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Analytical colorimetry —

Part 4: **Metamerism index for pairs of samples for change of illuminant**

Analyse colorimétrique —

Partie 4: Indice de métamérisme de paires d'échantillons pour changement d'illuminant

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Foreword

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This document was prepared by Technical Committee ISO/TC 256, *Pigments, dyestuff and extenders*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 298, *Pigments and extenders,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 18314-4:2020), which has been technically revised.

The main changes are as follows:

— a brief introduction about differentiation between metamerism and paramerism has been added in 8.1;

— Formula (1) has been updated to align with Formulae (2) and (4) to (24);

— the key of Figure A.1 has been updated.

A list of all parts in the ISO 18314 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document distinguishes three kinds of metamerism of pairs of samples:

a) Illuminant metamerism occurs if both of the object colours of a pair of samples are perceived as being the same only under a specific illuminant (e.g. under illuminant D65), while they differ under a different illuminant (e.g. illuminant A).

b) Observer metamerism occurs if the object colours of a pair of samples are perceived as being the same by one observer, while a different observer perceives a colour difference under the same illuminant and the same reference conditions.

NOTE 1 The observer metamerism is caused by differences between the distributions of spectral colour matching functions of different observers.

c) Field-size metamerism occurs if both of the object colours of a pair of samples are perceived as being the same on the retina for a size of an observation field (e.g. determined by the 2° standard observer), while they differ for a different observation field on the retina (e.g. 10°).

NOTE 2 The reason for field-size metamerism is based on the existent colour matching functions of an observer during an observation situation. The colour matching functions change with the size of the observation field on the retina. Such change of the observation field can also occur if, for example, the pair of samples is examined from different distances.

Analytical colorimetry —

Part 4:
Metamerism index for pairs of samples for change of illuminant

1 Scope

This document specifies a formalism for the calculation of the illuminant metamerism of solid surface colours. It cannot be applied to colours of effect coatings without metrical adaptation.

This document only covers the phenomenon of metamerism for change of illuminant, which has the greatest meaning in practical application. In the case where chromaticity coordinates of a pair of samples under reference conditions do not exactly match, this document gives guidance on which correction measures to take. Regarding the reproduction of colours, the metamerism index is used as a measure of quality in order to specify tolerances for colour differences between a colour sample and a colour match under different illumination conditions.

The quantification of the illuminant metamerism of pairs of samples is formally performed by a colour difference assessment, for which tolerances that are common for the evaluation of residual colour differences can be used.

NOTE In the colorimetric literature and textbooks, the term geometric metamerism is sometimes used for the case where two colours appear to be the same under a specific geometry for visual assessment and selected standard observer and standard illuminant pair, but are perceived as two different colours at changed observation geometry. The term geometric metamerism is different to metamerism described in this document.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

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

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

CIE 015, *Colorimetry*

3 Terms and definitions

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

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

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
metamerism
property of spectrally different colour stimuli that have the same tristimulus values in a specified colorimetric system

[SOURCE: CIE S 017:2020, 17-23-006]

3.2
paramerism
characteristic of a pair of samples with spectral colour stimulus functions which have different fundamental colour stimulus functions as well as different residuals or metameric black values within the visible spectral range

Note 1 to entry: Parameric objects are characterized by the fact that they reflect colour stimuli of different spectral power distribution functions under a specified standard illuminant, which cause approximately the same colour perception under the selected observation conditions.

3.3
colour difference
ΔE^*
difference between two colour stimuli, defined as a distance between the points representing them in a specified colour space

3.4
reference illuminant
illuminant with which other illuminants are compared

[SOURCE: CIE S 017:2022, 17-22-108]

3.5
test illuminant
illuminant, for which the *colour difference* (3.3) between the two samples to be tested is assessed

3.6
metamerism index for change in illuminant
M_t
colour difference ΔE^* (3.3) between the two samples under *test illuminant* (3.5) if $\Delta E^* = 0$ is observed under the *reference illuminant* (3.4)

3.7
correction method
algorithm for theoretically eliminating a *colour difference* (3.3) of the pair of samples under the *reference illuminant* (3.4)

4 Symbols

For the application of this document, the symbols given in Table 1 apply.

Table 1 — Symbols

Symbol	Identification
X, Y, Z	standard tristimulus values of a measured object colour
X_n, Y_n, Z_n	standard tristimulus values of the used illuminant
$\bar{x}$, $\bar{y}$, $\bar{z}$	colour-matching functions
L^*, a^*, b^*	basic coordinates of the CIELAB system
ΔL^*, Δa^*, Δb^*	differences between basic coordinates of the CIELAB system
M_t	metamerism index for change in illuminant

Table 1 *(continued)*

Symbol	Identification
$\vec{N}, \vec{N}_f, \vec{N}_r$	vector of the radiometric function of a sample with associated fundamental colour stimulus (f) and metameric black (r)
λ	wavelength
S	relative spectral distribution function of an illuminant
$\vec{W}$	vector of the standard tristimulus values
w	integration weights for the calculation of the standard tristimulus values
A	matrix of the integration weights w for the calculation of the standard tristimulus values
R	projection matrix
I	identity matrix
Index spl	sample
Index std	standard
Index t	colour under test illuminant
Index corr	corrected value
Index multipl	multiplicative correction
Index f	fundamental colour stimulus
Index r	metameric black values (residuals)
Index ref	reference illuminant
Index T	transposed matrix

5 Reference illuminant

The standard illuminant D65 shall be chosen as reference illuminant in accordance with ISO/CIE 11664-2. Other reference illuminants required in special cases shall be specified.

6 Test illuminant

The selection of the test illuminant depends on the application. If the test illuminants are not particularly specified, standard illuminant A in accordance with ISO/CIE 11664-2 and/or illuminants of the fluorescent lamp type, such as FL11 in accordance with CIE 015, shall be selected. The test illuminant used shall be indicated as an index to M, e.g. M_A or M_{FL11}.

When calculating the standard tristimulus values X, Y, Z under the selected test illuminants, the basic raster of wavelengths shall comply with those given in ISO/CIE 11664-2 or CIE 015 for A and D65, and in CIE 015 for FL11 and FL2. In cases of missing measuring values of the standard or sample for these wavelengths, these values shall be interpolated and/or extrapolated.

7 CIELAB coordinates L^*, a^*, b^*

The metamerism index, M_t, is based on the CIELAB coordinates L^*, a^*, b^* of samples 1 and 2 which are compared. L^*, a^*, b^* shall be calculated in accordance with ISO/CIE 11664-4 from the standard tristimulus values X, Y, Z. These values are derived from the sample for the CIE 1964 10° standard observer in accordance with ISO/CIE 11664-1 for the reference illuminant and the selected test illuminant. If calculating L^*, a^*, b^* under the test illuminant, the respective standard tristimulus values X_n, Y_n, Z_n of the entirely matt white surface shall be used in accordance with CIE 015). For the standard illuminants A and D65 or for the illuminant recommendation FL11, the standard tristimulus values X_n, Y_n, Z_n of the entirely matt white surface apply in accordance with Table 2.

Table 2 specifies standard tristimulus values for the frequently used standard illuminants D65 and A as well as illuminant FL11 and both of the standard observers according to CIE 015.

Table 2 — Standard tristimulus values

Standard tristimulus values	2° standard observer			10° standard observer		
	Illuminant					
	D65	A	FL11	D65	A	FL11
X_n	95,04	109,85	100,96	94,81	111,14	103,86
Y_n	100,00	100,00	100,00	100,00	100,00	100,00
Z_n	108,88	35,58	64,35	107,32	35,20	65,61

For fluorescent samples, the illuminant used for measurement shall be adjusted as close as possible to that illuminant for which the standard tristimulus values are determined.

NOTE In contrast to non-fluorescent samples, the calculation of metamerism indices for fluorescent samples is erroneous if the samples are measured only under one illuminant.

8 Metamerism index for change in illuminant

8.1 General calculation methods

Metamerism implies no colour difference under the reference illuminant. The colour difference under the test illuminant is used as metamerism index. This index is described in Formula (1):

$$M_t = \sqrt{\left(\Delta L_t^*\right)^2 + \left(\Delta a_t^*\right)^2 + \left(\Delta b_t^*\right)^2} \quad (1)$$

where

t is the colour under test illuminant;

$\Delta L_t^* = L_{spl,corr,t}^* - L_{std,t}^*$;

$\Delta a_t^* = a_{spl,corr,t}^* - a_{std,t}^*$;

$\Delta b_t^* = b_{spl,corr,t}^* - b_{std,t}^*$.

In case of a small colour difference already present under reference illuminant conditions, the colour difference at change of illuminant is called paramerism. To eliminate the effect of the difference under reference illuminant, a mathematically corrected virtual sample is created, having no remaining colour difference under the reference illuminant.

Three different correction methods for calculating a metamerism index in the case of paramerism have been proposed in References [6] to [13]. All methods assume that, for practical cases, there can already be a small difference between the colours of the sample and the standard, even under the reference illuminant from the very beginning, due to problems of fabrication. In the case of two methods, called the additive and the multiplicative correction, these inherent colour differences often merge with the difference introduced by the change of the illuminant. The third method, the spectral correction, works more fundamentally by the separation of inherent colour differences under the reference illuminant from those introduced by the change of the illuminant.

NOTE Annex A includes calculation examples.

8.2 Basic calculation of the metamerism index from colour differences

After this correction (see 8.1) leading to the virtual sample, the common formula for a metamerism index at change in illuminant, expressed in CIELAB coordinates for the test illuminant (t), is given by Formula (2):

$$M_t(x) = \sqrt{\left(\Delta L^*_{corr}\right)^2 + \left(\Delta a^*_{corr}\right)^2 + \left(\Delta b^*_{corr}\right)^2} \qquad (2)$$

where

t is the colour under test illuminant;

$\Delta L^*_{corr} = L^*_{spl,corr,t} - L^*_{std,t}$;

$\Delta a^*_{corr} = a^*_{spl,corr,t} - a^*_{std,t}$;

$\Delta b^*_{corr} = b^*_{spl,corr,t} - b^*_{std,t}$;

x nominates the correction method.

Formulae (1) and (2) are provided as examples if using the CIELAB colour space.

Analogous equations apply for other Euclidian colour spaces such as DIN 99o as specified in DIN 6176. In non-Euclidian colour spaces such as CIE 94 or CIEDE2000,[6] the specific colour differences are provided with colour-space dependent weight functions and, in regard to the latter case, are expanded by an additional rotation term. The CIELAB metric used in this document is an example and should be replaced in practical applications by one of the more recent metrics mentioned (e.g. CIE 94, CIEDE2000, DIN 99o), which are significantly more uniform than the CIELAB model.

8.3 Correction methods

8.3.1 Additive correction

When using the additive correction, the differences of colorimetric coordinates between the standard (std) and the sample (spl) under the reference illuminant (ref) are added to the respective differences between the standard and the sample under the test illuminant (t). The resulting calculation for the metamerism index M_t (add), expressed in differences of CIELAB coordinates, is then given by Formula (3):

$$M_t(\text{add}) = \sqrt{\left(\Delta L^*_{corr}\right)^2 + \left(\Delta a^*_{corr}\right)^2 + \left(\Delta b^*_{corr}\right)^2} \qquad (3)$$

where

$\Delta L^*_{corr} = L^*_{spl,t} - L^*_{std,t} - \Delta L^*_{ref}$;

$\Delta L^*_{ref} = L^*_{spl,ref} - L^*_{std,ref}$.

Analogous relationships apply for Δa^* and Δb^*. It should be noted that slightly different results are to be expected, if the correction is applied to standard tristimulus values prior to transformation into a uniform colour space such as CIELAB or DIN 99o.

8.3.2 Multiplicative correction

NOTE The multiplicative correction is specified in CIE 015 as the correction method.

When using the multiplicative correction, the standard tristimulus values of the sample (spl), which are observed under test conditions (t) are multiplied with the quotient of the standard tristimulus values of standard (std) and sample (spl), which are obtained under reference conditions (ref). The resulting calculation is given in Formula (4):

$$Y_{\text{spl,corr,t}} = Y_{\text{spl,t}} \frac{Y_{\text{std,ref}}}{Y_{\text{spl,ref}}} \tag{4}$$

in which case, again, analogous combinations for X_{corr} and Z_{corr} apply. Subsequently, a transformation into a uniform colour space (e.g. CIELAB) takes place and results in Formula (5):

$$M_t\,(\text{multipl}) = \sqrt{\left(\Delta L^*_{\text{corr}}\right)^2 + \left(\Delta a^*_{\text{corr}}\right)^2 + \left(\Delta b^*_{\text{corr}}\right)^2} \tag{5}$$

with

$$\Delta L^*_{\text{corr}} = L^*_{\text{spl,corr,t}} - L^*_{\text{std,t}} \,.$$

Analogous relationships apply for the two remaining specific differences Δa^*_{corr} and Δb^*_{corr}.

8.3.3 Spectral correction

The spectral method considers that under the reference illuminant, minor differences between the tristimulus values of the sample and the standard can already exist, which are not relevant for the metamerism characteristics. In order to first mathematically compensate them and only determine the effective component of metamerism at change in illuminant of sample pairs with given spectral reflectance, it is possible to mathematically split a spectral reflectance into two additive components.

One component describes only the function that is effective for the formation of the colour stimulus under the reference illuminant and the other component describes a function, which does not lead to a contribution to the colour stimulus when integrating via the stimulus under the reference illuminant.

This function necessarily includes positive and negative components. The fundamental colour stimulus function results from the first component of the spectral reflectance under the reference illuminant. This is effective for the formation of the colour. The respective second part of the colour stimulus function leads to a metameric black of the decomposition (residue), i.e. an invisible contribution with a resulting colour stimulus identical to zero.

The compensation of the deviations of the colour stimuli of a test sample from the standard sample, which are non-effective for metamerism characteristics, is realized by replacing the fundamental colour stimulus of the sample by that of the standard. The component that is effective for the metamerism characteristic remains unchanged, i.e. a new colour stimulus function of the sample is generated from the sum of the replaced fundamental colour stimulus and the unchanged second component. The sum determines the metamerism at change in illuminant with regard to the standard.

The mathematical description of the method of spectral correction starts with the general definition of the spectral reflection function of a sample in Formula (6) and the definition of a matrix of spectral weights [Formula (9)] to calculate the expected tristimulus values. This matrix of weights is composed from the spectral illuminant and the spectral matching functions of the observer in Formula (8). The product of the matrix of weights with the spectral reflection function results in the tristimulus values in Formula (11), which appear under the illuminant considered.

As specified in this document by Formulae (12) to (15), a decomposition into visible and invisible parts of colour stimuli uses the splitting of the spectral reflectance function under the defined reference illuminant into a “fundamental reflection function” [Formula (13)], and a “black reflection function” [Formula (14)]. These parts lead to the visible fundamental colour stimulus and the invisible black colour stimulus functions for the illuminant considered. So, it should always be noted that this method is only valid under the assumption that these components of the spectral reflection function describe

