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 hexagon in the $u'v'$ diagram joining the primaries and secondaries. This can be directly compared with the gamuts of other pigment sets plotted similarly or, more importantly, that obtained from a colour monitor display (or any other additive system). Obviously such a comparison should be treated with some caution because of the non-additive nature of the primaries (and also because such a diagram does not show luminance or lightness). Nevertheless, it is for such applications that CIELUV proves of some value in graphic technology.

B.3 CIELAB colour differences

(see CIE Publication 15.2)

$$\Delta L^* = L_1^* - L_2^*$$

$$\Delta a^* = a_1^* - a_2^*$$

$$\Delta b^* = b_1^* - b_2^*$$

$$\Delta C_{ab}^* = C_{ab1}^* - C_{ab2}^*$$

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

For ΔE_{ab}^* from L^*, a^* and b^* for sample 1 and sample 2,

$$\Delta E_{ab}^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}.$$

The CIE presently defines a metric hue difference, ΔH_{ab}^*, as

$$\Delta H_{ab}^* = [(\Delta E_{ab}^*)^2 - (\Delta L^*)^2 - (\Delta C_{ab}^*)^2]^{1/2}$$

B.4 CMC(l:c) colour difference ΔE_{cmc}

(see BS 6923[5])

$$\Delta E_{\text{cmc}} = [(\Delta L^*/lS_L)^2 + (\Delta C_{ab}^*/cS_C)^2 + (\Delta H_{ab}^*/S_H)^2]^{1/2}$$

where

ΔL^*, ΔC_{ab}^*, and ΔH_{ab}^* are as defined in B.3;
$S_L =$ 0,040 975L^*/(1 + 0,017 65L^*) unless $L^* < 16$, then $S_L = 0{,}511$;

$$S_C = 0{,}063\,8C_{ab}^*/(1 + 0{,}013\,1C_{ab}^*) + 0{,}638;$$

$$S_H = S_C(FT + 1 - F)$$

and where

$$F = \left\{ (C_{ab}^*)^4 / [(C_{ab}^*)^4 + 1\,900] \right\}^{1/2} \text{ and}$$

$T = 0{,}36 + |0{,}4\cos(h_{ab} + 35)|$; unless $164° \leqslant h_{ab} \leqslant 345°$, then

$$T = 0{,}56 + |0{,}2\cos(h_{ab} + 168)|.$$

NOTE 14 The CMC (Colour Measurement Committee, a British organization) colour difference is not presently CIE approved or recommended but a modified form is being considered by CIE along with other colour difference equations.

The values of the parameters in the CMC equation are derived from visual judgements based on acceptability, not perceptibility, differences for textiles. The value of ΔE_{cmc} correlates well with visual assessment of textiles when l = 2. The value of c is always 1 as presently used and is explicitly given here to show agreement with British Standard BS 6923[5]. (See also AATCC Test Method 173-1990.) However, other types of surface colours or acceptability differences might require other values of l and c, and even different values in different relations for S_L, S_C, S_H, F and T. The CMC colour difference model can be useful for establishing empirical tolerances.

For the colour differences below 3 the formula ΔE_{94}^* may be of advantage [see CIE Publication 116-1995 (formula 2.11)].

Annex C
(informative)

Spectral weights for illuminant D_{65} and 2° observer

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 for information.

The values of X_n = 95,047, Y_n = 100,000 and Z_n = 108,883 may be used to do colorimetric calculations.

NOTE 15 Adding the values of the weighting factors from 340 nm to 780 nm in table C.1 or in table C.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 of value as a data entry check of the tables.

Table C.1 — Weighting factors (W) for illuminant D_{65} 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
350	0,000	0,000	0,000
360	0,000	0,000	0,001
370	0,002	0,000	0,010
380	0,006	0,000	0,026
390	0,022	0,001	0,104
400	0,101	0,003	0,477
410	0,376	0,010	1,788
420	1,200	0,035	5,765
430	2,396	0,098	11,698
440	3,418	0,226	17,150
450	3,699	0,417	19,506
460	3,227	0,664	18,520
470	2,149	0,998	14,137
480	1,042	1,501	8,850
490	0,333	2,164	4,856
500	0,045	3,352	2,802
510	0,098	5,129	1,602
520	0,637	7,076	0,791
530	1,667	8,708	0,420
540	2,884	9,474	0,202
550	4,250	9,752	0,086
560	5,626	9,419	0,037
570	6,988	8,722	0,019
580	8,214	7,802	0,014
590	8,730	6,442	0,010
600	9,015	5,351	0,007
610	8,492	4,263	0,003
620	7,050	3,145	0,001
630	5,124	2,113	0,000
640	3,516	1,373	0,000
650	2,167	0,818	0,000
660	1,252	0,463	0,000
670	0,678	0,248	0,000
680	0,341	0,124	0,000
690	0,153	0,055	0,000
700	0,076	0,027	0,000
710	0,040	0,014	0,000
720	0,018	0,006	0,000
730	0,009	0,003	0,000
740	0,005	0,002	0,000
750	0,002	0,001	0,000
760	0,001	0,000	0,000
770	0,000	0,000	0,000
780	0,000	0,000	0,000
Sums	95,049	99,999	108,882

Table C.2 — Weighting factors (W) for illuminant D_{65} 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	−0,005
380	−0,008	0,000	−0,039
400	0,179	0,002	0,829
420	2,542	0,071	12,203
440	6,670	0,453	33,637
460	6,333	1,316	36,334
480	2,213	2,933	18,278
500	0,052	6,866	5,543
520	1,348	14,106	1,611
540	5,767	18,981	0,382
560	11,301	18,863	0,068
580	16,256	15,455	0,025
600	17,933	10,699	0,013
620	14,020	6,277	0,003
640	7,057	2,743	0,000
660	2,527	0,927	0,000
680	0,670	0,242	0,000
700	0,140	0,050	0,000
720	0,035	0,013	0,000
740	0,008	0,003	0,000
760	0,002	0,001	0,000
780	0,000	0,000	0,000
Sums	95,044	100,001	108,882

Annex D
(informative)

Sample backing material

Since graphic technology paper substrates are usually translucent and not opaque, images printed on the back side of the sheet will affect measurements. If a white backing is used, some of the light transmitted through the substrate will reflect back to the measuring instrument.

The best method for minimizing back-reflected light is to use a black backing material. For the purposes of this International Standard, a black backing material as specified in ISO 5-4, 4.7 is used. The backing material should be spectrally non-selective, diffuse-reflecting and have an ISO reflection density of 1,50 ± 0,20.

This approach provides the best correlation with other graphic technology standard measurement procedures such as those used for densitometry. However, it must be recognized that the standard for viewing of graphic arts materials (ISO 3664) does not define a specific backing material. Where other backings are used (e.g. paper, Munsell grey, etc.), the numerical results obtained from measurements made according to this International Standard may not provide a direct correlation with visual assessment. It is also important to note that this International Standard provides for the determination of colour stimulus values and not appearance. The perception of colour depends not only on the visual stimulus but on many other factors that include, but are not limited to, the surrounding colours, the illumination intensity level, degree of chromatic adaptation, etc.

Annex E
(informative)

Measurement geometry

E.1 Reflectance measurement geometry

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. These are based on 0° illumination and 45° collection (0°/45°) or its inverse (45°/0°), diffuse illumination and 0° collection or its inverse and the diffuse configurations may have the specular component included or excluded. The latter geometries are used by instruments which include integrating spheres and to permit inclusion of the specular component the 0° is offset, typically to an angle of 8°. Unfortunately, data from any one of these configurations cannot in general be modified to match data measured with another of the configurations although the procedure in annex H can be used to modify the measurement data for specific materials. For many applications the configuration chosen 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 a colorimetry standard for graphic arts applications one of the major goals is to develop a measurement profile that allows the widest interchange and applicability of data. This means that one instrument configuration must be chosen and some applications either will not be able to use the standard or will not be in an optimum application situation.

In developing this International Standard one of the principal applications considered was the appearance of printed images on paper. Information available from the companies representing the participants in the working group developing this International Standard strongly indicated that the 0°/45° or 45°/0° geometry provided the best correlation to the reflectance seen by a human observer using the standard viewing conditions defined for the graphic arts. In addition, in the graphic arts, colorimetric data is often used in conjunction with densitometric data. The current reflection densitometry standards, such as ISO 5-4, specify the use of 0°/45° or 45°/0° geometry.

ISO/TC 130, Working Group 3 (WG 3), has therefore chosen 0°/45° or 45°/0° geometry to recommend as the preferred reflectance measurement geometry for graphic arts applications and colorimetric data exchange. In making this recommendation WG 3 recognizes that there will be some specific applications and process control situations for which this International Standard will be unacceptable. It is hoped that the majority of the industry will accommodate it and find the benefits of a common database far outweigh the difficulties associated with any change in practice or necessary change in reference information.

One example of an important graphic arts application that may need to supplement this International Standard with additional instrumentation is the determination of specific surface effects such as "bronzing" of inks. The phenomenon of bronzing and the associated measurement issues that complicate this problem are explained in E.3.

E.2 Transmission Measurement Geometry

Measurement geometry is defined in this International Standard to be 0°/d or d/0°. For many years such a geometry was only defined by reference to an integrating sphere as is currently the case in CIE 15.2 and older versions of ISO 5-2. However, to more accurately reflect the measurement geometry commonly employed for densitometry, the current edition of ISO 5-2 defines ISO diffuse density. This geometry uses a diffusing medium such as opal glass or a plastic to diffuse the incident or emitted light. The characteristics of the diffuser are clearly specified.

For the purposes of this International Standard both methods of diffusing the light are considered to be acceptable. Sphere measurements must be of total transmittance, as defined in CIE 15.2. (This is the transmission equivalent of specular included geometry for reflectance measurements.) Measurements made using ISO diffuse density measurement geometry must use a diffusing material which meets the characteristics defined in ISO 5-2.

Total transmittance means, for example, that an instrument in which the sample is placed at the entrance port of an integrating sphere must have a diffusing material, similar to the interior of the sphere, at the point of impingement of the incident beam. Alternatively, the entrance port must be at a small angle to the point of impingement and a white reflector placed there. If neither of the above are followed, much of the light at the point of impingement may be reflected back through the entrance port. Thus, the entrance port acts as a light trap. Such measurements, which are the equivalent of specular excluded geometry for reflectance measurements, known as diffuse transmittance, are not acceptable for this International Standard.

As stressed in ISO 5-2, measurements made using an integrating sphere and an opal diffuser do not produce exactly the same results. This is primarily due to inter-reflections occurring between the sample and the diffuser in that method (which reflects many practical situations). However, since transmission spectrocolorimetry is not widely undertaken at present, no de facto standard method has evolved. Measurements are made both with sphere instruments and using procedures in which samples placed on diffuse illuminators are measured with spectroradiometers. Neither technique has evolved as the preferred method (unlike reflection spectrocolorimetry, in which 0°/45° or 45°/0° clearly has).

It is not the intent of this International Standard to impose one method or the other. However, the procedure suggested as desirable in ISO 5-2, in which the measurements are designated as either sphere or opal, is strongly recommended. ISO 5-2 states that the differences obtained by the two procedures are most significant at low densities and are typically 0,03 in density. (The precise value depends upon the characteristics of the substrate and diffuser surfaces.) This difference decreases with increasing density. As an example, a white (clear) sample with a diffuse density of 0,20 could read 0,22 with a sphere. To give an indication of what this means in colorimetry, these two values (if used for ISO visual density) would translate into L^* values of approximately 83,49 and 81,98.

For most practical purposes, air is used as the reference for all transmittance factor measurements although the perfect transmitting diffuser is specified by CIE. However, for the geometries specified in this International Standard any differences between the two are deemed to be insignificant.

E.3 Bronzing

One example of the use of an integrated sphere spectrophotometer to evaluate surface effects in printing is the measurement of bronzing.

Bronzing is a term used to describe a number of optical effects that plague the coatings, paint and printing industries. In printing, bronzing is normally attributed to a high pigment concentration and is referred to as "masstone bronzing". The orientation of pigment particles on the printed sheet and the change in pigment particle size have been suggested as other explanations for bronzing.

Bronzing on a printed sheet is observed by viewing the sheet at the angle of specular reflection for the light source. When illuminated with a white light, the specular reflection from a blue ink film that exhibits bronzing will have a reddish hue. Reds will have a yellowish hue.

In order to detect a bronze when making colour measurements, the colour must be observed at the angle of specular reflectance. Therefore, 0°/45° or 45°/0° geometry instruments will not detect the colour of a bronzed surface. Integrating sphere instruments can be utilized to measure bronzed samples. Two measurements can be made: one of the total reflectance factor (R_t) and one with the specular reflectance excluded. The specular reflectance is then the total reflectance factor minus the diffuse reflectance factor (R_d) at each wavelength, as expressed in the following equation:

$$R_s = R_t - R_d$$

where

R_t is the specular component included;

R_d is the specular component excluded;

R_s is the specular reflectance.

If bronzing is present, the specular component will show a difference in the colour of the specularly reflected surface light from the colour of the illuminant. If there is no bronzing, there will be no change in chromaticity coordinates and any difference in the magnitude of the specular reflectance will indicate a change in gloss.

A direct measurement of the specular reflectance can be made using a goniospectrophotometer. Light reflected at specific wavelengths is measured as a function of the angle of illumination and viewing. Such instrumentation is rare in the graphic arts industry because it is expensive and normally found only in research laboratories.

If a bronze is observed and/or measured, one solution is to reformulate the ink with a lower pigment concentration. Another solution is to reduce the time it takes for the ink to set, which will reduce the absorption of the ink vehicle into the substrate. Also, the printed sheets can be coated with an over-print varnish to minimize bronzing.

Annex F
(informative)

Aperture size in reflectance measurements

F.1 Discussion

Targets 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 targets and the small aperture required to read them requires special consideration of errors due to translucent blurring (lateral scattering).

When a sample is translucent, some of the illuminating light penetrates the sample and scatters laterally to points outside of the area viewed by the instrument detector, causing the reported reflectance factors to be lower than they would be if all the reflected light were collected. The interaction between the translucency of the sample and optical configuration of the instrument is called translucent blurring, and the difference in the reflectance factor measured on the translucent sample compared to the corrected reflectance factor is called translucent blurring error. [See F.2, b) and d).]

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

To minimize translucent blurring error, large uniform samples are measured by illuminating a spot larger than the measurement aperture (over-illumination). ISO 5-4 requires that the irradiated area of the specimen be greater than the sampling aperture, and that its boundary lie at least 2 mm beyond the boundary of the sampling aperture. Based on the principle of optical reciprocity, equivalent measurements can be made with the viewing area larger than the irradiated area (over-collection).

For targets 5 mm and smaller it is not practical to over-illuminate (or over-collect) with a 2 mm annular ring since the measurement aperture would be 1 mm or less. Typically, in instruments designed to read these small spots the annular ring is 0,5 mm to 1 mm.

To minimize translucent blurring errors on small spot spectrophotometers it is important to use highly opaque calibration standards such as metal tiles instead of the more translucent standards used to calibrate large spot instruments. This eliminates the largest source of translucent blurring error. Compared to white glass standards, targets on paper are relatively opaque and the use of black backing also reduces the scattering that causes translucent blurring error. ASTM E 805 [F.2, a)] specifies an annular ring approximately equal to the depth of penetration of the light into the specimen.

Another factor that should be considered in the selection of instrument aperture when measuring half-tone images is the relationship to screen ruling. Table F.1 shows the minimum recommended aperture size as a function of common screen ruling.

Table F.1 — Minimum recommended aperture size

Nominal screen frequency		Sampling aperture minimum size
lines/cm	lines/in	mm
26	65	3,5
33	85	3,0
39	100	3,0
47	120	2,0
52	133	2,0
59	150	2,0
79	200	1,5
118	300	1,0

F.2 References

a) ASTM E 805-93, *Practice for Identification of Instrumental Methods of Color or Color-Difference Measurement of Materials.*

b) HSIA, J.J. Optical Radiation Measurements: The Translucent Blurring Effect — Method of Evaluation and Estimation. *NSB Technical Note 594-12*, Oct. 1976.

c) SIGG, F. Errors in Measuring Halftone Dot Areas. *Journal of Applied Photographic Engineering*, Feb. 1983, vol. 9, No. 1, pp. 27-32.

d) SPOONER, D.L. Translucent Blurring Errors in Small Area Reflectance Spectrophotometer and Densitometer Measurements. *TAGA Proceedings*, 1991, pp. 130-143.

Annex G
(informative)

Fluorescence in measurement

The problems of fluorescence measurement in colorimetry are well understood. Unfortunately, without complex measuring and calculation methods it is impossible to predict the sensation which will be perceived under any real source. For most applications this is not practical and a technique is needed to define the likelihood of fluorescence of the sample being included in the measurement and, preferably, some method to estimate its likely significance on the measurement results.

Fluorescence occurs when certain wavelengths of electromagnetic radiation cause the absorbing medium to re-emit at different wavelengths. This creates problems of measurement if the emitted wavelengths fall within the visible spectrum. It is impossible to calculate the radiance (and hence tristimulus values) which will be emitted by the sample, under a particular radiation source, without a detailed knowledge of the characteristics of excitation and emission of the sample (as well as the spectral power distribution of the source). The only satisfactory method to achieve this, apart from measuring under that specific radiation source itself, is to use an instrument with two monochromators in order to measure the reflectance data for each incident waveband. Clearly, the radiance under any real source can then be computed, providing the spectral power distribution of the source is also measured.

Unfortunately, the complexity of this technique usually makes it impossible to implement it in practical instruments. The best that can be accomplished is to provide a method which indicates the presence of the phenomenon, with a limited estimate of its magnitude.

Various methods are feasible for this; three are recommended here.

— **Method A:** Dual source measurement. The sample should be measured with two sources one of which approximates the spectral power distribution of illuminant A, the other approximates that of D_{65}. (The latter has a significantly higher ultraviolet emission than the former.) If the resultant spectral data obtained from both sources is then used to compute the tristimulus values, relative to D_{50} (or, indeed, any illuminant), any difference between them provides an indication of fluorescence. By quoting the magnitude of ΔE the difference may be estimated. It is acceptable if the two sources are obtained by filtration of a single source. Ideally, the instrument manufacturer should provide spectral power distribution data which should be quoted when communicating the results to ensure the method may be approximated elsewhere.

— **Method B:** Single ultraviolet cut-off filter. A filter having little or no ultraviolet transmission may be inserted between the source and sample in the instrument. By measuring the sample with and without this filter, the degree of fluorescence may be assessed using the procedure given in method A.

— **Method C:** An extension of method B, which provides better information about the excitation wavelengths (and hence the significance of fluorescence under any real source) is to use two ultraviolet cut-off filters, one at a time, and compute the tristimulus values for each. Each ultraviolet filter should be inserted between the source and sample. The two filters should provide minimum transmittance in the wavebands 320 nm to 360 nm and 360 nm to 400 nm, respectively, and have maximum transmittance outside of these ranges. The manufacturer should specify these values and they should be quoted in the communication. The manufacturer should also specify the relative energy falling on the sample, compared to that in the visible region, for the source utilized, at the same wavebands. These may best be presented graphically and numerically and should also be communicated with the measurement data.

Following the procedure given in method A, the colour difference ΔE may be quoted as an estimate of the magnitude of fluorescence; this time there will be two colour differences to report, one for each filter measurement.

Both methods B and C presuppose that ultraviolet excitation is the problem; for most colorants encountered in graphic arts this is the case.

Any of the above methods may be used and should be referred to as ISO 13655 (Fluorescence specification) methods A, B or C. The colour difference(s) obtained should be quoted (together with the tristimulus values obtained), and any information pertaining to sources and filters should also be reported where available, or failing that, the instrument type should be reported.

NOTE 16 It is because of fluorescence that instruments which contain lamps that provide approximately continuous spectral characteristics are preferred. Fluorescent or flash lamps, with their associated line spectra, can provide unpredictable results in such situations.