0,000
680	0,469	0,184	0,000
700	0,088	0,034	0,000
720	0,023	0,009	0,000
740	0,005	0,002	0,000
760	0,001	0,000	0,000
780	0,000	0,000	0,000
Check sum	**94,812**	**100,001**	**107,306**
White point	**94,811**	**100,000**	**107,304**

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Table A.5 — Weighting functions (C/2°) for instruments with bandpass correction and 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	0,004 0
380	0,004	0,000	0,017
390	0,018	0,001	0,084
400	0,076	0,002	0,358
410	0,325	0,009	1,547
420	1,292	0,038	6,207
430	2,968	0,123	14,496
440	3,959	0,261	19,860
450	3,931	0,443	20,728
460	3,360	0,692	19,286

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Table A.5 *(continued)*

Wavelength nm	W_X	W_Y	W_Z
470	2,283	1,061	15,022
480	1,116	1,612	9,479
490	0,363	2,358	5,286
500	0,048	3,414	2,868
510	0,092	4,842	1,512
520	0,578	6,449	0,720
530	1,519	7,936	0,381
540	2,786	9,145	0,195
550	4,285	9,831	0,086
560	5,877	9,834	0,038
570	7,323	9,148	0,020
580	8,414	7,990	0,015
590	8,985	6,629	0,010
600	8,958	5,321	0,007
610	8,324	4,177	0,003
620	7,055	3,146	0,001
630	5,327	2,196	0,000
640	3,692	1,442	0,000
650	2,352	0,887	0,000
660	1,360	0,503	0,000
670	0,713	0,261	0,000
680	0,364	0,132	0,000
690	0,172	0,062	0,000
700	0,080	0,029	0,000
710	0,039	0,014	0,000
720	0,019	0,007	0,000
730	0,009	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	100,000 0	118,230
White point	98,074	100,000	118,232

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Table A.6 — Weighting functions (C/2°) for instruments with bandpass correction and measuring at 20 nm intervals

Wavelength nm	W_X	W_Y	W_Z
360	−0,001	0,000	−0,006
380	−0,011	0,000	−0,054
400	0,089	−0,001	0,393
420	2,919	0,085	14,033
440	7,649	0,511	38,518
460	6,641	1,382	38,120
480	2,364	3,206	19,564
500	0,069	6,910	5,752
520	1,198	12,876	1,442
540	5,591	18,258	0,357
560	11,750	19,588	0,073
580	16,794	15,991	0,026
600	17,896	10,696	0,013
620	14,018	6,261	0,003
640	7,457	2,902	0,000
660	2,746	1,008	0,000
680	0,712	0,257	0,000
700	0,153	0,055	0,000
720	0,034	0,012	0,000
740	0,007	0,003	0,000
760	0,002	0,001	0,000
780	0,000	0,000	0,000
Check sum	98,077	100,001	118,234
White point	98,074	100,000	118,232

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Table A.7 — Weighting functions (D65/10°) for instruments with bandpass correction and measuring at 10 nm intervals

Wavelength nm	$W_{10,X}$	$W_{10,Y}$	$W_{10,Z}$
360	0,000	0,000	0,000
370	0,000	0,000	0,000
380	0,000	0,000	−0,002
390	0,008	0,001	0,033
400	0,137	0,014	0,612
410	0,676	0,069	3,110
420	1,603	0,168	7,627
430	2,451	0,300	12,095
440	3,418	0,554	17,537
450	3,699	0,890	19,888
460	3,064	1,290	17,695

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Table A.7 *(continued)*

Wavelength nm	$W_{10.X}$	$W_{10.Y}$	$W_{10.Z}$
470	1,933	1,838	13,000
480	0,802	2,520	7,699
490	0,156	3,226	3,938
500	0,039	4,320	2,046
510	0,347	5,621	1,049
520	1,070	6,907	0,544
530	2,170	8,059	0,278
540	3,397	8,668	0,122
550	4,732	8,855	0,035
560	6,070	8,581	0,001
570	7,311	7,951	0,000
580	8,291	7,106	0,000
590	8,634	6,004	0,000
600	8,672	5,079	0,000
610	7,930	4,065	0,000
620	6,446	2,999	0,000
630	4,669	2,042	0,000
640	3,095	1,290	0,000
650	1,859	0,746	0,000
660	1,056	0,417	0,000
670	0,570	0,223	0,000
680	0,274	0,107	0,000
690	0,121	0,047	0,000
700	0,058	0,023	0,000
710	0,028	0,011	0,000
720	0,012	0,005	0,000
730	0,006	0,002	0,000
740	0,003	0,001	0,000
750	0,001	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	**94,809**	**100,000**	**107,307**
White point	**94,811**	**100,000**	**107,304**
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Table A.8 — Weighting functions (D65/10°) for instruments with bandpass correction and measuring at 20 nm interval

Wavelength nm	$W_{10.X}$	$W_{10.Y}$	$W_{10.Z}$
360	−0,001	0,000	−0,007
380	−0,043	−0,004	−0,200
400	0,378	0,035	1,667
420	3,138	0,320	14,979
440	6,701	1,104	34,461
460	6,054	2,605	35,120
480	1,739	4,961	15,986
500	0,071	8,687	4,038
520	2,183	13,844	1,031
540	6,801	17,327	0,229
560	12,171	17,153	0,002
580	16,465	14,150	−0,003
600	17,230	10,118	0,000
620	12,872	6,012	0,000
640	6,248	2,593	0,000
660	2,126	0,832	0,000
680	0,544	0,210	0,000
700	0,105	0,041	0,000
720	0,023	0,009	0,000
740	0,005	0,002	0,000
760	0,001	0,000	0,000
780	0,000	0,000	0,000
Check sum	**94,811**	**99,999**	**107,303**
White point	**94,811**	**100,000**	**107,304**
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A.5 UV-adjustment

For the measurement of materials containing fluorescent whitening agents, some means of setting the spectral power distribution of the incident radiation upon the test piece is required. The incident radiation shall be set to a specified UV-content (CIE illuminant C or D50, or CIE standard illuminant D65), within the spectral range (from 400 nm to 700 nm). There shall be a way to maintain this level or of mathematically simulating such a power distribution.

For this purpose, a filter having a half-peak cut-off wavelength of 395 nm shall be used or an equivalent procedure having the same impact shall be employed. If the filter is movable, it shall be mounted in a device which permits its position to be identified and maintained, and reproducibly reset.

NOTE The relative spectral power distributions of the CIE illuminants C, D50, and CIE standard illuminant D65[13],[14] are defined only for wavelengths longer than 300 nm.

A.6 Fluorescence elimination

For the measurement of radiance factors with the fluorescence effect eliminated, the instrument shall be equipped with a sharp cut-off UV-absorbing filter having a transmittance not exceeding 5 % at and below a

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wavelength of 410 nm and exceeding 50 % at a wavelength of 420 nm (i.e. a half-peak cut-off wavelength of 420 nm), or shall employ an equivalent procedure.

The cut-off filter shall have characteristics such that a reliable radiance factor value is obtained at 420 nm. This value shall be repeated at all lower wavelengths to provide adequate data for the colorimetric computations, provided that the International Standard for the quantity concerned does not include other instructions.

Instrument makers should recognize the need to provide the means to maintain at least three interchangeable and easily accessible calibrated situations, UV D65 corresponding to the CIE standard illuminant D65, UV C corresponding to the CIE illuminant C, and UV ex(420) corresponding to a fluorescence-eliminated (420 nm cut-off) situation.

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Annex B
(normative)

Calibration service — Photometric calibration

B.1 General

In this document, a sequence of non-fluorescent reference standards of three different levels is mentioned, the ultimate reference standard (the international reference standard of level 1) being the “perfect reflecting diffuser”. The use of the perfect reflecting diffuser as ultimate reference is in full agreement with a recommendation made by the prime authority on optical properties, the International Commission on Illumination (CIE), in 1969 [16].

To permit working instruments to relate their radiance factor measurements to this ultimate reference standard, the following procedure is specified.

B.2 Structure of the service

This calibration procedure involves two stages for fundamental reasons. The standardizing laboratory provides a transfer standard of level 2 with assigned radiance factor values directly traceable to the perfect reflecting diffuser. The authorized laboratories take this transfer standard and, with the help of a reference instrument conforming to this document, mediate to industrial laboratories a reference standard of level 3 with assigned radiance factor values which are traceable to the perfect reflecting diffuser through an instrument having the prescribed geometric characteristics. Calibration at the industrial laboratory level with a transfer standard of level 2 is not in accordance with this document.

NOTE A list of standardizing and authorized laboratories is available on the ISO/TC 6 website [17].

B.3 Standardizing laboratories

Certain laboratories equipped for absolute radiance factor measurements are appointed as “standardizing laboratories” in accordance with ISO 4094. The standardizing laboratories issue International reference standards of level 2 (IR2) to the authorized laboratories.

The standardizing laboratories are required to exchange reference standards of level 2 at intervals of no longer than five years, so that the level of agreement between their measurements is monitored and maintained.

B.4 Authorized laboratories

Laboratories having the necessary technical competence and maintaining reference instruments having the characteristics specified in Annex A of this document are appointed as “authorized laboratories” in accordance with ISO 4094. Each authorized laboratory maintains an instrument conforming to the requirements of Annex A as a reference instrument which is calibrated using a reference standard of level 2. The authorized laboratories then issue International reference standards of level 3 (IR3) on request to industrial laboratories which use the IR3 for the purpose of calibrating their instruments and working standards periodically.

Specific requirements for laboratories authorized to issue optical property reference transfer standards of level 3 are described in ISO 4094:2017, Annex A. One of these requirements is cited hereafter.

Authorized laboratories (ALs) shall engage in monthly bilateral comparisons and arrange for the results of these comparisons to be compiled, analysed and reported to all of the AL members on an annual basis. These

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inter-AL comparison results over a period of several years serve as the basis for the precision statement issued by the ALs, which is also available on the ISO/TC 6 website [17].

B.5 IR3 Non-fluorescent standards

The IR3 non-fluorescent reference standards shall have the following properties:

a) when properly cared for, their reflectance factors shall not change, within the precision of the instrument, over a reasonable period of time;

b) they shall be clean, opaque, and uniform in reflectance factor;

c) they shall be flat and shall have a smooth matt surface;

d) they shall be free from fluorescence.

B.6 Assignment of calibration values to IR3s

For the calibration of abridged spectrophotometers, the authorized laboratory shall provide reference standards having assigned reflectance factors obtained by direct measurement of the IR3 in the calibrated reference instrument.

For the calibration of three-filter colorimeters, the authorized laboratory shall provide reference standards having assigned R_x, R_y and R_z values. These shall be calculated for C/2° illuminant/observer conditions according to Formula (B.1) as follows (see ISO/TR 10688[19]):

$$R_x = (X - 0{,}167\,07\,Z)/78{,}321$$

$$R_y = Y/100 \qquad \text{(B.1)}$$

$$R_z = Z/118{,}232$$

where X, Y and Z are the tristimulus values, calculated in accordance with A.4.

If a reference standard is required for the calibration of a three-filter colorimeter for measurement under D65/10° illuminant/observer conditions, the assigned $R_{x.10}$, $R_{y.10}$ and $R_{z.10}$ values shall be calculated according to Formula (B.2) as follows:

$$R_{x.10} = (X_{10} - 0{,}167\,47\,Z_{10})/76{,}841$$

$$R_{y.10} = Y_{10}/100 \qquad \text{(B.2)}$$

$$R_{z.10} = Z_{10}/107{,}304$$

where X_{10}, Y_{10} and Z_{10} are the D65/10° tristimulus values, calculated in accordance with A.4.

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