
**Graphic technology — Spectral
measurement and colorimetric
computation for graphic arts images**

*Technologie graphique — Mesurage spectral et calcul colorimétrique
relatifs aux images dans les arts graphiques*

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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 on 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 the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 130, *Graphic technology*, in collaboration with Technical Committee ISO/TC 42, *Photography*.

This third edition cancels and replaces the second edition (ISO 13655:2009), which has been technically revised to:

- clarify the requirements of measurement mode M1;
- restrict the use of unnecessarily wide bandpass and sampling intervals;
- provide more realistic specification for the optical properties of a white backing material;
- restrict the adjustment method of predicting the fluorescent reflectance factor to UV activated substrates.

Introduction

There are many choices allowed when making spectral measurements and performing colorimetric computations. The specific choices made can result in different numerical values for the same property for the same sample. Thus, it might not be possible to make valid comparisons unless the data being compared are all based on the same set of measurement and computational choices. The purpose of this document is to specify a limited number of such choices for the measurement and computation of the colorimetric characteristics of graphic arts images and specimens, such as test charts, to allow valid and comparable data to be obtained. While this document references ISO 3664, the International Standard established for viewing conditions in graphic arts and photography, it is not expected that measured colorimetric data will provide an absolute correlation with visual colour appearance.

When the prior revision of this document was started, it was observed that almost all graphic arts specimens exhibited fluorescence. In most cases, this was due to optical brightening agents (OBA) contained in the paper substrates. In rare cases, the printing inks were fluorescent. According to the recommendations of the 1996 version of this document, this would have meant that the source used for the measurements (i.e. the spectral power distribution of the specimen illumination) was required to closely match CIE illuminant D50. Yet when the 2009 revision was started, not a single colour-measuring instrument sold for the graphic arts market provided an illumination system that closely matched CIE illuminant D50. Instead, most instruments used incandescent lamps for light sources. The spectral power distributions of such lamps have varying amounts of UV content. The variation in UV content between instruments could easily amount to a colour difference of $5 \Delta a^*$ when measuring substrates with a high level of optical brightening agents. Consequently, the measurement results for unprinted paper substrates and lighter colours differed appreciably between different instrument models. For a thorough study of fluorescence effects, see CIE Publication 163.

It had also been observed that graphic arts viewing booths vary with respect to UV content, even those that comply with the 1996 version of ISO 3664. The practical result was that specimens that have nearly identical measured colorimetric properties, at times will not visually match when viewed in the viewing booth, and vice versa. Only part of such discrepancies can be attributed to fluorescence. There can also be metameric effects due to “non-standard” observers and to instrument wavelength errors, in addition to deviations in the measurement source away from CIE D50. Despite these other potential influences, it was deemed important to provide measurement solutions that would minimize the systematic errors introduced by the interaction of paper fluorescence and variations in the spectral power distribution of the sample illumination. Methods for the correction of instrument errors and procedures for reliable visual evaluation of colour images are outside of the scope of this document.

In the 2009 revision, four measurement choices were defined for reflective measurements. Measurement condition M0 requires the source illumination to closely match that of illuminant A; this provides consistency with existing instrumentation and ISO 5-3. Measurement condition M1 requires the colorimetry of the specimen illumination to closely match CIE illuminant D50. Measurement condition M2 only requires that the spectral power distribution of the specimen illumination be provided in the wavelength range from 400 nm to at least 700 nm and have no substantial radiation power in the wavelength range below 400 nm (often referred to as “UVCut”). Measurement condition M3 has the same sample illumination requirements as M2 and includes a linear polarizer in the influx and efflux portions of the optical path with their principal axes of polarization in the orthogonal or “crossed” orientation. For specimens in which the fluorescence is primarily that of a UV activated blue emission, it is possible to use the method of a virtual fluorescent standard reported by Imura of Konica Minolta[24][25] to determine the total radiance factors for M0, M1 and M2 conditions. In this revision, [Annex A](#) has been revised providing a slightly narrower and more realistic set of spectral tolerances on the white backing materials. The properties of the white backing material are critical to reproducibility of readings of packaging printing on clear or translucent films.

Finally, as the CIE has been recommending the use of 5 nm intervals for practical tristimulus integration since the second revision of CIE Publication 15 and as graphic images can be composed of colour stimulus functions with very narrow transitions from the low values to the high values, this revision recommends that tristimulus values be based on spectral data collected with a 5 nm interval and a 5 nm bandpass. Since many of the instruments now in use in the field are equipped with 10 nm

intervals and 10 nm bandpass spectrometers, such readings are allowed with the recommendation that tristimulus calculations be preceded by applying bandpass correction to the spectral data as specified in ASTM E2729. The use of instruments with wider sampling intervals and bandpass has been deprecated with the exception of the use of such non-standard instruments to monitor the state of previously characterized materials or objects.

The requirements of this document are focused on colorimetric measurement equipment intended for use in the graphic arts environment. Helpful information on issues such as substrate backing materials, reporting, standardization, standard and improved colour difference metrics, fluorescence and ways to improve the inter-instrument agreement are included. These will be useful to technical advisors of graphic arts associations, specialized graphic arts research institutes, and practitioners with an interest in the basics of measurement and process control.

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Graphic technology — Spectral measurement and colorimetric computation for graphic arts images

1 Scope

This document specifies procedures for the measurements and colorimetric computations appropriate to objects that reflect, transmit and emit light, such as flat-panel displays. It also specifies procedures for computation of colorimetric parameters for graphic arts images. Graphic arts include, but are not limited to, the preparation of material for, and volume production by, production printing processes that include offset lithography, letterpress, flexography, gravure, screen and digital printing.

This document does not address spectral measurements appropriate to other specific application needs, such as those used during the production of materials, for example, printing paper and proofing media.

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 5-2, *Photography and graphic technology — Density measurements — Part 2: Geometric conditions for transmittance density*

ISO 5-4:2009, *Photography and graphic technology — Density measurements — Part 4: Geometric conditions for reflection density*

ISO 3664, *Graphic technology and photography — Viewing conditions*

ISO 11664-1, *Colorimetry — Part 1: CIE standard colorimetric observers*

ISO 11664-3, *Colorimetry — Part 3: CIE tristimulus values*

ISO 11664-4, *Colorimetry — Part 4: CIE 1976 L*a*b* Colour space*

ISO 28178, *Graphic technology — Exchange format for colour and process control data using XML or ASCII text*

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

CIE Publication 167:2005, *Recommended practice for tabulating spectral data for use in colour computations*

CIE Publication 176:2006, *Geometric Tolerances for Colour Measurements*

3 Terms and definitions

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

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

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

**3.1
adopted white**

spectral radiance distribution as seen by an image capture or measurement device and converted to colour signals that are considered to be perfectly achromatic and to have an observer adaptive luminance factor of unity, i.e. colour signals that are considered to correspond to a perfect white diffuser

[SOURCE: ISO 22028-1]

**3.2
bandwidth**

width of the spectral response function of the instrument, measured between the half-power points often termed full width at half maximum (FWHM)

**3.3
calibration**

set of operations that establish, under specified conditions, the relationship between values of quantities indicated by a measuring instrument or measuring system, or values represented by a material measure or a reference material, and the corresponding values realized by standards

Note 1 to entry: Contrary to a common usage, calibration is not the process of adjusting a measurement system such that it produces values that are believed to be correct. Calibration permits either the assignment of values of measurands to the indications (creating a reference table) or the decision to reset or adjust the device. Following the resetting or adjusting of the device, a calibration needs to be verified to ensure that the new device setting(s) provide indications within the accepted values.

[SOURCE: ISO/IEC Guide 99 (VIM)]

**3.4
CIE illuminant**

illuminant (3.6) defined by the International Commission on Illumination (CIE) in terms of relative spectral power distribution

[SOURCE: IEC 60050-845-03-12]

EXAMPLE CIE illuminants A, C, and various D illuminants.

**3.5
CIELAB chromaticness difference**

ΔC_h
difference between two colours of approximately the same lightness projected onto a constant lightness plane in the CIELAB colour space

Note 1 to entry: This is calculated as $\Delta C_h = \sqrt{(CIE\ \alpha_1^* - CIE\ \alpha_2^*)^2 + (CIE\ b_1^* - CIE\ b_2^*)^2}$

**3.6
illuminant**

numeric tabulation of the relative spectral distribution of the radiant (light) flux incident on the specimen surface

Note 1 to entry: The CIE defines an illuminant as “radiation with a relative spectral power distribution defined over the wavelength range that influences object colour perception”. In everyday English, the term is more widely used to mean any kind of light falling on a body or scene. See IEC 60050-845 for further information.

[SOURCE: IEC 60050-845-03-10]

3.7**opacity**

<of a substrate> measure of the property that describes the ability of a specimen to hide a surface behind and in contact with it

Note 1 to entry: The numerical value of opacity as used in this document is 100 times the ratio of the luminous reflectance factor of the substrate over black backing (as defined in [A.2](#)) to the luminous reflectance factor over white backing (as defined in [A.3](#)). This is different from the measurement of opacity used by the paper manufacturing industry and defined in ISO 2471.

3.8**opaque substrate**

substrate whose *opacity* ([3.7](#)), measured according to [A.3](#), is 0,99 or greater

3.9**transparent substrate**

clear material having minimal absorption or scattering of transmitted visible light

Note 1 to entry: Clear packaging film is an example of this type of material.

3.10**reflectance factor**

ratio of the radiant or luminous flux reflected in the directions delimited by the given cone to that reflected in the same directions by a perfect reflecting diffuser identically irradiated or illuminated

Note 1 to entry: The industry commonly uses the term reflectance rather than reflectance factor.

Note 2 to entry: It is important to specify the geometry that establishes the given conditions of measurement. See [Annex B](#).

[SOURCE: IEC 60050-845-04-64]

3.11**radiance factor**

<at a surface element of a non-self-radiating medium, in a given direction, under specified conditions of irradiation> ratio of the radiance of the surface element in the given direction to that of the perfect reflecting or transmitting diffuser identically irradiated and viewed

Note 1 to entry: For photoluminescent (fluorescent) media, the radiance factor contains 2 components, the reflected radiance factor, β_R , and the luminescent radiance factor, β_L . The sum of the reflected and luminescent radiance factors is the total radiance factor, β_T : $\beta_T = \beta_R + \beta_L$. The subscript R is used here for the reflected radiance factor because it is more intuitive than the traditional S and avoids confusion with the use of S to denote a state of polarization.

[SOURCE: IEC 60050-845-04-68]

3.12**specimen backing**

material placed behind and in contact with the specimen during measurement

Note 1 to entry: For this document, this can be either white or black.

3.13**spectrophotometer**

instrument for measuring the relative spectral *reflectance factor* ([3.10](#)) or *transmittance factor* ([3.18](#)) of a material across the visible spectrum in order to derive colorimetric quantities

3.14**spectroradiometer**

instrument for measuring radiometric quantities in narrow wavelength intervals over a given spectral region

[SOURCE: IEC 60050-845-05-07]

**3.15
standardization**

process of forcing or adjusting a measurement system to produce readings that correspond to a previously established *calibration* (3.3) using one or more homogeneous specimens or certified reference materials

Note 1 to entry: As defined here, standardization is normally carried out by an instrument user.

**3.16
telespectroradiometer**

spectroradiometer (3.14) that uses an optical relay component to allow measurements to be made at a distance from the specimen

**3.17
transmittance (for incident radiation of a given spectral composition, polarization, and geometrical distribution)**

ratio of the transmitted radiant or luminous flux to the incident flux in the given conditions

Note 1 to entry: It is important to specify the geometry that establishes the given conditions of measurement, for example, rectilinear geometry produces regular transmittance and integrating sphere produces diffuse transmittance. But an opal glass diffuser does not produce the same readings as an integrating sphere geometry. See [Annex B](#).

[SOURCE: IEC 60050-845-04-59]

**3.18
transmittance factor**

ratio of flux transmitted by a specimen in a given optical system to the flux transmitted when the specimen is removed from the sampling aperture

Note 1 to entry: For example, this is the case when radiation penetrating a slide situated in a projector and reaching a screen is compared to the radiation when the slide is removed from a projector and only an empty slide mount is in the projector.

4 Spectral measurement requirements

4.1 Instrument standardization and adjustment

The measurement device or system shall be verified (standardized and possibly adjusted) in accordance with its manufacturer's instructions. See also [Annexes C](#) and [D](#).

NOTE 1 ISO 15790 defines the use of a certified reference material (CRM) to check calibration of a measurement system. It also provides additional information relating to the use of CRMs, the determination of combined standard uncertainty and data reporting.

NOTE 2 Where multiple instruments are used for measurement, there can be differences in the resulting data due to the individual characteristics of the instruments and variations in measurement conditions. [Annexes C](#) and [D](#) provide information on the improvement of inter-instrument agreement and the use of certified reference materials.

4.2 Reflectance factor measurement

4.2.1 Wavelength range, wavelength interval and bandwidth

The data should be measured from 380 nm to 780 nm and shall be measured from 400 nm to 700 nm, inclusive. Data should be measured at 5 nm intervals with a spectral response function that is triangular with a 5 nm bandwidth at the half-power point, as specified in ISO 11664-3. Where unknown data are measured at other intervals and bandwidths, the sampling interval and bandwidth shall not exceed 10 nm. For applications where the spectral properties of the specimens are well established, conformance to process requirements may be assessed using 20 nm sampling. Measurement data taken

at greater than 10 nm interval shall be converted to 10 nm using one of the interpolation methods recommended in CIE Publication 167:2005. Where measurement data are collected at bandwidths and intervals of less than 5 nm, it may be widened using the method of [Annex E](#).

4.2.2 Illumination requirements and measurement conditions

4.2.2.1 Measurement condition M0

Historically, many spectrophotometers used in the graphic arts have used an incandescent lamp with a relative spectral power distribution that is close to CIE standard illuminant A, as defined in ISO 11664-2. In addition, this illuminant has historically been required for the measuring of density. M0 is provided to allow the identification of data measured using existing instrumentation or instrumentation optimized for photographic density measurements (see ISO 5-3).

The relative spectral power distribution of the flux incident on the specimen surface should conform to CIE illuminant A (corresponding to an incandescent source with a correlated colour temperature of 2 856 K). In practical instruments, this may be achieved using any source that provides radiant power at all wavelengths within the spectral range of 400 nm to 700 nm.

Because the specification of correlated colour temperature does not define UV, the UV content is not controlled under M0, and it is therefore recommended that M1 be used when there is the need to interchange data measured on samples that exhibit fluorescence. When instruments meeting M1 are not available and relative data are sufficient for process control or other data exchange applications, M0 instruments of like manufacturer and model provide a viable alternative.

4.2.2.2 Measurement condition M1

To minimize the variations in measurement results between instruments due to fluorescence (by optical brighteners in the substrate and/or fluorescence of the printing and/or proofing colorants), the spectral power distribution of the light flux incident on the specimen surface for the measurement should match CIE illuminant D50.

NOTE 1 Because ISO 3664 also specifies the use of D50, this will improve the consistency between measurement results made under condition M1 and visual assessment in viewing booths that meet the requirements of ISO 3664.

NOTE 2 For material testing as defined in ISO 5631-3, the UV-content of the illumination on the test piece has been adjusted to conform to that of CIE illuminant C. Therefore, measurements conforming to ISO 5631-3 might not be compatible with measurements conforming to this document.

There are two methods to achieve conformance to condition M1.

- a) The spectral power distribution of the measurement source at the sample plane should match CIE illuminant D50. It shall conform to the requirements for viewing condition P1 of ISO 3664. This method shall be used when both luminescent colorants and optical brighteners are of concern. The instrument manufacturer shall supply a representative spectral power distribution of the measurement source at the sample plane with the instrument documentation.
- b) A spectral match of the spectral power distribution of the measurement source in the range from 400 nm to 700 nm at the sample plane is not required if a compensation method is used with a controlled adjustment of the radiant power in the UV spectral region below 400 nm^{[24][25]}. This can be done by active adjustment of the relative power in this range with respect to a calibrated standard for D50. This compensation aims only to correct the effects of fluorescence of optical brighteners in the substrate. The spectral power distribution in the range from 400 nm to 700 nm shall contain radiant power at all wavelengths in this range.

It should be noted that for the proper evaluation of materials with optical brightening agents, it is important that the ratio of the power in the region between 300 nm and 400 nm to the power in the region between 400 nm to 500 nm be very similar to the ratio of D50 between these same regions.

The conformance of M1 measurement condition shall be judged indirectly by measuring a set of certified reference materials (CRMs) (see [Annex D](#)) that includes a specimen material with a high concentration of optical brighteners where the difference in CIE b^* measured with and without UV energy incident on the specimen material is greater than 3. Where the indicated values, including the combined uncertainty, are within the specified tolerances of the CRM, and the required documentations are provided, the instrument can be considered to be in conformance with this document.

NOTE 3 [Annex F](#) provides information on fluorescence and techniques to test for its presence.

NOTE 4 In cases where a printing ink fluoresces and accurate colorimetric data are required, measurement condition M1, Method 1 is the only choice. However, in most situations, instruments meeting Method 1 are not available and relative data is sufficient for process control or other data exchange applications. In such situations, comparison of data from instruments of like manufacturer and model can provide a viable alternative.

4.2.2.3 Measurement condition M2

To exclude variations in measurement results between instruments due to fluorescence of optical brightening agents in the substrate surface, the spectral power distribution of the measurement source at the sample plane shall only contain substantial radiation power in the wavelength range above 400 nm. This may be accomplished through appropriate design of the source or through the addition of a filter between the source and the specimen.

The visible fluorescence of optical brightener agents in paper is typically excited in the UV range from 300 nm up to 410 nm. In order to eliminate completely any fluorescence excitation of optical brighteners, the optimum cut-off wavelength for the UV component would be 420 nm. However, it is desirable also to measure reflectance factors at 400 nm and 410 nm. Therefore, for each instrument type, the optimum trade-off has to be found between a sufficient suppression of residual fluorescent excitation and a reasonable signal-to-noise ratio of the measurement signal.

NOTE 1 For common spectrophotometers with a tungsten light source, a typical UV-cut filter has the following transmittance characteristics:

- greater than 0,85 in the visible range above 420 nm;
- less than 0,50 at 410 nm;
- less than 0,10 at 400 nm;
- less than 0,01 at 395 nm.

Appropriate suppression of the UV portion of the spectral power distribution of the flux at the sample plane shall be verified using the test procedure of [Annex G](#).

For measurement condition M2, the source is not explicitly specified. However, it shall provide radiant power at all wavelengths in the wavelength range from 420 nm to at least 700 nm. The radiative power in each wavelength interval shall be sufficiently high, in order to enable precise calibration and repeatable measurement results according to the instrument specifications.

The utility of M2 data can be determined by first considering whether the substrate of the samples to be measured contains any optical brightening agents. If it does not, measurement conditions M0, M1 and M2 will ideally produce the same results. In this case, the primary differences will be due to specific differences in instruments.

NOTE 2 [Annex F](#) provides information on fluorescence and techniques to test for its presence.

4.2.2.4 Measurement condition M3

For use in the special cases detailed in informative [Annex H](#), an instrument may be equipped with means for polarization in order to suppress the influence of first-surface reflection on the colour coordinates. An instrument fitted with a polarization filter shall also meet the requirements of [4.2.2.3](#). Using the test

method of ISO 5-4:2009, Annex H, as modified below, the gloss suppression factors shall be determined for CIE X, CIE Y, CIE Z; none of which shall be lower than 50.

When using the test method of ISO 5-4 to evaluate an instrument providing colour coordinates, substitute "measured value reaches a maximum" for "reflection density reaches a minimum". [Formula \(1\)](#) becomes:

$$P = \frac{X_2}{X_1} \quad (1)$$

where

P is the gloss suppression factor;

X_1 is the value measured without the polarization means;

X_2 is the value measured with the polarization means.

The gloss suppression factor is computed in a similar manner for CIE Y and CIE Z.

For directional and uniplanar measurement geometries, which are not specified by this document, the polarization vectors of the illumination and measurement channels need to be either parallel or perpendicular to the plane of incidence of the test object.

4.2.3 Sample backing material

The specimen shall be backed by either a black or a white material that conforms to [A.2](#) or [A.3](#), respectively. Where samples being measured by reflection are transparent, the backing used shall be white and the method shown in [A.5](#) may be used to correct such measurements to an absolute reference.

NOTE For guidance concerning which sample backing material to use, refer to application standards such as those from the ISO 12647 series of process control standards.

4.2.4 Measurement geometry

The measurement geometry shall be (45°:0°) or (0°:45°), annular or circumferential (see [Annex B](#)). It shall also conform to the geometric conditions defined in CIE Publication 176:2006 and shall meet the requirement that the realized boundary of the larger of the illuminator region and the receiver region shall be outside the boundary of the smaller by at least 0,5 mm, as specified for small sampling apertures. While being measured the sample shall lie on a flat surface. The instrument base and the sample surface shall lie in the same plane.

NOTE 1 For angles and nomenclature for geometries, see [B.1.1](#).

NOTE 2 The use of (45°:0°) or (0°:45°) geometry will not always adequately address variations in all surface characteristics. Other instrumentation might be used to detect specific characteristics such as surface reflectance effects.

NOTE 3 [Annex B](#) provides further information on minimum sampling aperture size.

4.2.5 Data reporting

Reflectance factor shall be reported to the nearest 0,001 relative to a perfect reflecting diffuser having a reflectance factor of 1,000 at all wavelengths. This data shall be reported as either reflectance factor or percent reflectance factor (i.e. reflectance factor multiplied by 100). If the data are to be used for further calculations, then in order to minimize the accumulation of round-off errors, the full precision of the calculation should be carried forward. Bandpass characteristics of data should be reported, including function shape (triangular, trapezoidal, etc.) and bandwidth (FWHM). See [Annex L](#) for information on the impact of instrumental bandpass on the calculation of spectral quantities. For non-opaque specimen-substrate materials, the CIEXYZ data for the unprinted substrate material read over

white backing shall be reported. It is recommended that the unprinted substrate material over black backing also be reported, so that a white/black conversion, as described in [Annex A](#), can be carried out whenever necessary. See also [Clause 6](#).

4.3 Transmittance factor measurement

4.3.1 Wavelength range, wavelength interval and bandwidth

The data should be measured from 380 nm to 780 nm and shall be measured from 400 nm to 700 nm, inclusive. As indicated above, data should be measured at 5 nm intervals with a spectral response function that is triangular with a 5 nm bandwidth at the half-power point, as specified in ISO 11664-3. Where unknown data are measured at other intervals and bandwidths, the sampling interval and bandwidth shall not exceed 10 nm. For applications where the spectral properties of the specimens are well established, conformance to process requirements may be assessed using 20 nm sampling. Estimated data from wide bandpass readings shall be reported at 10 nm intervals. Where measurement data are collected at intervals of less than 5 nm, it may be widened to 5 nm using the method of [Annex I](#).

4.3.2 Measurement geometry

Measurement geometry should be normal:diffuse (0:d) or diffuse:normal (d:0), utilizing an integrating sphere. If used, it shall conform to the geometric conditions defined in CIE Publication 176:2006. Alternatively, an influx optic compliant with ISO 5-2 may also be used for relative comparisons only.

NOTE For more information, see [B.2](#).

4.3.3 Illumination requirements and measurement conditions

4.3.3.1 Measurement condition M0

Transmitting materials, regular or diffuse, rarely have use cases where the media carrying the image contains fluorescent colorants or additives. So generally, transmittance and transmittance factor readings are taken using the M0 measurement condition.

The relative spectral power distribution of the flux incident on the specimen surface should conform to CIE illuminant A (corresponding to an incandescent source with a correlated colour temperature of 2 856 K). In practical instruments, this may be achieved using any source that provides radiant power at all wavelengths within the spectral range of 400 nm to 700 nm.

Because the specification of correlated colour temperature does not define UV, the UV content is not controlled under M0, and it is therefore recommended that M1 be used when there is the need to interchange data measured on samples that exhibit fluorescence. For more information, see [4.2.2.1](#).

4.3.3.2 Measurement condition M1

There are a few use cases in graphic reproduction, mainly in large format digital printing, where the substrate is a fabric and the yarn has been previously treated with an optical brightening agent (OBA) to produce a whiter appearance of the fabric upon which the image has been printed. These printed fabrics are mainly used as back-lit signs. While the transmittance of such translucent materials is not a well-defined or standardized geometry of measurement, it is recommended that such materials should be characterized using the M1 condition in order to create a standardized, reference condition in which the OBA will consistently activated relative to the absorption of light by the colorants.

4.3.4 Resolution and data reporting

Transmittance factor shall be reported to the nearest 0,000 1 relative to a perfect transmitting diffuser having a transmittance factor of 1 000 0 at all wavelengths. This data may be reported as either a decimal value or as a percentage. If the data are to be used for further calculations, then in order to minimize the accumulation of round-off errors, the full precision of the calculation should be carried

forward. Bandpass characteristics of data should be reported, including function shape (triangular, trapezoidal, etc.) and bandwidth (FWHM). See [Annex L](#) for information on the impact of instrumental bandpass on the calculation of spectral quantities. The fact that an opal glass or other plane diffusing material geometry was used shall also be reported. See also [Clause 6](#).

NOTE Opal geometry is discussed in ISO 5-2.

4.4 Self-luminous displays (spectral radiance) measurement

4.4.1 Wavelength range, wavelength interval and bandwidth

The data should be measured from 380 nm to 780 nm and shall be measured from 400 nm to 720 nm, inclusive. Modern visual display units have backlights that will have a spike in radiance just beyond 700 nm and ignoring that spike will result in significant errors in the measured chromaticity. Data should be measured at intervals of 5 nm or less with a triangular spectral response function and a half-power point bandwidth equal to the measurement interval. Data shall be measured at 10 nm intervals where the spectral response function is triangular with a 10 nm bandwidth at the half-power point. Data taken at 10 nm intervals should be corrected for bandpass according to ASTM E2729[18]. Wider sampling intervals or bandwidth are not appropriate for modern visual display units.

4.4.2 Measurement geometry

4.4.2.1 General

The spectral data may be measured either with a spectroradiometer in contact with the display surface or a telespectroradiometer placed at a typical viewer position. The measurements shall be carried out in the direction of the normal to the display surface. The area measured for each sample shall have a diameter of no less than 4 mm and shall contain at least 150 pixels.

For measurements made with a spectroradiometer or telespectroradiometer, the angular width of the sensing cone, i.e. the angle region over which the efflux is sensed by the receiver, shall not be more than a half angle of $5,0^\circ$ and should not be more than a half angle of $2,5^\circ$.

4.4.2.2 Viewer position

These measurements will be specific to the viewing conditions. Generally, the ambient illumination should conform to ISO 3664. However, when the ambient illumination to be used in practice is known, it may be desirable to perform the measurements with this illumination. The illuminance level and chromaticity of the ambient illumination, as measured at the display faceplate, should be reported. Care should be taken to minimize reflection of the ambient illumination from the display faceplate towards the measurement device. Specular reflections should be avoided.

4.4.2.3 Contact

These measurements should be performed with the display in the dark. This can be achieved by covering the display and measurement device or by darkening the room. Care should be taken to ensure that only radiation from the sample area is measured.

Contact measurements are used to characterize the display only; they are independent of the ambient illumination. If contact measurements are performed but viewer position measurements are desired, it is necessary to add the veiling glare that would be observed by the viewer to obtain measurements equivalent to those obtained from the viewer position.

4.4.3 Polarization

The measurement shall be independent of polarization effects when the following test is performed: Rotate the instrument around the normal on the display surface. The resulting data points in the CIE xy

chromaticity coordinates shall fit into a circle of 0,002 radius. The deviation of luminance of each measurement shall be less than 1 % from the average luminance.

4.4.4 Resolution and data reporting

The measured efflux from the display surface with the small angular sensing cone corresponds to the spectral radiance. The radiance values of the spectrum shall be reported in units of $W/(m^2/sr/nm)$ at equally spaced wavelength intervals of 1 nm, 5 nm or 10 nm over the defined wavelength range. If the data are to be used for further calculations, then in order to minimize the accumulation of round-off errors, the full precision of the calculation should be carried forward. Bandpass characteristics of data should be reported, including function shape (triangular, trapezoidal, etc.) and bandwidth (FWHM). See [Annex L](#) for information on the impact of instrumental bandpass on the calculation of spectral quantities. Values derived from the radiance spectrum according to [5.2](#), such as CIE X , CIE Y and CIE Z or CIE x , CIE y and CIE L , may be reported. The luminance CIE L shall be reported in cd/m^2 . See also [Clause 6](#).

The uncertainty of the instrument shall be defined for the measurement of chromaticity coordinates of a typical monitor white in accordance with ISO 3664 (short-term repeatability, 75 cd/m^2 , D65). The uncertainty of the CIE xy chromaticity coordinates under these conditions shall be within the radius of <0,002. The deviation of luminance of each measurement shall be less than 1 % from the average luminance. See also [Clause 6](#).

5 Colorimetric computation requirements

5.1 Calculation of tristimulus values for reflecting and transmitting samples

5.1.1 General

Tristimulus values shall be calculated according to the procedures in ISO 11664-3, a standard based on long standing recommendations found in CIE Publication 15 on colorimetry. To provide consistency with graphic arts viewing conditions, defined in ISO 3664, calculated tristimulus values shall be based on CIE illuminant D50 and the CIE 1931 standard colorimetric observer (often referred to as the 2° standard observer), as defined in ISO 11664-1. For data taken at 5 nm, CIE Publication 15 contains tables of illuminant D50 and the 2° observer functions at 5nm intervals. [Annex I](#) provides further background and examples of the calculations.

Weighting factors, representing the product of CIE illuminant D50 and the 2° standard observer, to be used for weighting spectral reflectance and transmittance data collected at 10 nm intervals and bandwidths, shall be those given in [Table I.2](#) for 10 nm intervals, as taken, with permission, from ASTM E 308-13. The weights in the ASTM table interpolate 10 nm data to 1 nm intervals.

NOTE 1 The CIE recommends (ISO 11664-3) that the standard method of calculating tristimulus values (CIE X , CIE Y and CIE Z) use 1 nm intervals. However, that same standard also notes that, in some cases, the standard method cannot be used because the colour stimulus function or relative colour stimulus function is not available over the full range of 360 nm to 830 nm in 1 nm intervals. If it is demonstrated that the resulting errors are insignificant for the purpose of the user, tristimulus values can be calculated by numerical summation from 380 nm to 780 nm at wavelength intervals, $\Delta\lambda$, equal to 5 nm using colour matching functions $x(\lambda)$, $y(\lambda)$, $z(\lambda)$ defined in ISO 11664-1. It does not recommend wider sampling intervals and bandwidths.

NOTE 2 The 2° standard observer is preferred over the 10° standard observer, because it more closely matches the conditions under which image detail in printed material is being viewed. When judging large areas of uniform solid colours, such as in packaging printing, the 10° standard observer is known to give better correlation to visual evaluations.

NOTE 3 The weights given in [Table I.2](#) are taken from ASTM E308-13, Table 5.9 and are ideally intended to be used with 10 nm data that have been corrected to have a 1 nm half power width.

NOTE 4 Adding the values of the weights from 380 nm to 780 nm in [Table I.2](#) does not give a sum equal to the values for X_n , Y_n and Z_n . This is because the writers of ASTM E 308-13 computed X_n , Y_n and Z_n using the CIE standard tables to greater precision than the interpolation weights given by the summation of the table values. The check sums in [Table I.2](#) are provided for use in data transcription validation.

5.1.2 Calculations with data having 5 nm interval and bandwidth

For the standard 5 nm sampling interval, tristimulus values shall be calculated according to numerical procedures described in ISO 11664-3 and presented in [L.2](#). Tables of values for the D50 illuminant and 2° observer functions at 5 nm intervals are available in CIE Publication 15. [Table I.1](#) contains a sample of reflectance factor data at 5 nm along with the results of tristimulus calculation using this procedure.

5.1.3 Calculations with data having 10 nm interval and bandwidth

For 10 nm interval and bandwidth, data should first be corrected for bandpass using the method in ASTM E2729[18]. Tristimulus values shall be calculated using the numerical procedures shown in [L.3](#), which are taken from ASTM E308-13, with spectral weighting factors found in [Table I.2](#). [Table I.3](#) contains a sample of reflectance data at 10 nm along with the results of tristimulus calculation using this procedure.

NOTE The weights given in [Table I.2](#) are taken, with permission, from ASTM E308-13, Table 5.9 and are intended for use with 10 nm data that has been corrected for bandpass by one of the available methods, such as ASTM E2729[18], as specified in ISO 11664-3.

5.1.4 Calculations with data having other intervals and bandwidth

For interval and bandwidth less than 5 nm, data should be converted to 5 nm interval using the procedure in [Annex E](#). The procedures in [5.1.2](#) shall then be used to calculate tristimulus values.

For interval and bandwidth greater than 5 nm and less than 10 nm, data should be converted to 5 nm intervals using one of the interpolation methods in CIE Publication 167. The procedure in [5.1.2](#) shall then be used to calculate tristimulus values.

For interval and bandwidth greater than 10 nm and up to 20 nm, data should first be corrected for bandpass using the procedure in ASTM E2729[18]. The data should then be converted to 10 nm interval using one of the interpolation methods in CIE Publication 167. Tristimulus values shall be calculated using the numerical procedures shown in [L.3](#), which are taken from ASTM E308-13, with the spectral weighting factors found in [Table I.2](#).

5.2 Calculation of tristimulus values for self-luminous displays

The tristimulus values are obtained by discrete summation of the following products:

$$X = K_m \cdot \sum_{380}^{780} S_n(\lambda) \bar{x}(\lambda) \Delta\lambda \quad (2)$$

$$Y = K_m \cdot \sum_{380}^{780} S_n(\lambda) \bar{y}(\lambda) \Delta\lambda \quad (3)$$

$$Z = K_m \cdot \sum_{380}^{780} S_n(\lambda) \bar{z}(\lambda) \Delta\lambda \quad (4)$$

where

| | |
|--|---|
| λ | is the wavelength, in nanometres (nm); |
| $S_n(\lambda)$ | is the measured spectral power distribution, in $W/(m^2/sr/nm)$; |
| $\bar{x}(\lambda)$, $\bar{y}(\lambda)$ and $\bar{z}(\lambda)$ | are the colour matching functions of the CIE 1931 standard colorimetric observer (see ISO 11664-1); |
| $\Delta\lambda$ | is the wavelength sampling interval, corresponding to the instrument bandwidth or the adjusted bandwidth; |
| K_m | is the maximum spectral luminous efficacy of radiation in the CIE standard system of physical photometry and its value is 683 lm/W. |

If the bandwidth and wavelength interval of the available data are 1 nm, the pertinent colour matching function of ISO 11664-1 with data at 1 nm intervals shall be used for insertion into [Formulae \(2\) to \(4\)](#). If the readings are obtained with a 5 nm bandwidth and sampling interval, then the colour matching functions in ISO 11664-1 shall be extracted at every fifth point. These values at 5 nm intervals are exactly the same as those found in the 5 nm tables for the 1931 Standard Colorimetric Observer in CIE 15.

Where the available data are only available at a bandwidth and wavelength interval other than 1 nm or 5 nm, values of the radiance spectrum for 5 nm intervals shall be calculated from the measurement values using one of the following steps.

- If the available data are at a bandwidth and wavelength interval greater than 1 nm but less than 5 nm, values of the radiance spectrum at 5 nm intervals shall be calculated from the measurement values using the method of [Annex E](#).
- If the available data are at a bandwidth and wavelength interval greater than 5 nm but less than or equal to 10 nm, data interpolation shall be performed to provide values of the radiance spectrum at 5 nm intervals using one of the interpolation procedures of CIE Publication 167:2005.

Relative values X_r , Y_r and Z_r shall be obtained as shown in [Formulae \(5\) to \(7\)](#):

$$X_r = 100 X/Y_w \quad (5)$$

$$Y_r = 100 Y/Y_w \quad (6)$$

$$Z_r = 100 Z/Y_w \quad (7)$$

where

X_r , Y_r and Z_r are the values relative to the adopted white;

Y_w is the Y value of the adopted white.

X_r , Y_r and Z_r are the values of the measured area relative to the adopted white. In many cases, the adopted white will be selected to be the display white point; however, in some cases, it will be selected to be lower or higher in luminance. For example, if a display is used for soft proofing, the display white point might be set to match the paper white, in which case the adopted white CIE Y value will be higher than that of the display white point. In the case of a high dynamic range display, the adopted white CIE Y value might be selected to be much lower than that of the display white point, to allow above white colours to be reproduced on the display.

From the CIE 1931 tristimulus values, the chromaticity coordinates x , y and the CIE 1976 u' , v' uniform chromaticity coordinates shall be calculated using [Formulae \(8\) to \(11\)](#).

$$x = X/(X + Y + Z) \quad (8)$$

$$y = X/(X + Y + Z) \quad (9)$$

$$u' = 4x/(-2x + 12y + 3) \quad (10)$$

$$v' = 9y/(-2x + 12y + 3) \quad (11)$$

5.3 CIE 1976 ($L^*a^*b^*$) colour space; CIELAB colour space

5.3.1 General

It is important to note that the issue of uniform visual colour spaces and colour difference formulae is the subject of significant activity within CIE and related organizations. Much of this work applies to textile evaluation under D65. However, by analogy, this work may be extrapolated to apply to printed images viewed under D50. The reader is urged to follow the work of CIE for current developments in both uniform visual colour spaces and colour difference computations. Currently, for graphic arts applications, CIELAB uniform colour space and its associated colour difference computations suffice. For computation of CIELAB colour differences the formulae in [Annex J](#) shall be utilized. In accordance with ISO 11664-4, CIELAB values shall be computed using the formulae given in [5.3.2](#), [5.3.3](#), and [5.3.4](#).

If CIELAB values for a self-luminous display are to be compared to those of reflective or transmissive materials determined in accordance with this document, the display adopted white needs to be set to D50.

5.3.2 CIELAB colour space formulae

The CIELAB colour space formulae are given in [Formulae \(12\)](#) to [\(20\)](#).

$$L^* = 116[f(Y/Y_n)] - 16 \quad (12)$$

$$a^* = 500[f(X/X_n) - f(Y/Y_n)] \quad (13)$$

$$b^* = 200[f(Y/Y_n) - f(Z/Z_n)] \quad (14)$$

where

$$f(X/X_n) = (X/X_n)^{1/3} \quad \text{if} \quad X/X_n > (6/29)^3 \quad (15)$$

$$f(X/X_n) = (841/108) (X/X_n) + 4/29 \quad \text{if} \quad X/X_n \leq (6/29)^3 \quad (16)$$

and

$$f(Y/Y_n) = (Y/Y_n)^{1/3} \quad \text{if} \quad Y/Y_n > (6/29)^3 \quad (17)$$

$$f(Y/Y_n) = (841/108) (Y/Y_n) + 4/29 \quad \text{if} \quad Y/Y_n \leq (6/29)^3 \quad (18)$$

and

$$f(Z/Z_n) = (Z/Z_n)^{1/3} \quad \text{if} \quad Z/Z_n > (6/29)^3 \quad (19)$$

$$f(Z/Z_n) = (841/108) (Z/Z_n) + 4/29 \quad \text{if} \quad Z/Z_n \leq (6/29)^3 \quad (20)$$

and where

L^* , a^* and b^* are the CIE 1976 L^* , a^* and b^* coordinates;

X , Y and Z are tristimulus values calculated according to 5.1 or 5.2;

X_n , Y_n and Z_n are the white points from Table I.1 for conditions specified in 5.1.

In accordance with ISO 11664-4, the reverse transformations are:

$$f(Y/Y_n) = (L^* + 16)/116 \quad (21)$$

$$f(X/X_n) = a^*/500 + f(Y/Y_n) \quad (22)$$

$$f(Z/Z_n) = f(Y/Y_n) - b^*/200 \quad (23)$$

$$X = X_n [f(X/X_n)]^3 \quad \text{if} \quad f(X/X_n) > 6/29 \quad (24)$$

$$X = (108/841)X_n [f(X/X_n) - 4/29] \quad \text{if} \quad f(X/X_n) \leq 6/29 \quad (25)$$

$$Y = Y_n [f(Y/Y_n)]^3 \quad \text{if} \quad f(Y/Y_n) > 6/29 \text{ for } L^* > 8 \quad (26)$$

$$Y = (108/841)Y_n [f(Y/Y_n) - 4/29] \quad \text{if} \quad f(Y/Y_n) \leq 6/29 \text{ for } L^* \leq 8 \quad (27)$$

$$Z = Z_n [f(Z/Z_n)]^3 \quad \text{if} \quad f(Z/Z_n) > 6/29 \quad (28)$$

$$Z = (108/841)Z_n [f(Z/Z_n) - 4/29] \quad \text{if} \quad f(Z/Z_n) \leq 6/29 \quad (29)$$

NOTE Integer ratios, for example, 4/29, are used for the formulae in this subclause to avoid rounding errors. Approximate correlates of the perceived attributes lightness, chroma and hue are calculated as follows.

CIE 1976 lightness L^* as defined in Formula (17)

$$\text{CIE 1976 chroma} \quad C_{ab}^* = (a^{*2} + b^{*2})^{1/2} \quad (30)$$

$$\text{CIE 1976 hue angle} \quad h_{ab} = \arctan (b^*/a^*) \quad (31)$$

where a^* and b^* are the CIE 1976 a^* and b^* coordinates.

5.3.3 CIE 1976 colour difference formulae

The CIE 1976 colour difference formulae as given in Annex J shall be used to compute CIELAB colour differences.

5.3.4 CIEDE2000 colour difference formulae

The CIEDE2000 colour difference formulae as given in Annex K shall be used to compute CIEDE2000 colour differences.

6 Measurement data reporting requirements

6.1 Required information

When data generated in accordance with this document are reported, they shall be accompanied by the following information:

- a) a statement that the measurements and computations are in conformance with this document, ISO 13655;
- b) the measurement conditions used (M0, M1, M2 or M3);
- c) for reflection specimens, the specimen backing (black – also referred to “bb”, white – also referred to “wb”);
- d) for non-opaque sample substrate materials, the CIEXYZ data of the unprinted substrate material shall be reported for white backing and where practical should be reported for black backing (see [4.2.5](#));
- e) instrument brand/model (where a single instrument is used for the provided data);

EXAMPLE ISO 13655 (M0, wb, Cosmodrive).

NOTE Characterization data can be created from multiple instruments and therefore are not directly linked to a specific instrument. A typical example might be named: ISO 13655 (M2, bb).

- f) shall report whether the manufacturer’s requirements for standardization have been followed.

6.2 Recommended information

The required information should also be accompanied by:

- a) the originator of the data;
- b) the creation date of the data;
- c) a description of the purpose or contents of the data being reported;
- d) a description of the instrumentation used, including, but not limited to sampling aperture information;
- e) the wavelength interval used for calculation;
- f) the reference(s) used for standardization and the process used to ensure or evaluate the standardization consistency;

EXAMPLE 1 Standardized as per manufacturer recommendation and periodically verified internally.

EXAMPLE 2 Verified with in-house certified reference materials (as described in [Annex D](#)).

6.3 Electronic data reporting

If data are to be reported in electronic form, it shall comply with ISO 28178.

Annex A (normative)

Sample backing

A.1 General

Many substrates used in photography and printing are not totally opaque. Therefore, the characteristics of the material behind a specimen during measurement or any printing on the back side can modify the reflectance factor measured. Any change in the spectral reflectance factor data will impact any values computed from this data, for example, colorimetry, density, etc.

The impact on the values measured is dependent on the opacity of the substrate. Where the issue is printing on the back side of the substrate, a partial suppression of the impact is possible by using a black backing.

If the substrate has a very low opacity, the differences in measured spectral reflectance factor data between white and black backing can be quite significant. An approximate conversion between data measured with white and black backings is given in [A.4](#).

The common options for backing materials are:

- standard black backing as defined in [A.2](#);
- standard white backing as defined in [A.3](#);
- self backing with multiple sheets of the specimen substrate material.

Self backing is preferred only in the paper making industry. However, only standard black or white backing shall be used for applications within the scope of this document.

NOTE Self backing depends on the availability of the unprinted substrate material whenever a specimen is to be measured. This is often not the case. Another problem would arise with automated scanning instruments where the backing is inaccessibly hidden within the instrument.

A.2 Standard black backing

Black material shall conform to ISO 5-4.

ISO 5-4 requires the following properties:

- spectrally non-selective, i.e. the total range of spectral diffuse reflection density throughout the wavelength interval from 400 nm to 700 nm does not exceed 5 % of the average density obtained over the same interval;
- it should be diffusely reflecting (e.g., little or no perceptible specular reflection when viewed at any angle less than 45° from the normal, under typical office room illumination conditions). As black materials with a matte surface are prone to physical damage the black backing material should be semi-matte (ISO 8254-75° gloss less than 40 GU);
- opaque substrate;
- minimum ISO 5 visual reflection density of 1,30;
- maximum ISO 5 visual reflection density of 1,60.

A.3 Standard white backing

White material shall have the following characteristics.

- a) It shall be opaque (e.g., ceramic, plastic or paper). The opacity shall be equal to or greater than 99.

$$O_B = (Y_b/Y_w) \times 100 \quad (\text{A.1})$$

where

O_B is opacity ($0^\circ:45^\circ$, D50, 2° , Y) of the backing material;

Y_b is the CIE Y value computed from measurements made using black backing conforming to [A.2](#);

Y_w is the CIE Y value computed from measurements made using a stack of at least three sheets of the material to be used for backing.

- b) It should be diffusely reflecting (e.g., little or no perceptible specular reflection when viewed at any angle less than 45° from the normal, under typical office room illumination conditions – typically referred to as a matte appearance). As white materials with a matte surface are prone to physical damage the white backing material shall be semi-matte (ISO 75° gloss less than 40 GU);

NOTE 1 Many print shops do not own an ISO 8254-75° glossmeter. However, as gloss tends to increase as the angle increases, the same tolerance can be used with angles of 60° or 85° as used with inks and coatings.

- c) Its CIELAB C^* value shall not exceed 3 and should not exceed 2,4.
- d) It shall be non-fluorescing (no emission in the response band of interest when excited by the instrument source). This is equivalent to reading the backing sheet with M1 and M2 modes and the differences at any wavelengths greater than 410nm shall be less than or equal to 3σ (3 standard deviations) of 5 readings of the backing sheet using only the M2 mode.

The spectral reflectance factor values shall lie within the range of the curves given in [Table A.1](#).

NOTE 2 While the data in [Table A.1](#) are described as conforming to ISO/CIE geometry $0^\circ:45^\circ$, this does not preclude the use of an instrument with $45^\circ:0^\circ$ geometry since the backing is required to be diffusely reflecting and as such will follow the Helmholtz law of reciprocity so that the readings from the two geometries will be identical.

Table A.1 — Spectral reflectance factor

| Wavelength nm | Spectral reflectance factors | |
|------------------|------------------------------|-------------|
| | Upper limit | Lower limit |
| 380 | 0,74 | 0,12 |
| 390 | 0,80 | 0,19 |
| 400 | 0,84 | 0,37 |
| 410 | 0,87 | 0,61 |
| 420 | 0,88 | 0,75 |
| 430 | 0,89 | 0,78 |
| 440 | 0,90 | 0,79 |
| 450 | 0,90 | 0,79 |
| 460 | 0,91 | 0,79 |
| 470 | 0,91 | 0,79 |
| 480 | 0,91 | 0,79 |
| 490 | 0,91 | 0,79 |
| 500 | 0,91 | 0,79 |

Table A.1 (continued)

| Wavelength nm | Spectral reflectance factors | |
|------------------|------------------------------|-------------|
| | Upper limit | Lower limit |
| 510 | 0,91 | 0,79 |
| 520 | 0,91 | 0,79 |
| 530 | 0,91 | 0,79 |
| 540 | 0,91 | 0,79 |
| 550 | 0,91 | 0,79 |
| 560 | 0,91 | 0,79 |
| 570 | 0,91 | 0,79 |
| 580 | 0,91 | 0,79 |
| 590 | 0,91 | 0,79 |
| 600 | 0,91 | 0,79 |
| 610 | 0,91 | 0,79 |
| 620 | 0,91 | 0,79 |
| 630 | 0,91 | 0,79 |
| 640 | 0,91 | 0,79 |
| 650 | 0,91 | 0,79 |
| 660 | 0,91 | 0,79 |
| 670 | 0,91 | 0,79 |
| 680 | 0,91 | 0,79 |
| 690 | 0,91 | 0,79 |
| 700 | 0,91 | 0,79 |
| 710 | 0,91 | 0,79 |
| 720 | 0,91 | 0,79 |
| 730 | 0,91 | 0,79 |

A.4 Black/white backing conversion

One possible conversion method is based on the observation^[21] that if the differences of CIE X, CIE Y, and CIE Z between measurements made over two backing materials (i.e. black and white) are plotted versus CIE X, CIE Y, and CIE Z for measurements made over either backing, the best fit result is approximately a straight line. This leads, as an approximation, to a linear conversion.

For CIE X:

$$X_w = X_b \cdot (1 + C) - X_{\min} \cdot C \quad (\text{A.2})$$

with

$$C = \frac{X_{sw} - X_{sb}}{X_{sb} - X_{\min}} \quad (\text{A.3})$$

where

X_w is the converted value of X of the specimen over white backing;

X_b is the measured value of X of the specimen over black backing;

C is a constant;

- X_{sw} is the measured value of X of the specimen substrate over white backing;
- X_{sb} is the measured value of X of the specimen substrate over black backing;
- X_{min} is the minimum value of X of the specimen over black backing.

In practice, the X value of the four-colour solid (ID 1286 in ISO 12642-2) are very close to, or equal to, the minimum value and may be used as X_{min} .

Conversion of CIE Y and CIE Z is accomplished in an analogous manner and CIELAB values are computed in a similar fashion.

Black and white backing conversion methods are still an active field of research and the user is recommended to test each model in the light of the pertinent use case. Printing substrates vary not only in colour but also in physical properties. Changes in physical properties impact ink/substrate interaction and light scattering. Changes in ink/substrate interaction and light scattering often result in changes in the tone values of the printed material for the same ink laydown. Therefore, a change in a printing substrate will usually require changes in colorimetric aims (due to paper colour) and changes in tone reproduction and process control aims to correct for the changes in tone value (resulting from changes in physical characteristics).

The correction technique described in this Annex only accounts for the changes in substrate colour. Differences in ink absorptivity or hold-out will result in a colour shift that cannot be corrected so that new aims must be developed.

A.5 Measurement of transparent materials

For substrates viewed by transmitted light, the measurement conditions of 4.3 apply. In the case of transparent substrates, which are viewed by reflection, a reflectance factor measurement using either $0^\circ:45^\circ$ or $45^\circ:0^\circ$ geometry is appropriate, using a white sample backing with the characteristics described in A.3.

Reflectance measurements of transparent materials are highly dependent on the reflectance of the backing material. In order to correct such measurements so that they are relative to a perfect reflecting diffuser, the following computation should be performed:

$$R(\lambda) = R_t(\lambda)/R_b(\lambda) \quad (\text{A.4})$$

where

λ is the wavelength, in nanometres (nm);

$R_t(\lambda)$ is the reflectance of the transparent specimen over the white backing material at wavelength λ ;

$R_b(\lambda)$ is the reflectance of the white backing material itself (not covered by the transparent substrate) at wavelength λ ;

$R(\lambda)$ is the corrected reflectance at wavelength λ .

The correction can also be performed using CIEXYZ as follows:

$$X = 100 \times (X_t/X_b) \quad (\text{A.5})$$

$$Y = 100 \times (Y_t/Y_b) \quad (\text{A.6})$$

$$Z = 100 \times (Z_t/Z_b) \quad (\text{A.7})$$

where the subscripts “t” and “b” have the same meaning as above.

NOTE This correction only applies to clear and not translucent material.

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Annex B (informative)

Geometry

B.1 Reflectance measurement

B.1.1 Angles

The appearance of any opaque object is largely a function of the spectral reflectance of that object in combination with a wide range of surface effects such as gloss, shape, texture, etc. Unfortunately, this combination of spectral reflectance and surface effects is difficult to characterize and measure. The basic instrumentation available to make reflectance measurements is limited to three configurations or geometries. These are (0°:45°) or (45°:0°) and (d:8°) instruments. Unfortunately, data from any one of these configurations cannot be easily modified to match data measured with another of the configurations. Under certain circumstances, spectral calculations permit conversions (see Reference [22]). For many applications the geometry is not critical. For others, specific configurations offer unique advantages and for some applications, the configuration used has its basis in historical practice and databases rather than application requirements.

In developing this document, one of the principal applications considered was the appearance of printed images on paper. Information available strongly indicated that the 0°:45° or 45°:0° geometry provides the best correlation to the reflectance seen by a human observer using the standard viewing conditions specified in ISO 3664 for graphic arts and photography. In addition, in the graphic arts, colorimetric data is often used in conjunction with densitometric data. The current reflection densitometry standard ISO 5-4 specify the use of (0°:45°) or (45°:0°) geometry and CIE Publication 176 provides guidance on tolerances on the aims.

One example of an important graphic arts application where the geometry specified in this document is not adequate is the determination of “bronzing” of inks. An integrating sphere instrument is required for this purpose.

Compliance with ISO 5-4 requires one of the geometries “forty-five degree annular: normal”, “forty-five degree circumferential: normal”, “normal: forty-five degrees annular”, and “normal: forty-five degrees circumferential”. An annular geometry is achieved with a ring reflector whereas a circumferential geometry uses as an approximation of the annular geometry, for example, a number of light sources/sensors placed around the circumference; see CIE Publication 176:2006.

If, however, sensing and/or irradiation is limited to a single azimuthal angle, directional and texture effects are emphasized. These geometries are deprecated in ISO 5-4 and in CIE Publication 176 and hence in this document. They are known as “forty-five degrees directional: normal” and “normal: forty-five degrees directional”.

NOTE Further details on measuring geometry and geometry tolerances can be found in CIE Publication 176.

B.1.2 Over filling and under filling

Control patches on print control strips are seldom larger than 5 mm square and small spot (45°:0°) and (0°:45°) geometry spectrophotometers are available to read them. The small size of the control patches and the small sampling aperture required to read them requires special consideration of variations due to translucent blurring (lateral scattering) error.

When a specimen is translucent, at least to some degree, some of the illuminating light penetrates the specimen and scatters laterally to points outside of the area viewed by the instrument detector, causing the reported reflectance values to be lower than they would be if all the reflected light were collected.

The interaction between the translucency of the specimen and optical configuration of the instrument is called translucent blurring, and the difference in the reflectance factor measured on the translucent specimen compared to the corrected reflectance factor is called translucent blurring error[20][23].

White glass reflectance standards and pressed powder pellets often used to calibrate large sampling aperture spectrophotometers are generally translucent. Graphic arts proofing and printing substrates are also translucent to some degree.

To minimize translucent blurring error, large uniform specimens are measured by illuminating a spot larger than the sample aperture (“over filling”) or vice versa (“under filling”). ISO 5-4 states that “the realized boundary of the larger of the illuminator region and the receiver region shall be outside the boundary of the smaller by at least 2 mm. Where small sampling apertures are required, this dimension shall be at least 0,5 mm. The magnitude of the resulting lateral diffusion error should be accepted as part of the overall measurement uncertainty, or a greater boundary differential should be used.”

To minimize errors due to translucent blurring, it is important to use opaque standardization reference materials.

B.1.3 Sampling aperture size, scanning area

When measuring half-tones, screen ruling is another factor that should be considered when selecting the instrument sampling aperture. If the area measured is made too small, the measurements become erratic and depend on the number of half-tone dots that happen to be measured. For a periodic screen and a single measurement, a rule of thumb says that at least 79 half-tone dots need to be within the sampling aperture, although 177 is better. This corresponds to the rule that for circular apertures the diameter ought to be at least 10 times, better 15 times, greater than the screen width. Table B.1 shows the minimum and recommended circular sampling aperture diameters and areas, respectively, as a function of screen ruling. If the sampling aperture is not circular, no dimension should be smaller than the diameter of a circular aperture.

Sampling apertures smaller than those of Table B.1 are permissible if the greater uncertainty of the single measurement is reduced by averaging over multiple measurements that are performed over an area that is within the range given by columns 4 and 5 of Table B.1. This method is to be applied by scanning instruments.

For half-tones without a constant screen frequency (non-periodic screens), it is recommended to use Table B.1 with a pseudo screen frequency calculated by dividing 0,120 by the diameter of the minimum image element of the non-periodic screen.

EXAMPLE The minimum diameter of a given non-periodic screen is 20 μm (0,002 cm). The division of 0,120 by 0,002 cm yields 60/cm, hence the recommendations of the line labelled 59,1 (150) in Table B.1 apply.

Table B.1 — Circular sampling aperture diameters and areas for the measurement of half-tones

| Screen frequency cm ⁻¹ (lpi) | Diameter | | Area | |
|--|---------------|-------------------|----------------------------|--------------------------------|
| | Minimum mm | Recommended mm | Minimum mm ² | Recommended mm ² |
| 25,6 (65) | 3,9 | 5,9 | 12,0 | 27,0 |
| 33,5 (85) | 3,0 | 4,5 | 7,0 | 15,8 |
| 39,4 (100) | 2,5 | 3,8 | 5,1 | 11,4 |
| 47,2 (120) | 2,1 | 3,2 | 3,5 | 7,9 |
| 52,4 (133) | 1,9 | 2,9 | 2,9 | 6,4 |
| 59,1 (150) | 1,7 | 2,5 | 2,3 | 5,1 |
| 68,9 (175) | 1,5 | 2,2 | 1,7 | 3,7 |
| 78,7 (200) | 1,3 | 1,9 | 1,3 | 2,9 |
| 98,4 (250) | 1,0 | 1,5 | 0,8 | 1,8 |

B.2 Transmission measurement geometry

Transmission measurement geometry is defined in this document to be in accordance with ISO 5-2, i.e. (0:*d*) or (*d*:0), with an opal glass or a plastic as the diffusing medium. The characteristics of the diffuser are also specified in ISO 5-2. For half-tones, the recommendations given in [B.1.3](#) are also useful.

As stressed in ISO 5-2, measurements made using the CIE Publication 15:2004 integrating sphere method do not produce exactly the same results. This is primarily due to inter-reflections occurring between the specimen and the diffuser in the ISO 5-2 method (which reflects many practical situations). Experimental evidence^[21] indicates that the differences obtained by the two procedures are most significant at high transmittances and the error introduced is generally linear with transmittance (and CIEXYZ values). CIEXYZ values that are measured using an opal reference will be higher than those obtained using an integrating sphere reference. The degree of difference is a function of the opal material, as well as the surface characteristics of the material being measured (smoothness, matte level, etc.).

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Annex C (informative)

Improving inter-instrument agreement

C.1 Calibration

Measurement devices need to be standardized using their own, up-to-date, standardizing material or certified reference materials (CRMs). It is good practice to first verify that the reference material period of validity has not expired. Next, check whether the reflection values stored in the instrument indeed pertain to the white reference to be used, this is generally performed by checking that the serial number of the reference tile matches that of the instrument. Then, as part of the full standardization procedure, make a zero reflectance measurement (on a black-trap apparatus) if provided as part of the manufacturer's procedures and measure the white reflection reference. In all cases, follow the procedures specified by the manufacturer of the instrument and those that come with the reference material. In most modern instruments, many of the standardizing procedures have been automated to require little human intervention. It is always a good idea to verify a standardizing step, once completed, by measuring the reference material again and comparing results to target values.

C.2 Screen ruling and sampling apertures

Half-tone areas are not to be measured with a sampling aperture that is too small to effectively evaluate the specimen. See [Annex B](#) for more detailed information about the aperture sizes for use when measuring half-tones with various screen rulings. Different sampling apertures measure different areas of a specimen. Therefore, it is a good idea to use a common sampling aperture size and shape for the comparison of measurements.

C.3 Measurement conditions

Many cases of measurement disagreement can be traced to the comparison of data measured under different conditions. An operator often has a choice of various instruments and their physical options such as geometry ($0^\circ:45^\circ$ or diffuse:normal with the specular component included or excluded, $di:8^\circ$ or $de:8^\circ$), UV component of the measurement source flux (included or excluded) or a polarizing filter (engaged or not). Additionally, there are many computational options, which can change the values of the reported readings, including the CIE illuminants (A, D50, D65, C, etc.) and the standard observer function (2° or 10° visual field size). Make sure that instruments and their settings comply with the provisions of this document.

C.4 Common model and manufacturer

The best agreement is achieved when devices employed come from a single manufacturer, and better still, from the same product family.

C.5 Reference materials

Many instruments employ a feature allowing the user to enter reference data into the memory of the instrument manually or through a reference material measurement process or downloaded from an interfaced computer system. Measurements are then made relative to the reference material's values. This can be helpful when comparisons between different specimens are required or should pass/fail parameters be used. Care needs to be taken to ensure this reference function is not

accidentally activated. Such errors could result in gross measurement differences between two or more instruments. For further information, see [Annex D](#).

C.6 Spectral correction

If the measures recommended in [C.1](#) to [C.5](#) are not sufficient to significantly improve inter-instrument agreement, consider the methods described in References [\[19\]](#) and [\[22\]](#). These authors use regression analysis to correct the measured spectra such that they approximate those of a chosen reference instrument.

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Annex D (informative)

Certified reference materials (CRMs)

D.1 General

As defined in ISO Guide 30, these are reference materials, accompanied by a certificate, one or more of whose property values are certified by a procedure which establishes traceability to an accurate realization of the unit in which the property values are expressed, and for which each certified value is accompanied by an uncertainty at a stated level of confidence. For the graphic arts industry, a level of confidence of roughly 95 % is generally accepted as sufficient. This corresponds to a coverage factor of 2, or 2 statistical standard deviations in the case of a normal distribution. For more information, see ISO 15790.

Since the onset of colour measurement in graphic technology, it has been plagued by a relatively poor inter-instrument agreement. This was the reason for the introduction of [Annex C](#) into this document. Recently, the situation has been further confounded by the use of highly fluorescent papers as print substrates. This tends to amplify differences between instruments where the spectral composition of the source is not identical in the UV region.

A single set of certified reference materials, certified by or traceable to a single, internationally recognized basic standards institute, that is adopted by practically all manufacturers would serve the following purposes:

- to alert the users about the inter-instrument problem;
- to show them when an instrument is out of specifications;
- to set the stage for a gradual reduction of inter-instrument differences.

Suitable sets of CRMs

- a) would include patches for white, the primary and secondary solids of the process colours, as well as a number of tertiary intermediate tones,
- b) would employ colorants and ink formulations that reasonably agree with those used for practical prints and proofs in terms of spectral dependence, surface and scattering characteristics,
- c) would preferably be thick-film specimens because these are less sensitive to wear,
- d) would be provided with the spectra and the CIELAB values of all patches measured in accordance with this document, and
- e) would need to be certified, or traceable to, an internationally recognized basic standards institute such as NIST (USA), PTB (DE), NPL (UK), CTP (France) and NRC (Canada).

CRMs would enable users to determine whether their instrument is within or outside the specs and would allow them to have the instrument recalibrated by the manufacturer, if necessary. Alternatively, the data given by the instrument could be used to correct the data by means of software tools, which need to be offered by the vendors.

Where a CRM contains optical brightening agents, spectra and colorimetric data needs to be provided for both measurement conditions M1 and M2.

D.2 Use of certified reference materials

Following the manufacturer's procedures for setting up and standardizing the instrument, measure a CRM colour patch and compare the measured CIELAB values to the reference values from the CRM's certificate.

For this comparison to be meaningful, it is necessary to determine the combined standard uncertainty of the result of the measurement. In order to determine this quantity, it is necessary to first estimate the uncertainties of each component of the process. (These estimates may be determined by statistical or other methods.) This process requires a knowledge of all sources of uncertainty, including reproducibility, u_r , (see ISO 15790:2004, 6.1.5), CRM uncertainty, u_{CRM} , (see ISO 15790:2004, 6.1.6), and other known sources of measurement uncertainty. When each component of the uncertainty is expressed as a variance (for normal distributions, this is the equivalent of the square of one standard deviation) or an estimate thereof, the positive square root of the sum of the variances (and estimates thereof) is equal to the combined standard uncertainty (assuming that all of the sources of uncertainty are independent, that is that they are not correlated); see ISO 15790:2004, 6.1.7.

The uncertainty of a measurement result determined for the measurement of a CRM might not be equal to the uncertainty of results of measuring other materials, even though they may have been evaluated with the same instrument. For example, the gloss of a reflection-density CRM is a characteristic of a CRM which might not affect the instrument's ability to accurately measure the density of a CRM. However, if specimens with a gloss which differs from that of a CRM are measured with the same instrument, this gloss difference may affect the uncertainty of the measured results. In such a case, the effect of gloss should be determined, and combined with other sources of uncertainty. See ISO 15790 for the characteristics of CRMs, which may also need to be considered when evaluating measurement uncertainties.

Once the combined standard uncertainty of the measurement system has been determined, the instrument calibration should then be verified using a CRM. If the absolute value of the difference between the measured value and CRM reference value is equal to or less than the combined standard uncertainty, no correction need be applied. If the absolute value of the difference between the measured value and reference value is greater than the combined standard uncertainty, a correction should be applied to the measurement result.

Corrections are preferably made using the spectral methods mentioned in References [5] and [20]. Because these are tedious, it is preferable to use algorithms that either reside in the instrument's firmware or are supplied by the manufacturer as software for computers that communicate with the instrument. Alternatively, the instrument could be adjusted by the user or the manufacturer.

When the result of the CRM measurement is equal to or within the specification, the performance is verified and adjustment is not required. When the result of the calibration falls outside the instrument's specification, there is potentially a problem with the method of measurement, the frequency of calibration, the instrument or the CRM.

Annex E (informative)

Procedures for widening the bandwidth

This document describes procedures for tristimulus integration of spectral measurements taken with instruments of various bandwidths. The method used for tristimulus integration assumes that the instrument bandwidth and sampling interval are approximately equal (a 5 nm sampling interval assumes a 5 nm bandwidth). A triangular response function of the measuring instrument, with the half-power points defining the bandwidth, is also assumed. This assumption is based on the design of the classic laboratory instrument which uses slit apertures and a diffraction grating or prism.

Where data is available which has been collected at intervals that do not correspond to the desired 5 nm intervals of the available colorimetric weighting functions, it should be modified (resampled) to provide estimated (pseudo) data at the required interval. This should be done only if the data has been collected at an interval that is less (smaller) than the desired 5 nm interval and if the bandwidth corresponds to the sampling interval. The technique that shall be used to create the desired data is to successively apply a triangular weighting function to the existing data based on the desired (new) sampling intervals and bandwidth. This data is then summed over the interval and normalized by the sum of the weights used. This process is repeated for each new data point required.

The weighting function is as shown in [Formula \(E.1\)](#):

$$W(\lambda_{Xn}) = \frac{\Delta\lambda - |\lambda_{Yn} - \lambda_{Xn}|}{\Delta\lambda} \quad (\text{E.1})$$

where

- $W(\lambda_{Xn})$ is the weighting function at wavelength X_n ;
- λ_{Yn} is the wavelength for which data is to be computed;
- λ_{Xn} is the wavelength of available data;
- $\Delta\lambda$ is the desired bandwidth

The function is defined in the interval given by

$$|\lambda_{Yn} - \lambda_{Xn}| < \Delta\lambda$$

In those situations where data is not available at the ends of the measurement range, the data should be assumed to be uniform and the last available measured value should be used to define the end values.

EXAMPLE The following example assumes that data is available at 3 nm intervals and that data is desired at 5 nm intervals. In the region of 420 nm, the specific values are at wavelengths of 403 nm, 406 nm, 409 nm, . . . 436 nm. The computation for the value at 420 nm is accomplished by the following.

- a) Since the bandwidth ($\Delta\lambda$) is 5 nm, only data from 410 nm to 430 nm will be used in computation (data values at 412 nm, 415 nm, 418 nm, 421 nm, 424 nm, 427 nm and 430 nm).
- b) The weighting functions will be 412 (0,2), 415 (0,5), 418 (0,8), 421 (0,9), 424 (0,6), 427 (0,3) and 430 (0). The sum of the weights is 3,3.
- c) The spectral data at each wavelength X_n is multiplied by the value of the weighting factor X_n and the products are summed and divided by the sum of the weights (3,3 in this example). This is then the value to be used for a 5 nm bandpass centred at 420 nm.

d) This process is repeated at wavelengths within the range of 340 nm to 780 nm at 5 nm intervals.

The same procedure is used to modify other available data intervals to provide input for colorimetric computation.

Narrowing the bandwidth is a more difficult procedure and is not, in general, a unique transformation. For more information on how to modify a measured reflectance factor curve to narrow the apparent bandwidth, see References [\[18\]](#), [\[27\]](#), [\[28\]](#) and [\[30\]](#).

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Annex F (informative)

Fluorescent specimens

F.1 General

At present, almost all graphic technology printing substrates exhibit substantial fluorescence. In most cases, this is due to the presence of optical brightening agents in the printing substrate materials. These require ultraviolet radiation of wavelengths below 400 nm for their excitation and then emit light in the blue region. The result is a shift of the CIELAB b^* coordinate towards the blue by about 1 to 10.

In rare cases, however, fluorescing colorants are used in the printing and proofing inks that respond to visible radiation well above 400 nm for their excitation. While practically all UV-excited fluorescence can be avoided by complying with the UV-cut specification M2 in [4.2.2.3](#), effects due to visible-light fluorescing colorants cannot be avoided and therefore tests for their presence are required.

The tests described below are appropriate only for specimens that contain UV activated fluors. Specimens containing the so-called daylight fluors, mentioned in the previous paragraph, have an excitation band that is significantly overlapped with the visible emission band. Such visible activated fluors cannot be easily assessed for the level or presence of fluorescence.

F.2 Historical tests for presence of fluorescence

F.2.1 General

The tests described below are appropriate only for specimens that contain UV activated fluors. Specimens containing so-called daylight activated fluors, that is, having an excitation band that is significantly overlapped with the visible emission band, cannot be easily assessed for the level or presence of fluorescence^[25].

F.2.2 Dual source measurement

The specimen is measured with two sources, one of which approximates illuminant A, the other of which approximates D65. The two spectral power distributions are strongly different. The resultant spectral data is then used to compute the tristimulus values, relative to D50, for both sources. The CIELAB difference between them is a measure of the fluorescence. It is acceptable if the two sources are obtained by filtration of a single source. If the instrument manufacturer provides the two spectral power distributions of the measurement sources, these are to be quoted when communicating the results in order to permit independent checks.

F.2.3 Single ultraviolet cut-off filter

This method only tests for the presence or absence of UV-excited fluorescence. If the instrument is provided with an optional UV-cut filter, for example, a filter with the transmission characteristics implicit in the specification in [4.2.2.3](#), measure the specimen with and without the UV-cut filter in the illumination light path. The CIELAB difference between the two measurements is a measure of UV-excited fluorescence.

F.2.4 Samples with and without optical brightener

This method tests for the change in total radiance factor between a white material with no brightener and the same material with a high level of optical brightener added. These material standards do not

need to be certified. The method requires that the two patches be read using the standard instrument conditions and the differences between the two spectral radiance factors be computed. The CIELAB difference between the readings of the patches is a measure of the UV-excited fluorescence.

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Annex G (normative)

Test method for UV-cut conformance

G.1 Test materials

Two substrates and a test filter are required.

G.1.1 Substrates

Substrate 1, consisting of a non-fluorescing white standard (WS); the white calibration tile of some instruments would suffice. Substrate 2, a paper with a high concentration of optical brighteners where the difference in CIE b^* measured with and without a UV-cut filter is in the range of 3 to 5.

G.1.2 Test filter

A test filter having the spectral transmittance characteristics is required:

- a) greater than 0,65 in the visible range above 420 nm;
- b) less than 0,50 at 410 nm;
- c) less than 0,20 at 400 nm;
- d) less than 0,01 at 390 nm.

NOTE This is equivalent to commercially available filters including the Wratten 2B and the FujiFilm SC-41 but not limited to either of these. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of the product named.

G.2 Preparatory procedures

The following procedures shall be noted prior to performing this test.

- a) The substrates shall be placed over a black backing.
- b) Care should be taken to maintain proper instrument placement over the substrate.
- c) For the test procedure described in [G.3](#), the test filter can be placed over the light path or optionally over both illumination and pickup as long as the resultant double absorption in the blue area does not increase signal-to-noise to a degree that affects the ability to make repeatable measurements.
- d) Instrument repeatability shall be verified prior to the test.

G.3 Procedure

Perform the following test measurements with the instrument operating in the M2 measuring mode.

- a) For the first measurement, place the test filter ([G.1.2](#)) in the illumination light path of the instrument and measure the spectral reflectance factor of the Substrate 1, (WS) ([G.1.1](#)).
- b) For the second measurement, remove the test filter and measure the spectral reflectance factor of Substrate 1, (WS).

- c) For the third measurement, place the test filter in the illumination light path of the instrument and measure the spectral reflectance factor of Substrate 2 (the optically brightened paper) (G.1.1).
- d) For the fourth measurement, remove the test filter and measure the spectral reflectance factor of Substrate 2 (the optically brightened paper).
- e) Calculate the spectral reflectance factor of Substrate 2 relative to Substrate 1, with the test filter included, by dividing the third measurement with the first measurement.
- f) Calculate the spectral reflectance factor of Substrate 2 relative to Substrate 1, without the test filter, by dividing the fourth measurement with the second measurement.
- g) In order to remove a residual scaling error between the two relative spectra in the green to red wavelength region, the mean value of the spectral reflectance factors in the range from 550 nm to 670 nm is computed for both cases, resulting in M5 (mean value of the relative spectrum with test filter) and M6 (mean value of the relative spectrum without test filter).
- h) Each value of the relative spectrum with the test filter [e]) is then multiplied by the factor (M6/M5).
- i) Subtract the relative spectra with [h]) and without [f]) the test filter.
- j) Compare the relative reflection factors at 440 nm. The difference shall be smaller than 0,03.

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Annex H (informative)

Special cases: Use of polarization

Although first-surface reflection is an important component of the optical stimulus that reaches the eye, there are special cases where first-surface reflection tends to dilute or disturb the effect that one seeks to measure. The installation of crossed polarizing filters removes most of the unwanted reflection signal. Due to the relatively high UV absorption of most polarizing filters, they are normally used in conjunction with, or they double as, UV-cutoff filters.

A classic example is the densitometric control of ink film thickness in sheet-fed offset printing. It was discovered that the installation of crossed polarizing filters serves to extend the linear part of the density versus ink film thickness dependence towards higher values, and serves to greatly reduce density dry-back. A similar effect is observed with the CIELAB colour drift due to ink drying; the drift is reduced significantly if polarizers are incorporated. Also, the linear part of the dependence of the CIELAB colour locus on the ink film thickness is extended. This is useful for process control at the make-ready stage while printing with high-intensity inks. Nevertheless it should be noted, in agreement with ISO 13656, that for controlling the production run (production after the OK copy), densitometry is the primary option.

In ink formulation, the correlation between the measured colour coordinates and the concentration of the constituent colorants is improved and hence the accuracy of the resulting ink formulation is improved.

It is further observed that with bronzing inks, the correlation between the visual impression and the measured colour coordinates is improved.

Notwithstanding the beneficial effects of crossed polarizers in the special cases mentioned above, it needs to be noted that for most other instances in colorimetry, the use of polarizers is counterproductive. This includes, but is not limited to, the comparison of matt and glossy specimens (often the case with proof and production prints) and the measurement of print specimens which have been surface finished with laminating films or which consist of a transparent plastic material that has been printed on the back side.

Annex I (informative)

Example computations for converting spectral measurements to tristimulus values

I.1 General

This document describes the method for collecting the fundamental spectral properties of materials or from sources and converting the tabulated spectral data into CIE tristimulus values, CIELAB colour space coordinates and computing colour differences between two such computations. Such conversions are defined to be based on the numerical integration of the colour stimulus function Φ_λ , which for object mode colorimetry is obtained by multiplying the spectral reflectance or transmittance data by the amount of radiation (light) available using the values from an illuminant table as shown in [Formulae \(I.1\)](#) and [\(I.2\)](#).

$$\Phi(\lambda) = R(\lambda) \times S(\lambda) \quad (\text{I.1})$$

or

$$\Phi(\lambda) = T(\lambda) \times S(\lambda) \quad (\text{I.2})$$

The colour stimulus function is then to be combined with the standard observer or colour matching functions and numerically integrated from 380 nm to 780 nm as shown in [Formula \(I.3\)](#)

$$\begin{aligned} X &= k \int_{380}^{780} \Phi(\lambda) \times \bar{x}(\lambda) d\lambda \\ Y &= k \int_{380}^{780} \Phi(\lambda) \times \bar{y}(\lambda) d\lambda \\ Z &= k \int_{380}^{780} \Phi(\lambda) \times \bar{z}(\lambda) d\lambda \end{aligned} \quad (\text{I.3})$$

$$k = \frac{100}{\int_{380}^{780} S(\lambda) \times \bar{y}(\lambda) d\lambda}$$

While it is assumed that the colour stimulus function and the colour matching functions are analytic functions of the wavelength, the exact form of these functions are not generally known. Thus, the functions are normally approximated by a discrete sampling of the data at number of evenly spaced wavelengths across the desired range (380 nm to 780 nm). Analytic integration, which requires infinitesimal steps, shall be approximated using numerical integration.

This Annex provides worked examples for a set of spectral data in order that users of this document may verify that they have in fact implemented the standard correctly. It has been a standard practice in graphic reproduction not to include spectral data in reference materials, profiles and characterization data sets. Even though such spectral data were originally obtained, the creators of the sets would use the spectra to compute tristimulus data and then discard the original spectra. It is therefore one goal of this Annex that we now provide a standard data set in tabular format which can be used to examine the process of numerical integration of a reflectance curve, illuminant (D50) and observer (1931 colour matching functions).

I.2 Standard sampling interval computational procedures for object colours

When converting measured spectral reflectance or transmittance factor into colorimetric values, one needs to approximate the unit nanometre numerical integration with a simpler, weighted summation. In an algebraic summation, the normalization constant k , included the constant $\Delta\lambda = 5 \text{ nm}$ in both the numerator and the denominator of the calculation and so, unlike the case for self-luminous colorimetry, the measurement step size need not be included in the summation. The procedure is thus very simple, if the object colour data has been collected at 5 nm intervals with a 5 nm spectral bandpass. See [Formula \(I.4\)](#).

$$\begin{aligned}
 X &= k \sum_{380}^{780} R(\lambda) \times S(\lambda) \times \bar{x}(\lambda) \\
 Y &= k \sum_{380}^{780} R(\lambda) \times S(\lambda) \times \bar{y}(\lambda) \\
 Z &= k \sum_{380}^{780} R(\lambda) \times S(\lambda) \times \bar{z}(\lambda) \\
 k &= 100 / \sum_{380}^{780} S(\lambda) \times \bar{y}(\lambda)
 \end{aligned}
 \tag{I.4}$$

where

- λ is the wavelength, in nanometres (nm);
- $R(\lambda)$ is the spectral reflectance factor at wavelength λ ;
- $S(\lambda)$ is the relative spectral power distribution at wavelength λ ;
- $\bar{x}(\lambda)$ is the spectral colour-matching function at wavelength λ for CIE X;
- $\bar{y}(\lambda)$ is the spectral colour-matching function at wavelength λ for CIE Y;
- $\bar{z}(\lambda)$ is the spectral colour-matching function at wavelength λ for CIE Z.

For data collected at the recommended 5 nm sampling interval and 5 nm bandwidth, the weights referenced here are simply the product of a CIE illuminant, such as D50 and a CIE standard observer, such as the 1931 2° colour-matching functions, taken from CIE Publication 15, Tables T.1 and T.4. If the measured spectral data begin at a wavelength greater than 360 nm, then all the weighting values for wavelengths less than the first measured wavelength shall be computed, summed and added to the weighting value for the first wavelength measured. If the last measured spectral data point is at a wavelength less than 780 nm, then all the weighting values for wavelengths greater than the last measured wavelength shall be summed and added to the weighting value for the last measured wavelength.

Table I.1 — Reflectance factor data for a set of process colours

| Wavelength (nm) | C | M | Y | K | Wavelength (nm) | C | M | Y | K |
|--------------------|-------|-------|-------|------|--------------------|------|-------|-------|------|
| 380 | 27,20 | 20,03 | 19,32 | 2,00 | 600 | 5,91 | 38,34 | 92,33 | 2,15 |
| 385 | 32,18 | 19,32 | 18,73 | 2,00 | 605 | 5,31 | 51,65 | 92,38 | 2,17 |
| 390 | 37,06 | 18,53 | 17,85 | 2,00 | 610 | 4,94 | 63,35 | 92,55 | 2,19 |
| 395 | 41,28 | 17,79 | 16,77 | 2,00 | 615 | 4,91 | 72,66 | 92,74 | 2,21 |
| 400 | 44,52 | 17,28 | 15,68 | 2,00 | 620 | 4,99 | 79,65 | 93,05 | 2,24 |

Table I.1 (continued)

| Wavelength (nm) | C | M | Y | K | | Wavelength (nm) | C | M | Y | K |
|--------------------|-------|-------|-------|------|--|--------------------|-------|-------|-------|------|
| 405 | 47,14 | 17,25 | 14,50 | 2,00 | | 625 | 5,06 | 84,44 | 93,37 | 2,27 |
| 410 | 49,50 | 17,81 | 13,23 | 2,00 | | 630 | 5,09 | 87,39 | 93,72 | 2,30 |
| 415 | 51,59 | 18,87 | 12,06 | 2,00 | | 635 | 5,25 | 89,38 | 94,12 | 2,33 |
| 420 | 53,88 | 20,14 | 11,09 | 2,00 | | 640 | 5,47 | 91,03 | 94,54 | 2,36 |
| 425 | 57,44 | 21,35 | 10,18 | 2,00 | | 645 | 5,91 | 92,21 | 94,94 | 2,39 |
| 430 | 60,59 | 22,32 | 9,42 | 2,00 | | 650 | 6,52 | 92,96 | 95,37 | 2,43 |
| 435 | 64,74 | 23,12 | 8,68 | 2,00 | | 655 | 7,16 | 93,42 | 95,69 | 2,47 |
| 440 | 70,35 | 23,59 | 8,00 | 2,00 | | 660 | 7,84 | 93,63 | 95,61 | 2,51 |
| 445 | 74,85 | 23,59 | 7,63 | 2,00 | | 665 | 8,45 | 93,59 | 95,31 | 2,55 |
| 450 | 77,49 | 23,36 | 7,97 | 2,00 | | 670 | 8,81 | 93,49 | 95,05 | 2,59 |
| 455 | 78,95 | 22,60 | 8,70 | 2,00 | | 675 | 8,77 | 93,35 | 94,85 | 2,64 |
| 460 | 79,80 | 21,25 | 9,46 | 2,00 | | 680 | 8,58 | 93,33 | 94,69 | 2,68 |
| 465 | 80,51 | 19,56 | 9,96 | 2,00 | | 685 | 8,24 | 93,67 | 94,82 | 2,73 |
| 470 | 80,70 | 17,68 | 9,87 | 2,00 | | 690 | 7,82 | 94,22 | 95,22 | 2,78 |
| 475 | 80,33 | 15,79 | 9,65 | 2,00 | | 695 | 7,35 | 94,71 | 95,74 | 2,83 |
| 480 | 79,81 | 14,05 | 10,08 | 2,00 | | 700 | 6,50 | 95,08 | 96,20 | 2,88 |
| 485 | 78,76 | 12,55 | 12,28 | 2,01 | | 705 | 5,90 | 95,45 | 96,57 | 2,93 |
| 490 | 77,11 | 11,18 | 17,43 | 2,01 | | 710 | 5,50 | 95,78 | 96,92 | 2,98 |
| 495 | 75,35 | 9,98 | 26,40 | 2,01 | | 715 | 5,58 | 96,08 | 97,26 | 3,04 |
| 500 | 73,38 | 8,86 | 38,89 | 2,01 | | 720 | 6,15 | 96,30 | 97,50 | 3,09 |
| 505 | 70,81 | 7,71 | 52,84 | 2,01 | | 725 | 7,13 | 96,52 | 97,67 | 3,14 |
| 510 | 67,66 | 6,58 | 65,42 | 2,01 | | 730 | 8,50 | 96,78 | 97,85 | 3,20 |
| 515 | 63,73 | 5,50 | 74,53 | 2,01 | | 735 | 10,39 | 97,05 | 98,02 | 3,25 |
| 520 | 59,16 | 4,67 | 80,16 | 2,02 | | 740 | 13,39 | 97,17 | 98,23 | 3,31 |
| 525 | 54,10 | 4,15 | 83,61 | 2,02 | | 745 | 18,57 | 97,33 | 98,49 | 3,36 |
| 530 | 48,84 | 3,80 | 85,86 | 2,02 | | 750 | 26,44 | 97,53 | 98,63 | 3,42 |
| 535 | 43,61 | 3,63 | 87,54 | 2,02 | | 755 | 37,10 | 97,79 | 98,63 | 3,48 |
| 540 | 38,52 | 3,61 | 88,95 | 2,03 | | 760 | 49,39 | 98,06 | 98,71 | 3,53 |
| 545 | 33,39 | 3,58 | 89,91 | 2,03 | | 765 | 61,07 | 98,18 | 98,92 | 3,59 |
| 550 | 28,36 | 3,42 | 90,54 | 2,04 | | 770 | 70,32 | 98,15 | 99,08 | 3,64 |
| 555 | 23,25 | 3,07 | 90,96 | 2,04 | | 775 | 77,31 | 98,19 | 99,13 | 3,70 |
| 560 | 18,46 | 2,79 | 91,26 | 2,05 | | 780 | 83,08 | 98,48 | 99,27 | 3,75 |
| 565 | 14,60 | 2,69 | 91,36 | 2,06 | | | | | | |
| 570 | 11,98 | 2,71 | 91,39 | 2,07 | | X | 18,90 | 35,72 | 77,84 | 2,07 |
| 575 | 10,16 | 2,97 | 91,47 | 2,08 | | Y | 28,54 | 18,16 | 83,64 | 2,09 |
| 580 | 8,79 | 4,06 | 91,69 | 2,09 | | Z | 60,60 | 16,01 | 10,62 | 1,65 |
| 585 | 7,72 | 7,36 | 91,93 | 2,10 | | | | | | |
| 590 | 6,97 | 14,38 | 92,14 | 2,12 | | | | | | |
| 595 | 6,45 | 25,22 | 92,32 | 2,13 | | | | | | |

I.3 Wide sampling interval computational procedures for object colours

When computing tristimulus values from spectral data with 10 nm interval data, the numerical integration can be approximated using the ASTM spectral weights method. This method applies weighting functions at each wavelength that are the algebraic equivalent of interpolating the measured spectral data to 1 nm intervals and then multiplying the 1 nm data by the 1 nm CIE illuminant D50 and CIE standard observer values taken from ISO 11664-1 and ISO 11664-2. Examples are shown for both spectral reflectance and transmittance readings. Unmeasured data are extrapolated as equal to the last measured value.

$$X = \sum_{\lambda=360}^{780} R(\lambda) \times W_X(\lambda) \tag{I.5}$$

$$Y = \sum_{\lambda=360}^{780} R(\lambda) \times W_Y(\lambda) \tag{I.6}$$

$$Z = \sum_{\lambda=360}^{780} R(\lambda) \times W_Z(\lambda) \tag{I.7}$$

where

- λ is the wavelength, in nanometres (nm);
- $R(\lambda)$ is the spectral reflectance factor at wavelength λ ;
- $W_X(\lambda)$ is the weighting factor at wavelength λ for CIE X;
- $W_Y(\lambda)$ is the weighting factor at wavelength λ for CIE Y;
- $W_Z(\lambda)$ is the weighting factor at wavelength λ for CIE Z.

The computation of the CIE X, CIE Y and CIE Z values for transmission sample data shall be as follows:

$$X = \sum_{\lambda=380}^{780} T(\lambda) W_X(\lambda) \tag{I.8}$$

$$Y = \sum_{\lambda=380}^{780} T(\lambda) W_Y(\lambda) \tag{I.9}$$

$$Z = \sum_{\lambda=380}^{780} T(\lambda) W_Z(\lambda) \tag{I.10}$$

where

- λ is the wavelength, in nanometres (nm);
- $T(\lambda)$ is the spectral transmittance factor at wavelength λ ;
- $W_X(\lambda)$ is the weighting factor at wavelength λ for CIE X;
- $W_Y(\lambda)$ is the weighting factor at wavelength λ for CIE Y;
- $W_Z(\lambda)$ is the weighting factor at wavelength λ for CIE Z.

NOTE 1 This procedure is consistent with ASTM E 308-13.