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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

Reference number
ISO 13655:2009(E)

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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.

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

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

ISO 13655 was prepared by Technical Committee ISO/TC 130, *Graphic technology*, in collaboration with Technical Committee ISO/TC 42, *Photography*.

This second edition cancels and replaces the first edition (ISO 13655:1996), which has been technically revised in the following parts:

Clause 4, “Spectral measurement requirements”, was revised concerning the spectral power distribution of the measurement source, the measurement of self-luminous displays, and the backing material to be used for reflectance measurement.

Clause 5, “Colorimetric computation requirements” was amended by inclusion of the CIE 1976 a, b colour space (see ISO 11664-4).

Some of the previous eight annexes were combined and shortened, two new annexes were introduced, and the Bibliography was updated.

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 is all based on the same set of measurement and computational choices. The purpose of this International Standard is to specify a limited number of such choices for the measurement and computation of the colorimetric characteristics of graphic arts images to allow valid and comparable data to be obtained. While this International Standard 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 revision of this International Standard was started, it was observed that almost all graphic arts specimens exhibited fluorescence. In most cases, this was due to optical brightening agents contained in the paper substrates. In rare cases, the printing inks were fluorescent. According to the recommendations of the 1996 version of this International Standard, this would have meant that the source used for the measurements (i.e. the spectral power distribution of the sample illumination) was required to closely match CIE illuminant D50. Yet when this 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 distribution 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 Δb^* when measuring papers 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 has 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 is 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 International Standard.

In this revision, four measurement choices are specified. 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 420 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 polarizing filter in the influx and efflux portions of the optical path with their principal axes of polarization in the orthogonal or “crossed” orientation.

The requirements of this International Standard 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.

INTERNATIONAL STANDARD **ISO 13655:2009(E)**

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

1 Scope

This International Standard establishes procedures for the measurements and colorimetrical computations appropriate to objects that reflect, transmit, or self-illuminate, including flat-panel displays. It also establishes procedures for computation of colorimetric parameters for graphic arts images. Graphic arts includes, but is not limited to, the preparation of material for, and volume production by, production printing processes that include offset lithography, letterpress, flexography, gravure and screen printing.

This International Standard does not address spectral measurements appropriate to other specific application needs, such as those used during the production of materials, e.g. printing ink, printing paper and proofing media.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the reference 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 11664-1:2007, *Colorimetry — Part 1: CIE standard colorimetric observers*

ISO 11664-2:2007, *Colorimetry — Part 2: CIE standard illuminants*

ISO 11664-4:2008, *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.

3 Terms and definitions

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

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

[ISO 22028-1]

3.2
bandwidth
width of the spectral response function of the instrument, measured between the half-power points

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

[ISO/IEC Guide 99 (VIM)]

NOTE 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.

3.4
CIE illuminant
illuminant defined by the International Commission on Illumination (CIE) in terms of relative spectral power distribution

NOTE Examples are CIE illuminants A, C, and various D illuminants.

3.5
illuminant
numeric tabulation of the relative spectral distribution of the radiant (light) flux incident on the specimen surface

NOTE 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 60050-845:1987 | CIE Publication 17.4:1987 (a joint publication between the IEC and CIE) for further information.

3.6
opacity of substrate
measure of the property that describes the ability of a specimen to hide a surface behind and in contact with it

NOTE The numerical value of opacity as used in this International Standard 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.

3.7
opaque substrate
substrate whose opacity, measured according to A.3, is 0,99 or greater

3.8
transparent substrate
clear material having minimal absorption or scattering of transmitted visible light

EXAMPLE Clear packaging film.

3.9
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

[IEC 60050-845:1987 | CIE Publication 17.4:1987]

NOTE 1 The industry commonly uses the term reflectance rather than reflectance factor.

NOTE 2 It is important to specify the geometry that establishes the given conditions of measurement. See Annex C.

3.10
specimen backing
material placed behind and in contact with the specimen during measurement

NOTE For this International Standard this can be either white or black.

3.11
spectroradiometer
instrument for measuring radiometric quantities in narrow wavelength intervals over a given spectral region

[IEC 60050-845:1987 | CIE Publication 17.4:1987]

3.12
telespectroradiometer
spectroradiometer that uses an optical relay component to allow measurements to be made at a distance from the specimen

3.13
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

[IEC 60050-845:1987 | CIE Publication 17.4:1987]

NOTE It is important to specify the geometry that establishes the given conditions of measurement. See Annex C.

3.14
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 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.

3.15
polarizing filter
filter that converts randomly polarized light into linearly polarized light while absorbing all radiation with wavelengths less than 400 nm

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 E and F.

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 E and F 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 360 nm to 780 nm and shall be measured from 400 nm to 700 nm, inclusive. Data should be measured at 10 nm intervals with a spectral response function that is triangular with a 10 nm bandwidth at the half-power point. Where data is measured at other intervals and bandwidths, which shall not exceed 20 nm (interval and bandwidth), estimated data shall be reported at 10 nm intervals, and the data shall be adjusted to simulate measurement data obtained with a triangular spectral response function with a 10 nm bandwidth.

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 a correlated colour temperature of 2 856 K). In practical instruments, the relative spectral power distribution of the flux incident on the specimen surface should conform to a correlated colour temperature of 2 856 K ± 100 K.

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 on sheets that exhibit fluorescence. When instruments meeting M1 are not available and relative data is 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 International Standard.

There are two methods to achieve conformance to condition M1.

1) The spectral power distribution of the measurement source at the sample plane should match CIE illuminant D50. It shall conform to the UV range metamerism index specified for viewing condition P1 of ISO 3664. This method is to be used when both luminescent colorants and optical brighteners are of concern.

2) 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. 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 be continuous.

The instrument manufacturer should supply a representative spectral power distribution of the measurement source at the sample plane with the instrument documentation.

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 and 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 F) 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, the instrument can be considered to be in conformance with this International Standard.

NOTE 3 Annex D provides information on fluorescence and techniques to test for its presence.

NOTE 4 In cases where a printing ink fluoresces and accurate colorimetric data is required, measurement condition M1 is the only choice. However, in many situations, instruments meeting M1 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 provides 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 will have 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 H.

For measurement condition M2, the source is not explicitly specified. However, it shall be continuous 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.

NOTE 2 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 3 Annex D 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 G, an instrument may be equipped with a polarizing filter in order to suppress the influence of first-surface reflection on the colour co-ordinates. An instrument fitted with a polarizing filter shall also meet the requirements of 4.2.2.3. Using the test method of ISO 5-4:2009, Annex D, 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 co-ordinates, substitute “measured value reaches a maximum” for “reflection density reaches a minimum”. The equation becomes:

$$P = \frac{X_2}{X_1}$$

where:

P is the gloss suppression factor;

X_1 is the value measured without the polarizing filter;

X_2 is the value measured with the polarizing filter.

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

NOTE For directional and uniplanar measurement geometries, which are not specified by this International Standard, 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 circular; see Annex C. It shall also conform to the geometric conditions defined in ISO 5-4 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 C.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 “bronzing”.

NOTE 3 Annex C 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). For non-opaque sample substrate materials, the CIEXYZ data for the unprinted substrate material shall be reported for both black and white backing, 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 360 nm to 780 nm and shall be measured from 400 nm to 700 nm, inclusive. Data should be measured at 10 nm intervals where the spectral response function is triangular with a 10 nm bandwidth at the half-power point. Where data is measured at other intervals and bandwidths, data shall be computed that estimates the values that would have been obtained from measurements made at 10 nm intervals with a triangular spectral response function with a 10 nm bandwidth at the half-power point. Measurement data shall not be collected at intervals greater than 20 nm.

Where measurement data is collected at intervals of less than 10 nm, it may be widened using the method of Annex I.

4.3.2 Measurement geometry

Measurement geometry shall be normal:diffuse (0:d) or diffuse:normal (d:0). It shall conform to the geometric conditions defined in ISO 5-2.

NOTE For more information, see C.2.

4.3.3 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. The fact that an opal geometry was used shall also be reported. See also Clause 6.

4.4 Self-luminous displays (spectral radiance) measurement

4.4.1 Wavelength range, wavelength interval and bandwidth

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.

NOTE CIE recommends (CIE Publication DS 014-3) that the standard method of calculating tristimulus values (CIE X, CIE Y and CIE Z) use 1 nm intervals. However, that same document 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.

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° and should not be more than a half angle of 2,5°.

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.

NOTE 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. 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 reflective and transmissive samples

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. Computation shall be at 10 nm intervals. Factors representing the product of CIE illuminant D50 and the 2 ° standard observer data, to be used for weighting spectral reflectance and transmittance data, shall be those given in Table 1 for 10 nm intervals, as taken, with permission, from ASTM E 308:2006.

NOTE 1 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.

NOTE 2 The weights given in Table 1 are based on triangular bandpass characteristics as referred to in 4.3.1.

NOTE 3 Adding the values of the weights from 360 nm to 780 nm in Table 1 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 308:2006 computed X_n, Y_n and Z_n to greater precision than given by the summation of the table values. The check sums in Table 1 are provided for use in data transcription validation.

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

$$X = \sum_{\lambda = 360}^{780} R(\lambda) \times W_X(\lambda) \tag{1}$$

$$Y = \sum_{\lambda = 360}^{780} R(\lambda) \times W_Y(\lambda) \tag{2}$$

$$Z = \sum_{\lambda = 360}^{780} R(\lambda) \times W_Z(\lambda) \tag{3}$$

where

λ is the wavelength, in nanometres (nm);

$R(\lambda)$ is the 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:

$$X = \sum_{\lambda = 360}^{780} T(\lambda) \times W_X(\lambda) \tag{4}$$

$$Y = \sum_{\lambda = 360}^{780} T(\lambda) \times W_Y(\lambda) \tag{5}$$

$$Z = \sum_{\lambda = 360}^{780} T(\lambda) \times W_Z(\lambda) \tag{6}$$

where

λ is the wavelength, in nanometres (nm);

$T(\lambda)$ is the 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.

If the measured spectral data begin at a wavelength greater than 360 nm, then all the weighting values in Table 1 for wavelengths less than the first measured wavelength shall be 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 in Table 1 for wavelengths greater than the last measured wavelength shall be summed and added to the weighting value for the last measured wavelength.

NOTE 4 This procedure is consistent with ASTM E 308:2006.

EXAMPLE Reflectance data are provided from 400 nm to 700 nm at 10 nm bandwidth and interval. First, sum the weights contained in Table 1 from 360 nm to 390 nm and from 710 nm to 780 nm for $W_X(\lambda)$, $W_Y(\lambda)$, *and* $W_Z(\lambda)$ individually and add them to the values for 400 nm and 700 nm, respectively. Enter the spectral and weight data into a spreadsheet or similar program and carry out the wavelength-wise multiplications. The results of that summation are the values for CIE X; for CIE Y, for CIE Z.

Table 1 — Spectral weights, $W(\lambda)$, for illuminant D50 and the 2° observer for calculating tristimulus from data at 10 nm intervals

Wavelength (nm)	**Spectral weights**		
	$W_X(\lambda)$[a]	$W_Y(\lambda)$[a]	$W_Z(\lambda)$[a]
360	0,000	0,000	0,001
370	0,001	0,000	0,005
380	0,003	0,000	0,013
390	0,012	0,000	0,057
400	0,060	0,002	0,285
410	0,234	0,006	1,113
420	0,775	0,023	3,723
430	1,610	0,066	7,862
440	2,453	0,162	12,309
450	2,777	0,313	14,647
460	2,500	0,514	14,346
470	1,717	0,798	11,299
480	0,861	1,239	7,309
490	0,283	1,839	4,128
500	0,040	2,948	2,466
510	0,088	4,632	1,447
520	0,593	6,587	0,736
530	1,590	8,308	0,401
540	2,799	9,197	0,196
550	4,207	9,650	0,085
560	5,657	9,471	0,037
570	7,132	8,902	0,020
580	8,540	8,112	0,015
590	9,255	6,829	0,010

Table 1 (*continued*)

Wavelength (nm)	**Spectral weights**		
	$W_X(\lambda)$[a]	$W_Y(\lambda)$[a]	$W_Z(\lambda)$[a]
600	9,835	5,838	0,007
610	9,469	4,753	0,004
620	8,009	3,573	0,002
630	5,926	2,443	0,001
640	4,171	1,629	0,000
650	2,609	0,984	0,000
660	1,541	0,570	0,000
670	0,855	0,313	0,000
680	0,434	0,158	0,000
690	0,194	0,070	0,000
700	0,097	0,035	0,000
710	0,050	0,018	0,000
720	0,022	0,008	0,000
730	0,012	0,004	0,000
740	0,006	0,002	0,000
750	0,002	0,001	0,000
760	0,001	0,000	0,000
770	0,001	0,000	0,000
780	0,000	0,000	0,000
Check sums	96,421	99,997	82,524
White point	$X_n = 96{,}422$	$Y_n = 100{,}000$	$Z_n = 82{,}521$

[a] The values of these weighting functions are extracted, with permission, from Table 5.9 of ASTM E 308:2006.

5.2 Calculation of tristimulus values for self-luminous displays

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

$$X = k \sum_{\lambda=360}^{780} S_n(\lambda)\bar{x}(\lambda)\Delta\lambda \tag{7}$$

$$Y = k \sum_{\lambda=360}^{780} S_n(\lambda)\bar{y}(\lambda)\Delta\lambda \tag{8}$$

$$Z = k \sum_{\lambda=360}^{780} S_n(\lambda)\bar{z}(\lambda)\Delta\lambda \tag{9}$$

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 CIE Publication 15:2004);

$\Delta\lambda$ is the wavelength sampling interval, corresponding to the instrument or the adjusted bandwidth;

k is a conversion factor from watts to lumens and its value is 683 lm/W.

If the bandwidth and wavelength interval of the available data is 1 nm, the pertinent colour matching function of ISO 11664-1 with data at 1 nm intervals shall be used for insertion into Equations (7) to (9).

Where the available data is 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 is 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 I.
- If the available data is 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 15:2004.

Relative values X_r, Y_r and Z_r shall be obtained as follows:

$$X_\mathrm{r} = 100X/Y_\mathrm{w} \tag{10}$$

$$Y_\mathrm{r} = 100Y/Y_\mathrm{w} \tag{11}$$

$$Z_\mathrm{r} = 100Z/Y_\mathrm{w} \tag{12}$$

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.

NOTE 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 co-ordinates x, y and the CIE 1976 u', v' uniform chromaticity co-ordinates shall be calculated using Equations (13) to (16).

$$x = X/(X + Y + Z) \tag{13}$$

$$y = Y/(X + Y + Z) \tag{14}$$

$$u' = 4x/(-2x + 12y + 3) \tag{15}$$

$$v' = 9y/(-2x + 12y + 3) \tag{16}$$

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 equations 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. In accordance with ISO 11664-4, these values shall be computed using the equations given in 5.3.2 and 5.3.3 .

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

5.3.2 CIELAB colour space equations

The CIELAB colour space equations are given in Equations (17) to (36).

$$L^* = 116[f(Y/Y_n)] - 16 \tag{17}$$

$$a^* = 500[f(X/X_n) - f(Y/Y_n)] \tag{18}$$

$$b^* = 200[f(Y/Y_n) - f(Z/Z_n)] \tag{19}$$

where

$$f(X/X_n) = (X/X_n)^{1/3} \quad \text{if} \quad X/X_n > (6/29)^3 \tag{20}$$

$$f(X/X_n) = (841/108)\,(X/X_n) + 4/29 \quad \text{if} \quad X/X_n \leqslant (6/29)^3 \tag{21}$$

and

$$f(Y/Y_n) = (Y/Y_n)^{1/3} \quad \text{if} \quad Y/Y_n > (6/29)^3 \tag{22}$$

$$f(Y/Y_n) = (841/108)\,(Y/Y_n) + 4/29 \quad \text{if} \quad Y/Y_n \leqslant (6/29)^3 \tag{23}$$

and

$$f(Z/Z_n) = (Z/Z_n)^{1/3} \quad \text{if} \quad Z/Z_n > (6/29)^3 \tag{24}$$

$$f(Z/Z_n) = (841/108)\,(Z/Z_n) + 4/29 \quad \text{if} \quad Z/Z_n \leqslant (6/29)^3 \tag{25}$$

and where

L^*, a^* and b^*	are the CIE 1976 L^*, a^* and b^* co-ordinates;
X, Y and Z	are the values calculated from Equations (1) to (9);
X_n, Y_n and Z_n	are the white points from Table 1 for conditions specified in 5.1.

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

$$f(Y/Y_n) = (L^* + 16)/116 \tag{26}$$

$$f(X/X_n) = a^*/500 + f(Y/Y_n) \tag{27}$$

$$f(Z/Z_n) = f(Y/Y_n) - b^*/200 \tag{28}$$

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

$$X = (108/841)X_n[f(X/X_n) - 4/29] \quad \text{if} \quad f(X/X_n) \leqslant 6/29 \tag{30}$$

$$Y = Y_n[f(Y/Y_n)]^3 \quad \text{if} \quad f(Y/Y_n) > 6/29 \text{ for } L^* > 8 \tag{31}$$

$$Y = (108/841)Y_n[f(Y/Y_n) - 4/29] \quad \text{if} \quad f(Y/Y_n) \leqslant 6/29 \text{ for } L^* \leqslant 8 \tag{32}$$

$$Z = Z_n[f(Z/Z_n)]^3 \quad \text{if} \quad f(Z/Z_n) > 6/29 \tag{33}$$

$$Z = (108/841)Z_n[f(Z/Z_n) - 4/29] \quad \text{if} \quad f(Z/Z_n) \leqslant 6/29 \tag{34}$$

NOTE Integer ratios, e.g. 4/29, are used for the equations 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 Equation (17)	
CIE 1976 chroma	$C^*_{ab} = (a^{*2} + b^{*2})^{1/2}$	(35)
CIE 1976 hue angle	h_{ab} = arctan (b^*/a^*)	(36)

where a^* and b^* are the CIE 1976 a^* and b^* co-ordinates.

5.3.3 CIE 1976 colour difference equations

The CIE 1976 colour difference equations are given in Equations (37) to (43).

$$\Delta E^*_{ab} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \tag{37}$$

$$\Delta L^* = L^*_1 - L^*_2 \tag{38}$$

$$\Delta a^* = a^*_1 - a^*_2 \tag{39}$$

$$\Delta b^* = b^*_1 - b^*_2 \tag{40}$$

$$\Delta C^*_{ab} = C^*_{ab1} - C^*_{ab2} \tag{41}$$

$$\Delta h_{ab} = h_{ab1} - h_{ab2} \tag{42}$$

$$\Delta H^*_{ab} = k\sqrt{\left(\Delta E^*_{ab}\right)^2 - (\Delta L^*)^2 - \left(\Delta C^*_{ab}\right)^2}\ ;\ k = -1 \text{ if } \Delta h_{ab} < 0,\ k = 1 \text{ elsewhere;} \tag{43}$$

where

ΔE^*_{ab}	is the CIE 1976 L^*, a^*, b^* colour difference;
ΔL^*	is the CIE L^* difference between specimens 1 and 2;
Δa^*	is the difference of the CIE 1976 a^* values between specimens 1 and 2;
Δb^*	is the difference of the CIE 1976 b^* values between specimens 1 and 2;

ΔC^*_{ab} is the CIE 1976 a, b chroma difference between specimens 1 and 2;

ΔH^*_{ab} is the CIE 1976 a, b metric hue difference between specimens 1 and 2;

Δh_{ab} is the CIE 1976 a, b hue angle difference, in radian, between specimens 1 and 2.

6 Measurement data reporting requirements

6.1 Required information

When data generated in accordance with this International Standard is reported, they shall be accompanied by the following information:

a) a statement that the measurements and computations are in conformance with this International Standard, ISO 13655:2009;

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) 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 is not directly linked to a specific instrument. A typical example might be named: ISO 13655 (M2, bb).

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) for non-opaque sample substrate materials, the CIEXYZ data of the unprinted substrate material shall be reported for both black and white backing (see 4.2.5).

6.3 Electronic data reporting

If data is 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, e.g. 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 and ink making industries. However, only standard black or white backing shall be used for applications within the scope of this International Standard.

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.

NOTE 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;
- diffuse-reflecting (i.e. no perceptible specular reflection when viewed at any angle under typical office room illumination conditions);
- essentially opaque;
- minimum ISO 5 visual reflection density of 1,30.

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.

$$O_\mathrm{B} = (Y_\mathrm{b}/Y_\mathrm{w}) \times 100 \qquad \text{(A.1)}$$

where

O_B is opacity (0°:45°, 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 shall be diffuse-reflecting (e.g. no perceptible specular reflection when viewed at any angle under typical office room illumination conditions).

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).

e) The spectral reflectance factor values shall exceed those of Table A.1 but the CIE L^* value shall not exceed 97.

Table A.1 — Spectral reflectances

Wavelength nm	**Spectral reflectance factor value**
400	0,30
410	0,30
420	0,75
450	0,75
460	0,80
670	0,80
680	0,75
700	0,75
NOTE This corresponds to a CIE L^* greater than 92.	

A.4 Black/white backing conversion

One possible conversion method is based on the observation[20] 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:

$$X_{\mathrm{w}} = X_{\mathrm{b}} \cdot (1 + C) - X_{\mathrm{min}} \cdot C \tag{A.2}$$

with

$$C = \frac{X_{\mathrm{sw}} - X_{\mathrm{sb}}}{X_{\mathrm{sb}} - X_{\mathrm{min}}} \tag{A.3}$$

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 value of X of the specimen in the group having the lowest value of X over black backing, typically an area where three or four inks are printed on top of each other with 100 % coverage (if this value is not known, a value of zero may be used for X_{min}).

Conversion of CIE Y and CIE Z is accomplished in an analogous manner and CIELAB values are computed there from.

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.

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°:45° or 45°:0° 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:

$$R(\lambda) = R_{\mathrm{t}}(\lambda) / R_{\mathrm{b}}(\lambda) \tag{A.4}$$

where

λ is the wavelength, in nanometres (nm);

$R_{\mathrm{t}}(\lambda)$ 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:

$$X = X_t / X_b \tag{A.5}$$

$$Y = Y_t / Y_b \tag{A.6}$$

$$Z = X_t / Z_b \tag{A.7}$$

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

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

Annex B
(informative)

Computation of the CIE 2000 total colour difference (CIEDE2000)

One recommended procedure for calculation of small colour differences is the use of the CIEDE2000 formula as described in CIE Publication 15:2004 and CIE Publication 142. It is also advisable to consult the CIE website (http://www.cie.co.at) for the latest publications in this field.

The parametric factors for variation in the experimental conditions, k_L, k_C, k_H are 1, 1, 1 for the following conditions: Standard illuminant D65, illuminance 1 000 lx, homogenously-coloured object samples in direct edge contact, with a CIE 1976 total colour difference not exceeding 5, the samples subtending a visual angle greater than 4°, the samples lying on a background with a uniform, neutral grey colour with $L^* = 50$.

Presently, there are no established parametric factors for the viewing condition P1 specified in ISO 3664, i.e. 2 000 lx and D50, which is nearly always employed in graphic technology. In the interim period, until more decisive experimental results are available, the choice of 1, 1, 1 is regarded as the best solution.

The CIEDE2000 total colour difference formula corrects for the non-uniformity of the CIELAB colour space for small colour differences under reference conditions. Improvements to the calculation of total colour difference for industrial colour difference evaluation are made through corrections for the effects of lightness dependence, chroma dependence, hue dependence and hue-chroma interaction on perceived colour difference. The scaling along the a^* axis is modified to correct for a non-uniformity observed with grey colours. The resulting recommendation for the CIEDE2000 total colour difference ΔE_{00}^* and its calculation is summarized below, quoted from CIE Publication 15:2004. A sample calculation is given in ASTM D 2244.

$$\Delta E_{00}^* = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{k_C S_C}\right)\left(\frac{\Delta H'}{k_H S_H}\right)} \tag{B.1}$$

where

$\Delta L'$ is the transformed lightness difference between specimens 1 and 2, see Equation (B.2);

$\Delta C'$ is the transformed chroma difference between specimens 1 and 2;

$\Delta H'$ is the transformed hue difference between specimens 1 and 2;

R_T is the rotation function, see Equation (B.11);

k_L, k_C and k_H are the parametric factors for variation in the experimental conditions;

S_L, S_C and S_H are the weighting functions, see Equations (B.7) to (B.9).

First, a localized modification of the scaling along the a^* axis is made which is most significant for colours at low chroma.

$$L' = L^* \tag{B.2}$$

$$a' = a^*(1 + G) \tag{B.3}$$

$$b' = b^* \tag{B.4}$$

with

$$G = 0{,}5\left\{1 - \sqrt{\frac{\overline{C}_{\mathrm{ab}}^{*7}}{\overline{C}_{\mathrm{ab}}^{*7} + 25^7}}\right\} \tag{B.5}$$

and

$$\overline{C}_{\mathrm{ab}}^{*} = 0{,}5(C_{\mathrm{ab1}}^{*} + C_{\mathrm{ab2}}^{*}) \tag{B.6}$$

where

L' is the transformed lightness;

a' is the transformed a^* (red-green opponent) co-ordinate;

b' is the transformed b^* (yellow-blue) co-ordinate;

G is a quantity that depends on the mean chroma of specimens 1 and 2.

The transformed L', a', b' values are then used to calculate hue angle, chroma and lightness. These new quantities are designated by a prime mark. With these results the weighting functions and the rotation function are determined using the following equations:

$$S_{\mathrm{L}} = 1 + \frac{0{,}015(\overline{L'} - 50)^2}{\sqrt{20 + (\overline{L'} - 50)^2}} \tag{B.7}$$

$$S_{\mathrm{C}} = 1 + 0{,}045\overline{C'} \tag{B.8}$$

$$S_{\mathrm{H}} = 1 + 0{,}015\overline{C'}T \tag{B.9}$$

with

$$T = 1 - 0{,}17\cos(\overline{h'} - 30°) + 0{,}24\cos(2\overline{h'}) + 0{,}32\cos(3\overline{h'} + 6°) - 0{,}20\cos(4\overline{h'} - 63°) \tag{B.10}$$

where

S_{L}, S_{C} and S_{H} are the weighting functions;

$\overline{L'}$ is the mean of the transformed lightnesses for specimens 1 and 2;

$\overline{C'}$ is the mean of the transformed chromas for specimens 1 and 2;

T is a quantity that depends on the mean of the transformed hue angles for specimens 1 and 2;

$\overline{h'}$ is the mean of the transformed hue angles for specimens 1 and 2.

Finally, the rotation function is calculated from the following equations:

$$R_{\mathrm{T}} = -R_{\mathrm{C}}\sin(2\Delta\Theta) \tag{B.11}$$

with

$$\Delta\Theta = 30^\circ \exp\left\{-\left[(\bar{h}' - 275^\circ)/25\right]^2\right\} \qquad \text{(B.12)}$$

and

$$R_\mathrm{C} = 2\sqrt{\frac{\bar{C}'^7}{\bar{C}'^7 + 25^7}} \qquad \text{(B.13)}$$

where

R_T is the rotation function;

$\Delta\Theta$ is the hue angle difference depending on the mean of the transformed hue angles for specimens 1 and 2;

$\bar{h}'$ is the mean of the transformed hue angles for specimens 1 and 2;

R_C is a quantity that depends on the mean of the transformed chromas for specimens 1 and 2;

$\bar{C}'$ is the mean of the transformed chromas for specimens 1 and 2.

Annex C
(informative)

Geometry

C.1 Reflectance measurement

C.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 [21]). 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 International Standard, 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.

One example of an important graphic arts application where the geometry specified in this International Standard 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 15:2004.

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 hence in this International Standard. 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.

C.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 [19][22].

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 calibration reference materials.

C.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 ten times, better 15 times, greater than the screen width. Table C.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 C.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 C.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 C.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 C.1 apply.

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

Screen frequency	**Diameter**		**Area**	
	Minimum	**Recommended**	**Minimum**	**Recommended**
cm^{-1} (lpi)	mm	mm	mm^2	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

C.2 Transmission measurement geometry

Measurement geometry is defined in this International Standard 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 C.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 [20] 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.).

Annex D
(informative)

Fluorescent samples

D.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^* co-ordinate towards the blue by about 1 to 10.

In rare cases, however, fluorescing colorants are used in the printing and proofing inks that require 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.

D.2 Historical tests for presence of fluorescence

D.2.1 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.

D.2.2 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, e.g. 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.

D.2.3 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.

Annex E
(informative)

Improving inter-instrument agreement

E.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. Then, as part of the full calibration procedure, make a zero reflectance measurement (on a black-trap apparatus) 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.

E.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 C 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.

E.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°:45° or diffuse:normal with the specular component included or excluded, di:8° or de:8°), 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 International Standard.

E.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.

E.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 F.

E.6 Spectral correction

If the measures recommended in E.1 to E.5 are not sufficient to significantly improve inter-instrument agreement, consider the methods described in References[18] and [21]. These authors use regression analysis to correct the measured spectra such that they approximate those of a chosen reference instrument.

Annex F
(informative)

Certified reference materials (CRMs)

F.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 E into this International Standard. 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 and, finally, 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 International Standard;

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.

F.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 [19]. 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 G
(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 polarizing filters 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 co-ordinates 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 co-ordinates is improved.

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.

Notwithstanding the beneficial effects of polarizing filters in the special cases mentioned above, it needs to be noted that for most other instances in colorimetry, the use of polarizing filters 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 H
(normative)

Test method for UV-cut conformance

H.1 Test materials

Two substrates and a test filter are required.

H.1.1 Substrates, having the following characteristics.

H.1.1.1 Substrate 1, consisting of a non-fluorescing white standard (WS), the white calibration tile of some instruments would suffice;

H.1.1.2 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 be in the range of 3 to 5.

H.1.2 Test filter, having the spectral transmittance characteristics:

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 International Standard and does not constitute an endorsement by ISO of the product named.

H.2 Preparatory procedures

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

- The paper shall be placed over a black backing.
- Care should be taken to maintain proper instrument placement over the sample.
- For the test procedure described in H.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.
- Instrument repeatability shall be verified prior to the test.

H.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 (H.1.2) in the illumination light path of the instrument and measure the spectral reflectance factor of the WS (H.1.1.1).

b) For the second measurement remove the test filter and measure the spectral reflectance factor of 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 the optically brightened paper (H.1.1.2).

d) For the fourth measurement, remove the test filter and measure the spectral reflectance factor of the optically brightened paper.

e) Calculate the spectral reflectance factor of the optically brightened paper relative to WS, with the test filter included, by dividing the third measurement with the first measurement.

f) Calculate the spectral reflectance factor of the optically brightened paper relative to WS, without the test filter included, 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.

Compare the relative reflection factors at 440 nm. The difference shall be smaller than 0,03.

Annex I
(informative)

Procedures for widening the bandwidth

This International Standard 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 10 nm sampling interval assumes a 10 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 10 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 10 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 follows:

$$W\left(\lambda_{Xn}\right)=\frac{\Delta\lambda-\left|\lambda_{Yn}-\lambda_{Xn}\right|}{\Delta\lambda}$$

where

$W\left(\lambda_{Xn}\right)$ 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

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

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 10 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 following.

a) Since the bandwidth ($\Delta\lambda$) is 10 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 10 nm bandpass centred at 420 nm.

d) This process is repeated at wavelengths within the range of 340 nm to 780 nm at 10 nm intervals.

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

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