INTERNATIONAL STANDARD

ISO 13655

First edition
1996-10-01

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 13655:1996(E)

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International Organization for Standardization
Case postale 56 • CH-1211 Genève 20 • Switzerland

Printed in Switzerland

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.

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.

International Standard ISO 13655 was prepared by Technical Committee ISO/TC 130, *Graphic technology*.

Annex A forms an integral part of this International Standard. Annexes B to J are for information only.

Introduction

There are many practices for making spectral measurements and colorimetric computations allowed in CIE Publication 15.2. The choice of instrument geometry, illuminant, observer, etc. are all left to the user. Unfortunately, the selections made will result in different numerical values for the same parameter for the same material. Furthermore, measurements made under one method usually cannot be converted to correspond to a different method. Thus, one may not be able to make valid comparisons using data from different methodologies. The purpose of this International Standard is to specify a methodology for the measurement of graphic arts images which results in valid and comparable data. While this International Standard references the standard established for graphic arts viewing conditions, it is not intended to provide an absolute correlation with visual colour appearance.

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

1 Scope

This International Standard establishes a methodology for reflection and transmission spectral measurement and colorimetric parameter computation for graphic arts images. Graphic arts includes, but is not limited to, the preparation of material for, and volume production by, production printing processes which include offset lithography, letterpress, flexography, gravure and screen printing.

This International Standard does not apply to three-filter (tristimulus) colorimeters although annexes B, D, E, F and G may also be relevant to those instruments.

This International Standard applies to colour measurement of limited volume reproductions of coloured images such as those produced with photographic, ink jet, thermal transfer, diffusion, electrophotography, mechanical transfer or toner technology (e.g. off-press proofs) when used for graphic arts applications.

This International Standard does not address the spectral measurement of light emitted by video monitors nor does it supersede the specification of other measurement geometries appropriate to specific application needs, such as the evaluation of materials (e.g. ink and paper) used in the graphic arts.

NOTE 1 Procedures for colour measurement of spectral data from video monitors are included in ASTM E 1336-91[4]. The use of integrating sphere geometry for paper evaluation is covered in ISO 2469[2].

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 5-2:1991, *Photography — Density measurements — Part 2: Geometric conditions for transmission density.*

ISO 5-4:1995, *Photography — Density measurements — Part 4: Geometric conditions for reflection density.*

ISO 3664:1975, *Photography — Illumination conditions for viewing colour transparencies and their reproductions.*

CIE Publication 15.2:1986, *Colorimetry.*

3 Definitions and abbreviations

For the purposes of this International Standard, the following definitions and abbreviations apply.

3.1 CIE: Commission Internationale de l'Eclairage.

3.2 CIE illuminants: Illuminants A, D_{50}, D_{65} and other D illuminants, defined by the CIE in terms of relative spectral power distributions.

3.3 illuminant: Radiation with a relative spectral power distribution defined over the wavelength range that influences object colour perception.

3.4 measurement illuminant: Characteristic of the radiant flux (light) incident on the specimen surface.

3.5 radiance factor: Ratio of the radiance of the surface element in the given direction to that of a perfect reflecting or transmitting diffuser identically irradiated.

3.6 reflectance factor: Ratio of the radiant or luminous flux reflected in the directions delimited by the given cone to that reflected in the same direction by a perfect reflecting diffuser identically irradiated or illuminated.

3.7 sample backing: Surface on which the sample is placed for measurement.

3.8 transmittance factor (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.

3.9 bandwidth: Width of the spectral response function at the half-power point.

NOTE 2 For spectral measurement equipment a triangular response function is assumed.

4 Spectral measurement requirements

4.1 Instrument calibration

The measurement instrument shall be calibrated in accordance with its manufacturer's instructions. The calibration standard provided by the manufacturer shall be traceable to a national standardizing institution.

NOTE 3 Where multiple instruments are used for measurement, there will be differences in the resulting data due to the individual characteristics of the instruments. Annex H provides a methodology by which such data can be brought into better agreement. The methodology is applicable to both reflection and transmission spectrophotometry.

4.2 Spectral power distribution of the measurement source

4.2.1 Non-fluorescing materials

If the materials do not fluoresce, the spectral power distribution of the measurement source is not a concern and so no specification is given for the conformity of the spectral power distribution of the measurement source to the illuminant specified in 5.1.

4.2.2 Fluorescing materials

To minimize the variations in measurements between instruments due to fluorescence, the spectral power distribution of the measurement source shall match CIE illuminant D_{50} specified in 5.1 over the wavelength range of potential energy absorption and emission.

NOTE 4 It is recognized that many instruments presently do not have a measurement source that matches illuminant D_{50}. Annex G provides further information on fluorescence and techniques to test for its presence.

4.3 Wavelength range and interval for measured values

The data should be measured from 340 nm to 780 nm at 10 nm intervals and shall be measured from 400 nm to 700 nm, inclusive, at intervals of no more than 20 nm. The reference for spectral data shall be based on computed data at 10 nm intervals, where the spectral response function is triangular with a 10 nm bandwidth.

NOTE 5 Instrumentation with different intervals and response functions will produce different results. These differences can be reduced by proper selection of bandpass shape for a given interval and by applying the proper method of calculation for the bandpass characteristic and interval selected.

4.4 Reflectance factor measurement

4.4.1 Sample backing material

A sample backing material as defined in ISO 5-4:1995, 4.7, shall be placed under or behind the sample during measurement to eliminate variability due to sample backing and any material printed on the reverse side of the sample. See annex D.

4.4.2 Measurement geometry

Measurement geometry shall be 45°/0° or 0°/45° and conform with the geometric conditions defined in ISO 5-4.

NOTES

6 The use of 45°/0° or 0°/45° geometry will not adequately address variations in all surface characteristics. Other instrumentation can be used to detect specific characteristics such as "bronzing". See annex E.

7 It is recognized that many instruments do not conform to the requirement in ISO 5-4 for a 2 mm boundary beyond the sampling aperture due to the physical size of the press colour bars which are normally measured. Annex F provides further information on aperture size.

4.4.3 Measurement reporting

Measured reflectance factors shall be multiplied by 100 and shall be reported to the nearest 0,01 %, or decimal equivalent, relative to a perfect reflecting diffuser having 100 % reflectance at all wavelengths.

4.5 Transmittance factor measurement

4.5.1 Measurement geometry

Measurement geometry shall be normal/diffuse (0°/d) or diffuse/normal (d/0°) and conform either to the geometric conditions defined in ISO 5-2 or those of CIE 15.2

The measurement geometry and the use of an integrating sphere or opal diffuser shall be reported. (See annex E.)

4.5.2 Measurement reporting

Measured transmittance factor shall be multiplied by 100 and shall be reported to the nearest 0,01 %, or decimal equivalent, relative to the perfect transmitting diffuser having 100 % transmittance at all wavelengths. (See annex E.)

5 Colorimetric computation requirements

5.1 Calculation of tristimulus values

To provide consistency with graphic arts viewing conditions, defined in ISO 3664, calculated tristimulus values shall be based on CIE illuminant D_{50} and the CIE 1931 standard colorimetric observer (often referred to as the 2° standard observer) as defined in CIE Publication 15.2. Computation shall be at 10 nm or 20 nm intervals. Factors representing the product of CIE illuminant D_{50} 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 and table 2 for 20 nm intervals, as taken from ASTM E 308[3]. The user is strongly encouraged to use data at 10 nm intervals to improve the accuracy of the results.

NOTE 8 The 2° standard observer was selected rather than the 10° standard observer, because it more closely matches the size of image detail found in printed material.

If the measured spectral data begin at a wavelength greater than 340 nm, then all the weighting factors in table 1 or table 2 for wavelengths less than the first measured wavelength shall be summed and added to the weighting factor for the first wavelength measured.

If the last measured spectral data are at a wavelength less than 780 nm, then all the weighting factors in table 1 or table 2 for wavelengths greater than the last measured wavelength shall be summed and added to the weighting factor for the last wavelength measured.

The general form of these computations is:

Reflection

$$X = \sum_{\lambda=340}^{\lambda=780} [R(\lambda) \cdot W_X(\lambda)]$$

$$Y = \sum_{\lambda=340}^{\lambda=780} [R(\lambda) \cdot W_Y(\lambda)]$$

$$Z = \sum_{\lambda=340}^{\lambda=780} [R(\lambda) \cdot W_Z(\lambda)]$$

Transmission

$$X = \sum_{\lambda=340}^{\lambda=780} [T(\lambda) \cdot W_X(\lambda)]$$

$$Y = \sum_{\lambda=340}^{\lambda=780} [T(\lambda) \cdot W_Y(\lambda)]$$

$$Z = \sum_{\lambda=340}^{\lambda=780} [T(\lambda) \cdot W_Z(\lambda)]$$

where

$R(\lambda)$ is the reflectance factor at wavelength λ;

$T(\lambda)$ is the transmittance factor at wavelength λ;

$W_X(\lambda)$ is the weighting factor at wavelength λ for tristimulus value X;

$W_Y(\lambda)$ is the weighting factor at wavelength λ for tristimulus value Y;

$W_Z(\lambda)$ is the weighting factor at wavelength λ for tristimulus value Z.

If measured data is at intervals and bandpass is smaller than 10 nm, the method described in annex A shall be used to widen the bandpass of the data.

NOTE 9 The weighting factors given in table 1 and table 2 are based on triangular bandpass characteristics as referred to in 4.3.

The values of X_n = 96,422, Y_n = 100,000 and Z_n = 82,521 shall be used to do colorimetric calculations.

NOTES

10 Adding the weighting factors from 340 nm to 780 nm in table 1 or in table 2 does not give a sum equal to the values for X_n, Y_n and Z_n. This is because X_n, Y_n and Z_n were computed to greater precision in ASTM E 308 than as given by the summation of the table values. The sums for X, Y and Z in the tables are useful as a data entry check.

11 As a convenience for those applications which cannot conform to this International Standard but which use CIE illuminant D_{65}, weighting factors used to calculate tristimulus values for CIE illuminant D_{65} and the CIE 1931 standard colorimetric observer (often referred to as the 2° standard observer) are included in annex C.

12 Tables 1 and 2 and tables C.1 and C.2 have been reproduced, with permission, from the Annual Book of ASTM Standards, copyright American Society for Testing and Materials, 1916 Race St., Philadelphia, PA 19130, USA.

Table 1 — Weighting factors (W) for illuminant D_{50} and 2° observer for calculating tristimulus values at 10 nm intervals

Wavelength nm	$W_X(\lambda)$	$W_Y(\lambda)$	$W_Z(\lambda)$
340	0,000	0,000	0,000
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
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
Sums	96,421	99,997	82,524

Table 2 — Weighting factors (W) for illuminant D_{50} and 2° observer for calculating tristimulus values at 20 nm intervals

Wavelength nm	$W_X(\lambda)$	$W_Y(\lambda)$	$W_Z(\lambda)$
340	0,000	0,000	0,000
360	−0,001	0,000	−0,003
380	−0,007	0,000	−0,034
400	0,100	0,001	0,459
420	1,651	0,044	7,914
440	4,787	0,325	24,153
460	4,897	1,018	28,125
480	1,815	2,413	15,027
500	0,044	6,037	4,887
520	1,263	13,141	1,507
540	5,608	18,442	0,375
560	11,361	18,960	0,069
580	16,904	16,060	0,026
600	19,537	11,646	0,014
620	15,917	7,132	0,003
640	8,342	3,245	0,000
660	3,112	1,143	0,000
680	0,857	0,310	0,000
700	0,178	0,064	0,000
720	0,044	0,016	0,000
740	0,011	0,004	0,000
760	0,002	0,001	0,000
780	0,001	0,000	0,000
Sums	96,423	100,002	82,522

NOTE — Although weighting factors are provided for 20 nm intervals, the user is strongly encouraged to use data at 10 nm intervals to improve the accuracy of the results.

5.2 Calculation of other colorimetric parameters

Colorimetric parameters shall be calculated using the equations given in CIE Publication 15.2. The equations for CIELAB L^*, a^*, b^*, C^*_{ab} and h_{ab} and their associated colour difference equations are included in annex B, together with the equations for CMC colour difference.

5.3 Data reporting

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

a) confirmation that measurements and computations are in conformance with ISO 13655;

b) originator of the data;

c) date of creation of the data;

d) a description of the purpose or contents of the data being exchanged;

e) a description of the instrumentation used, including, but not limited to, the brand and model number;

f) measurement source (light source and filter) conditions used;

g) wavelength interval used.

Annex A
(normative)

Procedures for widening the bandwidth of narrow bandpass instruments

The body of this International Standard describes procedures for tristimulus integration of spectral measurements taken with either 10 nm or 20 nm bandwidth instruments. 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 and a 20 nm sampling interval implies a 20 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 or 20 nm intervals of the available colorimetric weighting functions weighting, it must be modified (resampled) to provide estimated (pseudo) data at the required interval. This shall be done only if the data has been collected at an interval that is less (smaller) than the desired 10 nm or 20 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:

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

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 shall be assumed to be uniform and the last available measured value shall be used to define the end values.

NOTE 13 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 as follows:

1 Since the bandwidth ($\Delta\lambda$) is 10 nm, only data from 410 to 430 will be used in computation (data values at 412, 415, 418, 421, 424, 427 and 430).

2 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.

3 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.

4 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 with the available 10 nm and 20 nm weighting functions.

Annex B
(informative)

Computation of CIELAB, CIELUV and CMC(l:c) parameters

B.1 CIELAB colorimetric parameters

(see CIE Publication 15.2)

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

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

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

for: $X/X_n > 0{,}008\,856$, $f(X/X_n) = (X/X_n)^{1/3}$

$Y/Y_n > 0{,}008\,856$, $f(Y/Y_n) = (Y/Y_n)^{1/3}$

$Z/Z_n > 0{,}008\,856$, $f(Z/Z_n) = (Z/Z_n)^{1/3}$

for: $X/X_n \leqslant 0{,}008\,856$, $f(X/X_n) = 7{,}786\,7(X/X_n) + 16/116$

$Y/Y_n \leqslant 0{,}008\,856$, $f(Y/Y_n) = 7{,}786\,7(Y/Y_n) + 16/116$

$Z/Z_n \leqslant 0{,}008\,856$, $f(Z/Z_n) = 7{,}786\,7(Z/Z_n) + 16/116$

where

$X_n = 96{,}422$, $Y_n = 100{,}000$ and $Z_n = 82{,}521$ for the conditions described in 5.1.

$$C^*_{ab} = (a^{*2} + b^{*2})^{1/2}$$

$$h_{ab} = \tan^{-1}(b^*/a^*)$$

where

$0° \leqslant h_{ab} < 90°$ if $a^* > 0$, $b^* \geqslant 0$

$90° \leqslant h_{ab} < 180°$ if $a^* \leqslant 0$, $b^* > 0$

$180° \leqslant h_{ab} < 270°$ if $a^* < 0$, $b^* \leqslant 0$

$270° \leqslant h_{ab} < 360°$ if $a^* \geqslant 0$, $b^* < 0$

B.2 CIELUV colorimetric parameters

(see CIE Publication 15.2)

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

$$u^* = 13L^*(u' - u'_n)$$

$$v^* = 13L^*(v' - v'_n)$$

where

$$u' = 4X/(X + 15Y + 3Z)$$

$$v' = 9Y/(X + 15Y + 3Z)$$

and u'_n, v'_n are the values of u', v' for the reference white.

The two spaces defined above are examples of Uniform Colour Spaces. They are called this because the uniformity of them, in terms of numerical difference, between colours which are perceived as having equal differences, is far better than for XYZ. Two such spaces were approved by the CIE in 1976 because there were somewhat conflicting requirements. One of these was that the colour space should have an associated chromaticity diagram whose coordinates must be linearly related to x and y.

For users who are concerned with the mixing of coloured lights (which includes the television industry) the linearity of the XYZ system is an important property since it means that the colour obtained by mixing coloured lights is easily predicted because of additivity. It follows from this that the colour gamut obtained by mixing three additive stimuli can be defined simply by constructing linear boundaries in colour space between the primaries and the white and black. When specified for a chromaticity diagram this simplifies to a triangle joining the chromaticity values of the primaries. Hence the requirement that a Uniform Colour Space must have an associated chromaticity diagram as achieved by plotting u' against v'.

Pigments do not exhibit additive behaviour. Non-turbid media, such as dyes, approximate it well when colorimetric density is used. However, that is of limited use to graphic technology where pigments, which exhibit turbid behaviour, are the normal reproduction colorants. It is frequently stated, though rarely proved, that CIELAB provides a more uniform space in the region of interest to graphic technology. In this context it has become the preferred colour space for this industry and is widely quoted. However, since it does not have a linear relationship to XYZ (because of the cube-roots in the calculation of a^* and b^*) there is no chromaticity diagram associated with it. Thus the colour gamut of a set of additive primaries cannot be easily calculated. Whilst it is not strictly accurate to do so, because of the non-additive behaviour exhibited by pigments, the colour gamut of a set of pigments for colour reproduction is sometimes approximated by a