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Colorimetry —

Part 5: CIE 1976 L*u*v* colour space and u', v' uniform chromaticity scale diagram

Colorimétrie —

*Partie 5: Espace chromatique L*u*v* et diagramme de chromaticité uniforme u', v' CIE 1976*

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Foreword

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This document was prepared by the International Commission on Illumination (CIE) in cooperation with Technical Committee ISO/TC 274, *Light and lighting*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 139, *Paints and varnishes*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO/CIE 11664-5:2016), which has been technically revised.

The main changes are as follows:

— list of ISO/CIE 11664 series *Colorimetry* shifted from Foreword to Introduction;

— text in 3.1, 4.2, 4.3, and 4.4 updated;

— previous Formula (24) deleted and related formula numbers updated accordingly;

— sign in Formula (26) updated;

— Bibliography updated;

— minor editorial changes.

A list of all parts in the ISO/CIE 11664 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.

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Introduction

The three-dimensional colour space produced by plotting CIE tristimulus values (*X*,*Y*,*Z*) in rectangular coordinates is not visually uniform, nor is the (x,y,Y) space nor the two-dimensional CIE x,y chromaticity diagram. Equal distances in these spaces and diagrams do not represent equally perceptible differences between colour stimuli. For this reason, in 1976, the CIE introduced and recommended two new spaces (known as CIELAB and CIELUV) whose coordinates are non-linear functions of *X*, *Y* and *Z*. The recommendation was put forward in an attempt to unify the then very diverse practice in uniform colour spaces and associated colour difference formulae.[2][8] Both these more-nearly uniform colour spaces have become well accepted and widely used. Numerical values representing approximately the relative magnitude of colour differences can be described by simple Euclidean distances in the spaces or by more sophisticated formulae that improve the correlation with the relative perceived size of differences.

The purpose of this document is to specify procedures for calculating the coordinates of the CIE 1976 L*u*v* (CIELUV) colour space and the Euclidean colour difference values based on these coordinates. This document also specifies a related chromaticity diagram that is a projection of the CIE x,y chromaticity diagram maintaining straight lines of dominant and complementary wavelengths. It does not cover the alternative uniform colour space, CIELAB,[5] nor does it cover more sophisticated colour difference formulae based on CIELAB, such as the CMC formula,[3] the CIE 94 formula,[1] the DIN 99 formula,[4] and the CIEDE2000 formula[6].

The ISO/CIE 11664 series consists of the following parts, under the general title *Colorimetry*:

— *Part 1: CIE standard colorimetric observers*

— *Part 2: CIE standard illuminants*

— *Part 3: CIE tristimulus values*

— *Part 4: CIE 1976 L*a*b* Colour space*

— *Part 5: CIE 1976 L*u*v* Colour space and u′, v′ uniform chromaticity scale diagram*

— *Part 6: CIEDE2000 Colour-difference formula*

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Colorimetry —

Part 5:
CIE 1976 L*u*v* colour space and u', v' uniform chromaticity scale diagram

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1 Scope

This document specifies the method of calculating the coordinates of the CIE 1976 L*u*v* colour space including correlates of lightness, chroma, saturation and hue. It includes two methods for calculating Euclidean distances in this space to represent the relative perceived magnitude of colour differences. It also specifies the method of calculating the coordinates of the u′,v′ uniform chromaticity scale diagram.

This document is applicable to tristimulus values calculated using the colour-matching functions of the CIE 1931 standard colorimetric system or the CIE 1964 standard colorimetric system. This document is applicable for the specification of colour stimuli perceived as belonging to a reflecting or transmitting object, where a three-dimensional space more uniform than tristimulus space is required. This includes self-luminous displays, like computer, television and smart-phone displays, if they are being used to simulate reflecting or transmitting objects and if the stimuli are appropriately normalized.

This document, as a whole, does not apply to colour stimuli perceived as belonging to an area that appears to be emitting light as a primary light source or that appears to be specularly reflecting such light. Only the u′,v′ uniform chromaticity scale diagram defined in 4.1 and the correlates of hue and saturation defined in 4.3 apply to such colour stimuli.

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*

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

No terms and definitions are listed in this document.

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/

CIE maintains a terminological database for use in standardization at the following address:

— ILV: International Lighting Vocabulary: available at https://cie.co.at/e-ilv

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3.2 Symbols and abbreviated terms

X, Y, Z	tristimulus values of a test stimulus calculated using the colour-matching functions of the CIE 1931 standard colorimetric system (also known as the CIE 2° standard colorimetric system)
Y_n	tristimulus value, Y, of a specified white colour stimulus calculated using the colour-matching functions of the CIE 1931 standard colorimetric system
x, y	chromaticity coordinates of a test stimulus calculated using the colour-matching functions of the CIE 1931 standard colorimetric system
L^*	CIELUV lightness
u^*, v^*	CIELUV u^*, v^* coordinates
u', v'	CIE 1976 chromaticity coordinates
u'_n, v'_n	CIE 1976 chromaticity coordinates of a specified white stimulus
s_{uv}	CIELUV saturation
C^*_{uv}	CIELUV chroma
h_{uv}	CIELUV hue angle
$\Delta(u',v')$	CIELUV chromaticity difference
ΔL^*	CIELUV lightness difference
$\Delta u^*, \Delta v^*$	CIELUV u^*, v^* differences
ΔC^*_{uv}	CIELUV chroma difference
Δh_{uv}	CIELUV hue angle difference
ΔH^*_{uv}	CIELUV hue difference
ΔE^*_{uv}	CIELUV colour difference

If the character "Δ" is not available, it may be replaced by the character "D".

The terms "CIE 1976 L*u*v*" and "CIELUV" may be used interchangeably.

Where tristimulus values are calculated using the colour-matching functions of the CIE 1964 standard colorimetric system (also known as the CIE 10° standard colorimetric system), a subscript 10 shall be added to all the above symbols.

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4 Calculation method

4.1 Uniform chromaticity scale diagram (UCS diagram)

The CIE 1976 uniform chromaticity scale diagram is a projective transformation of the CIE x,y chromaticity diagram yielding perceptually more uniform colour spacing. It is produced by plotting, as abscissa and ordinate, respectively, quantities defined by the following formulae:

$$u' = 4X/(X + 15Y + 3Z) \quad (1)$$

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$$v' = 9Y/(X + 15Y + 3Z) \tag{2}$$

where *X, Y, Z* are the tristimulus values of the test colour stimulus based on the CIE 1931 standard colorimetric system defined in accordance with ISO/CIE 11664-1.

The same quantities may be obtained by the following formulae:

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

$$v' = 9y/(-2x + 12y + 3) \tag{4}$$

where *x* and *y* are obtained by the following formulae:

$$x = X/(X + Y + Z) \tag{5}$$

$$y = Y/(X + Y + Z) \tag{6}$$

Euclidean distances in the UCS diagram can be used to represent approximately the relative perceived magnitude of colour differences between colour stimuli of negligibly different luminances, of approximately the same size, and viewed in identical surroundings, by an observer photopically adapted to a field with the chromaticity of CIE standard illuminant D65 defined in accordance with ISO/CIE 11664-2. It is possible that the values given by this document do not correlate well with relative perceived colour differences in other viewing conditions. These Euclidean distances are defined by the following formula:

$$\Delta(u', v') = \left[(\Delta u')^2 + (\Delta v')^2 \right]^{1/2} \tag{7}$$

where

$$\Delta u' = u'_1 - u'_0 \tag{8}$$

$$\Delta v' = v'_1 - v'_0 \tag{9}$$

and the subscripts 0 (usually the reference) and 1 (usually the test) indicate the two stimuli being compared.

4.2 Uniform colour space

The CIE 1976 L*u*v* colour space is a three-dimensional, approximately uniform colour space produced by plotting in rectangular coordinates, *L**, *u**, *v**, quantities defined by the following formulae:

$$L^* = 116\, f(Y/Y_n) - 16 \tag{10}$$

$$u^* = 13\, L^* (u' - u'_n) \tag{11}$$

$$v^* = 13\, L^* (v' - v'_n) \tag{12}$$

where

$$f(Y/Y_n) = (Y/Y_n)^{1/3} \qquad \text{if } (Y/Y_n) > (6/29)^3 \tag{13}$$

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$$f(Y/Y_n) = (841/108)(Y/Y_n) + 4/29 \qquad \text{if } (Y/Y_n) \leq (6/29)^3 \tag{14}$$

In these formulae, Y, u' and v' describe the test colour stimulus and Y_n, u'_n and v'_n describe a specified white stimulus.

In the case of simulated reflecting or transmitting objects produced on a self-luminous display, all the tristimulus values shall first be normalized by the same factor so that Y would be equal to 100 for an object with 100 % reflectance or transmittance.

If the angle subtended at the eye by the test stimulus is between about 1° and 4°, the tristimulus values X, Y, Z calculated using the colour-matching functions of the CIE 1931 standard colorimetric system should be used. If this angular subtense is greater than 4°, the tristimulus values X_{10}, Y_{10}, Z_{10} calculated using the colour-matching functions of the CIE 1964 standard colorimetric system should be used. The same colour-matching functions and the same specified white stimulus shall be used for all stimuli to be compared with each other.

If the tristimulus values X, Y, Z are obtained by spectrophotometry, the tristimulus values X_n, Y_n, Z_n of the specified white stimulus shall be calculated using the same method as used for the test stimulus (same colour-matching functions, same range and interval of wavelength, and same bandwidth). If the tristimulus values X, Y, Z are obtained by direct measurement using a tristimulus colorimeter, X_n, Y_n, Z_n shall be measured using the same tristimulus colorimeter and a white reflectance standard calibrated relative to a perfect reflecting diffuser.

NOTE 1 For real object colours, the specified white stimulus normally chosen for X_n, Y_n, Z_n is light reflected from a perfect reflecting diffuser illuminated by the same light source as the test object. In this case, X_n, Y_n, Z_n are the tristimulus values of the light source normalized by a common factor so that Y_n is equal to 100. For simulated object colours, the specified white stimulus normally chosen is one that has the appearance of a perfect reflecting diffuser, again normalized by a common factor so that Y_n is equal to 100.

NOTE 2 Examples of values of X_n, Y_n and Z_n for specific illuminants and specific calculation methods have been published[2].

NOTE 3 Formula (14) is based on a suggestion by Reference [7].

NOTE 4 A value of 7,787 is approximately equal to the term (841/108) in Formula (14). The approximate value may be used in practice.

NOTE 5 A value of 0,008 856 is approximately equal to the term $(6/29)^3$ in Formula (13) and Formula (14). The approximate value can be used in practice.

NOTE 6 The fractions 6/29 and 4/29 in Formula (13) and Formula (14) are exactly equal to the fractions 24/116 and 16/116 appearing in CIE 015:2018.

NOTE 7 The term (841/108) in Formula (14) is derived from and exactly equal to $(1/3)(29/6)^2$.

NOTE 8 Formula (10) reduces to $L^* \approx 903{,}3(Y/Y_n)$ when $Y/Y_n \leq (6/29)^3$.

When CIELUV values are reported, they should be accompanied by all relevant information relating to the measurement conditions and the procedures used to calculate the input tristimulus values.

Annex A provides information on the calculation of X, Y, Z when L^*, u^*, v^* are given.

4.3 Correlates of lightness, saturation, chroma and hue

Approximate correlates of the perceived attributes lightness, saturation, chroma, and hue shall be calculated as follows:

CIE 1976 lightness: L^* as defined in 4.2

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CIE 1976 u,v saturation (CIELUV saturation):

$$s_{uv} = 13\left[(u' - u'_n)^2 + (v' - v'_n)^2\right]^{1/2} \quad (15)$$

CIE 1976 u,v chroma (CIELUV chroma):

$$C^*_{uv} = \left[\left(u^*\right)^2 + \left(v^*\right)^2\right]^{1/2} = L^* \cdot s_{uv} \quad (16)$$

CIE 1976 u,v hue angle (CIELUV hue angle):

$$h_{uv} = \arctan\left(v^* / u^*\right) \quad (17)$$

CIELUV hue angle, h_{uv} shall lie between 0° and 90° if u^* and v^* are both positive, between 90° and 180° if v^* is positive and u^* is negative, between 180° and 270° if v^* and u^* are both negative, and between 270° and 360° if v^* is negative and u^* is positive. If $u^* = 0$ and v^* is positive, $h_{uv} = 90°$. If $u^* = 0$ and v^* is negative, $h_{uv} = 270°$, and if $u^* = 0$ and $v^* = 0$, h_{uv} is undetermined.

4.4 Colour differences

Euclidean distances in CIELUV colour space can be used to represent approximately the relative perceived magnitude of colour differences between object colour stimuli of approximately the same size, viewed in identical white to middle-grey surroundings, by an observer photopically adapted to a field with the chromaticity of CIE standard illuminant D65 defined in ISO/CIE 11664-2. It is possible that the values given by this document do not correlate well with relative perceived colour differences in other viewing conditions.

Differences between two stimuli denoted by subscripts 0 (usually the reference) and 1 (usually the test) shall be calculated as follows:

$$\Delta L^* = L^*_1 - L^*_0 \quad (18)$$

$$\Delta u^* = u^*_1 - u^*_0 \quad (19)$$

$$\Delta v^* = v^*_1 - v^*_0 \quad (20)$$

$$\Delta C^*_{uv} = C^*_{uv,1} - C^*_{uv,0} \quad (21)$$

$$\Delta h_{uv} = h_{uv,1} - h_{uv,0} \quad (22)$$

$$\Delta H^*_{uv} = 2\left(C^*_{uv,1} \cdot C^*_{uv,0}\right)^{1/2} \sin\left(\Delta h_{uv}/2\right) \quad (23)$$

where the value of Δh_{uv} in Formula (23) is in radians.

If the line joining the two colours crosses the positive u^* axis, Formula (22) will give a value outside the range ±180°. In this case, the value of Δh_{uv} should be corrected by adding or subtracting 360° to bring it within this range.

NOTE 1 The quantity ΔH^*_{uv} is introduced to provide congruence with the perceptual understanding that a colour difference can be divided into a vector sum of a lightness difference, a chroma difference and a hue difference.

NOTE 2 The division of CIELUV colour differences into hue and chroma differences is progressively less useful as the absolute value of Δh_{uv} approaches 180°.

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NOTE 3 In information technology and other fields, the subscripts r (for reference) and t (for test) are sometimes used instead of 0 and 1, respectively. Similarly, in industrial evaluation of small colour differences, s (for standard) and b (for batch) are sometimes used. In other applications, std (for standard) and spl (for sample) are sometimes used.

The CIE 1976 u,v colour difference, ΔE^*_{uv}, between two colour stimuli is calculated as the Euclidean distance between the points representing them in the space:

$$\Delta E^*_{\mathrm{uv}} = \left[(\Delta L^*)^2 + (\Delta u^*)^2 + (\Delta v^*)^2 \right]^{1/2} \tag{24}$$

or

$$\Delta E^*_{\mathrm{uv}} = \left[(\Delta L^*)^2 + \left(\Delta C^*_{\mathrm{uv}}\right)^2 + \left(\Delta H^*_{\mathrm{uv}}\right)^2 \right]^{1/2} \tag{25}$$

These two definitions of ΔE^*_{uv}, are equivalent.

Other ways of calculating ΔH^*_{uv} are as follows:

$$\Delta H^*_{\mathrm{uv}} = \left[\left(\Delta E^*_{\mathrm{uv}}\right)^2 - (\Delta L^*)^2 - \left(\Delta C^*_{\mathrm{uv}}\right)^2 \right]^{1/2} \tag{26}$$

where ΔE^*_{uv}, is calculated from Formula (24) and ΔH^*_{uv} has the same sign as Δh_{uv}

$$\Delta H^*_{\mathrm{uv}} = k\left[2\left(C^*_{\mathrm{uv},1} \cdot C^*_{\mathrm{uv},0} - u^*_1 \cdot u^*_0 - v^*_1 \cdot v^*_0 \right) \right]^{1/2} \tag{27}$$

where $k = -1$ if $u^*_1 \cdot v^*_0 > u^*_0 \cdot v^*_1$; otherwise, $k = 1$ and

$$\Delta H^*_{\mathrm{uv}} = \left(u^*_0 \cdot v^*_1 - u^*_1 \cdot v^*_0 \right) \Big/ \left[0{,}5\left(C^*_{\mathrm{uv},1} \cdot C^*_{\mathrm{uv},0} + u^*_1 \cdot u^*_0 + v^*_1 \cdot v^*_0 \right) \right]^{1/2} \tag{28}$$

NOTE 4 Formula (28) cannot be used when either of the compared chromas is zero.

NOTE 5 More details on the various methods of calculating ΔH^*_{uv} are given by Reference [9] for Formula (23), by Reference [11] for Formula (27), and by Reference [10] for Formula (28).

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