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Photometry — The CIE system of physical photometry

Photométrie — Le système CIE de photométrie physique

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by the International Commission on Illumination (CIE) in cooperation with Technical Committee ISO/TC 274, *Light and lighting*.

This first edition of ISO/CIE 23539 cancels and replaces ISO 23539:2005/CIE S 010:2004, which has been technically revised.

The main changes are as follows:

— The scope of the document has changed to incorporate the spectral luminous efficiency functions published by the CIE for a) mesopic vision and b) 10° photopic vision, on the basis of CIE 018:2019.

— The International System of Units (SI) and its reformulation of the definition of the candela – effective on 20 May 2019 – has been incorporated (Resolution 1, 26th CGPM, 2018).

— A list of normative references has been added.

— Specific requirements have been added regarding the use of units, tabulated values and interpolation of intermediate values.

— The background of the CIE system of physical photometry, specifically the evolution of the photometric base unit, has been updated in Annex C.

— The CIE 2015 cone-fundamental-based spectral luminous efficiency functions for a) 2° field size and b) 10° field size have been added in Annex E based on CIE 170-2:2015.

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

Introduction

The purpose of photometry is to measure light as perceived by human eyes. The brightness of a luminous surface depends not only on the amount of radiation it emits, transmits or reflects, but also on its spectral composition and on the visual response function of the observer viewing it. Because human visual response varies at different light levels and from person to person, precise photometry requires the definition of representative standard observers. The CIE system of physical photometry specifies procedures for the quantitative evaluation of optical radiation in terms of internationally agreed spectral luminous efficiency functions for human vision. $V(\lambda)$ represents photopic vision, $V'(\lambda)$ represents scotopic vision and $V_{\mathrm{mes};m}(\lambda)$ represents mesopic vision, the latter being intermediate between photopic and scotopic vision. Furthermore, $V_{10}(\lambda)$ represents 10° photopic vision. These luminous efficiency functions adopted from CIE 018:2019[1] and BIPM-2019/05,[2] together with the SI base unit, the candela, constitute a system that enables the calculation of values of photometric quantities for optical radiation as well as light-emitting, light-transmitting or light-reflecting surfaces, to be precisely determined based on the International System of Units (SI), regardless of the spectral composition of the radiation emitted, transmitted or reflected.

The CIE system of physical photometry has some limitations in respect to the brightness of coloured surfaces: two light sources of different colour but with the same measured luminance value will not necessarily be perceived as equally bright. CIE has therefore published a more complex model (CIE 200:2011)[3] for specific situations. For eye-mediated non-image-forming effects of light induced partially or completely by the intrinsically photosensitive retinal ganglion cells (ipRGCs), CIE S 026/E:2018[4] is used.

Photometry — The CIE system of physical photometry

1 Scope

This document specifies the characteristics of the system of physical photometry established by the CIE and accepted as the basis for the measurement of light. It defines the photometric quantities, units and standards that make up the CIE system of physical photometry and that have been officially accepted by the Comité International des Poids et Mesures (CIPM). This comprises:

— the definition of photometric quantities, symbols and units;

— the definition of CIE spectral luminous efficiency functions for photopic vision, scotopic vision, mesopic vision and 10° photopic vision;

— the definition of CIE photometric observers that conforms to these functions;

— the definition of maximum luminous efficacy for photopic vision, mesopic vision, scotopic vision and 10° photopic vision.

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.

CIE S 017, *ILV: International Lighting Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in CIE S 017 and the following 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/

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

— CIE e-ILV: available at https://cie.co.at/e-ilv

3.1
CIE photometric observer
CIE observer
ideal observer having a relative spectral responsivity that conforms to a CIE-defined spectral luminous efficiency function for human vision and that complies with the summation law implied in the definition of luminous flux

Note 1 to entry: CIE has defined spectral luminous efficiency functions for photopic vision, $V(\lambda)$, and scotopic vision, $V'(\lambda)$, which are CIE standard photometric observer(s). Furthermore, CIE has defined CIE photometric observers for mesopic vision, $V_{mes;m}(\lambda)$, and 10° photopic vision, $V_{10}(\lambda)$, as well as published definitions of cone-fundamental-based spectral luminous efficiency functions[5].

Note 2 to entry: CIE photometric observers are distinct from CIE standard photometric observers, which only include spectral luminous efficiency functions for photopic vision, $V(\lambda)$, and scotopic vision, $V'(\lambda)$.

Note 3 to entry: Other spectral luminous efficiency functions defined in this document are also intended to define CIE photometric observers.

Note 4 to entry: Other spectral luminous efficiency functions will possibly be included as CIE photometric observers. However, only the functions tabled in Clause 8 relate the given spectral radiometric quantity to the International System of Units (SI).

3.2
10° photopic vision
10° vision
photopic vision based on the CIE 10° photopic photometric observer

Note 1 to entry: 10° photopic vision corresponds to vision by the normal eye in situations where the visual target has an angular subtense larger than 4° or is seen off-axis.

4 Photometric quantities and units

4.1 Photometric quantities

The most commonly used photometric quantities are:

— luminous flux;

— luminous intensity;

— luminance;

— illuminance.

These quantities are defined in CIE S 017 and their definitions, adopted by the Consultative Committee for Photometry and Radiometry (CCPR) of the International Committee for Weights and Measures (CIPM), are referred to in this clause. After the redefinition of the SI units in 2019,[6] the definition of the unit of candela is tied to the definitions of the SI units kilogram, second and metre. It is important to note that the 2019 reformulation of the definition of the candela does not make a numerical difference in the calculations of the photometric quantities.

To avoid confusion, photometric quantities are distinguished symbolically from their radiometric equivalents by the subscript “v”, whereas radiometric quantities receive the subscript “e”. The same subscripts are also applicable to photometric and radiometric quantities other than those listed (e.g. luminous exposure, radiant exposure). For photometric quantities using spectral luminous efficiency functions other than that for 2° photopic vision, $V(\lambda)$, the quantity names and symbols described in Clause 6 are used.

For many practical purposes the simplest physical quantity used in optical radiometry is the radiant flux or radiant power, Φ_e, measured in watts (W), which is emitted by a source of radiation, transmitted by a medium of propagation or received at a surface. The corresponding photometric quantity is the luminous flux, Φ_v, measured in lumen (lm), derived from radiant flux, Φ_e, by evaluating the radiation according to its action upon a CIE standard photometric observer or CIE photometric observer. In this document the relation between radiometric quantities and photometric quantities is shown by example using the relation between the radiant flux and the (photopic) luminous flux using the CIE standard photometric observer for photopic vision, as well as other CIE photometric observers. The general relation between a given luminous flux, $\Phi_{v,X}$, for a specific photometric condition, X, and the spectral radiant flux $\Phi_{e,\lambda}(\lambda)$ is given in 7.3, with specific observers shown in 7.5 to 7.8.

The most commonly used photometric quantities given in this subclause, as well as others such as luminous exitance and luminous exposure, are defined in CIE S 017. All photometric quantities can be formulated in terms of luminous flux and appropriate geometric factors. The defining relationships for other photopic, scotopic and mesopic photometric quantities are formed from the formulae in 7.5 to 7.8 by replacing the symbols for radiant flux and luminous flux with the appropriate radiometric and photometric symbols.

Where a particular spectral luminous efficiency function is not specified, the photopic condition is implied.

4.2 Photometric units

The General Conference on Weights and Measures (CGPM) has fundamentally revised the SI to be based on seven defining constants.[6] In particular, the luminous efficacy of a monochromatic radiation of frequency 540 × 10^{12} Hz, K_{cd}, is introduced and its value is set to 683 lm·W^{-1}. This constant relates the photometric units (lm, cd and lx) directly to the corresponding radiometric units (W, W·sr^{-1} and W·m^{-2}).

As a consequence, the SI unit of luminous intensity of a source in a given direction, the candela, symbol cd, is defined by taking the fixed numerical value of the luminous efficacy of monochromatic radiation of frequency 540 × 10^{12} Hz, K_{cd}, to be 683 when expressed in the unit lm·W^{-1}, which is equal to cd·sr·W^{-1}, or cd·sr·kg^{-1}·m^{-2}·s^3, where the kilogram, metre and second are defined in terms of h, c and $\Delta\nu_{Cs}$.

This definition of the candela applies equally to any photometric condition (photopic vision, scotopic vision, mesopic vision and 10° photopic vision). The evolution of the photometric units is found in Annex C.

5 CIE standard spectral luminous efficiency functions

5.1 General

Photometric quantities are related to radiometric quantities through internationally agreed spectral weighting functions defined by the CIE as “spectral luminous efficiency functions”. These spectral luminous efficiency functions provide representations of the relative spectral sensitivity of the human visual system under defined conditions and are normalized to unity at the wavelength of peak sensitivity. The relevant spectral luminous efficiency function is applied as a spectral weighting to the spectral distribution of the corresponding radiometric quantity in order to calculate the corresponding photometric quantity (see Clause 7 for further details).

The most common spectral luminous efficiency functions are:

— $V(\lambda)$: photopic luminous efficiency function;

— $V'(\lambda)$: scotopic luminous efficiency function;

— $V_{mes;m}(\lambda)$: mesopic luminous efficiency function;

— $V_{10}(\lambda)$: 10° photopic efficiency function.

These are described in 5.2 to 5.5 and given as tabled values in Clause 9.

This document defines the spectral luminous efficiency functions for photopic, scotopic, mesopic and 10° photopic photometric conditions. These functions shall be used in the determination of photometric quantities when the corresponding condition is met.

Outside the specified spectral range, all values of the luminous efficiency functions shall be set to zero. See also 8.3.2.

5.2 Photopic vision

The spectral luminous efficiency function $V(\lambda)$ applies to photopic vision and shall be used for determination of photometric quantities at luminance levels above 5 cd·m^{-2}. It is important to note that the $V(\lambda)$ function applies at all luminance levels for foveal vision or for all on-axis visual tasks (objects seen by the eye are in a narrow field of view in central vision i.e. ≤4°). It is defined by the numerical values given in Table 6, the wavelength being measured in standard air.[7] For numerical computations, the peak value of the $V(\lambda)$ function shall be evaluated at 555 nm exactly. For calculation purposes, linear interpolation shall be used exclusively to evaluate $V(\lambda)$ at wavelengths intermediate to those given in Table 6.

5.3 Scotopic vision

The spectral luminous efficiency function $V'(\lambda)$ applies to scotopic vision and shall be used for determination of photometric quantities in situations where the eye is adapted to average luminance levels less than 0,005 cd·m^{-2}. This function is defined by the numerical values given in Table 7, the wavelength λ being measured in standard air. For numerical computations, the peak value of the $V'(\lambda)$ function shall be evaluated at 507 nm exactly. For calculation purposes, linear interpolation shall be used exclusively to evaluate $V'(\lambda)$ at wavelengths intermediate to those given in Table 7.

5.4 Mesopic vision

The spectral luminous efficiency function $V_{\mathrm{mes};m}(\lambda)$ applies to mesopic vision under given adaptation conditions and shall be used for determination of photometric quantities at luminance levels in the intermediate range between photopic and scotopic vision. The procedure to calculate $V_{\mathrm{mes};m}(\lambda)$ for a given adaptation coefficient, m, is given in this subclause and the calculation of the mesopic luminous flux is given in 7.7 as an example.

The spectral luminous efficiency function for mesopic vision is denoted by $V_{\mathrm{mes};m}(\lambda)$ and is defined according to Formula (1):

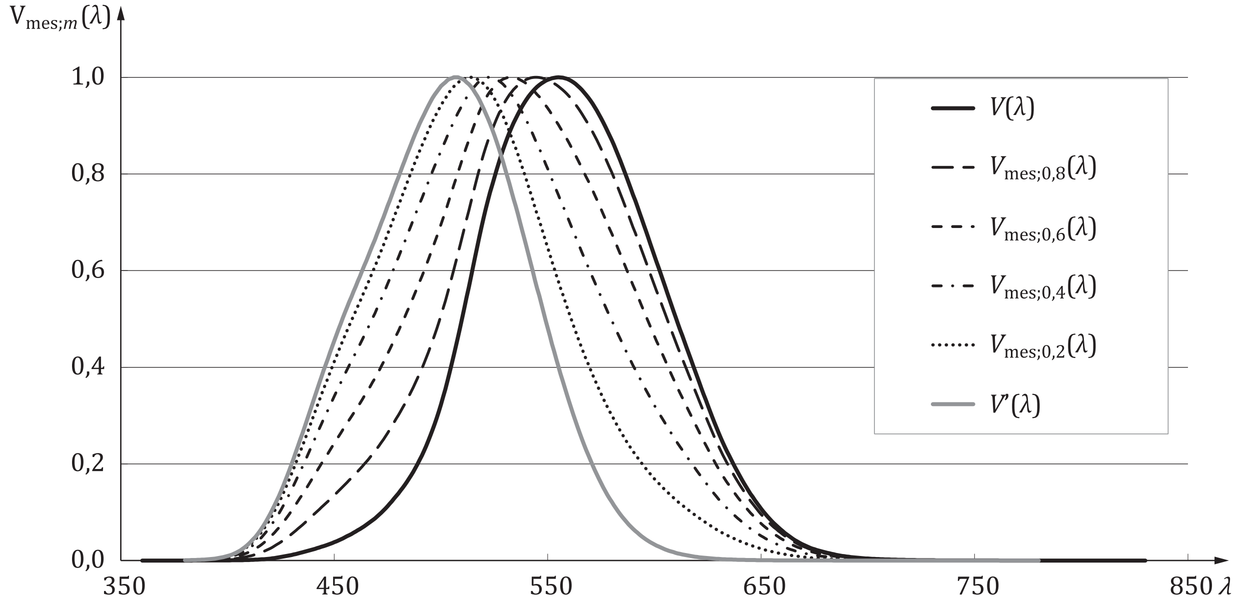
$$V_{\mathrm{mes};m}(\lambda)=\frac{1}{M(m)}\{mV(\lambda)+(1-m)V'(\lambda)\}\ \text{for}\ 0\leq m\leq 1 \quad (1)$$

where

m is the adaptation coefficient, the value of which depends on the visual adaptation conditions (see 7.7);

$M(m)$ is a normalizing function such that $V_{\mathrm{mes};m}(\lambda)$ attains a maximum value of 1.

Figure 1 shows the curves of the mesopic spectral luminous efficiency function $V_{\mathrm{mes};m}(\lambda)$ for m = 0,2; 0,4; 0,6; 0,8 as examples, plotted with $V(\lambda)$ and $V'(\lambda)$. Table A.1 in Annex A shows the values of $V_{\mathrm{mes};m}(\lambda)$ for m = 0,8 as an example, which corresponds to the visual adaptation condition for a typical road lighting luminance level (≈ 1 cd·m^{-2}), considering Formulae (12) and (13).



Key

λ wavelength in nm

$V_{mes;m}(\lambda)$ spectral luminous efficiency for mesopic vision

Figure 1 — The spectral luminous efficiency for mesopic vision, $V_{mes;m}(\lambda)$, at m = 0,2; 0,4; 0,6; 0,8 as examples, plotted with $V(\lambda)$ and $V'(\lambda)$

5.5 10° photopic vision

The spectral luminous efficiency function $V_{10}(\lambda)$ applies for 10° photopic vision and shall be used for measurements in situations where the visual target has an angular subtense larger than 4° or is seen off-axis. The values of $V_{10}(\lambda)$ are given in Table 8.

6 Names, symbols and units for photometric quantities

6.1 General

This clause describes the relations between the names, symbols and units for photometric quantities used in the CIE system of physical photometry.

The SI defines the photometric units through the introduction of the constant K_{cd} = 683 lm·W^{-1}, i.e. the luminous efficacy for monochromatic radiation of frequency 540 × 10^{12} Hz. Thus, by construction the unit of the photometric quantity “luminous flux” is lumen and therefore independent of the photometric condition (i.e. photopic, scotopic, mesopic, 10° photopic), see also Formula (2). The independence of the unit from the observer holds also for the other photometric units, i.e. for all photometric quantities listed in 4.1 the same SI units – cd, lm, lx, cd·m^{-2} – apply, and these shall not be modified.

Also, when a photometric quantity is expressed with photometric units, additivity shall hold (at least within the stated visual adaptation conditions).

Photometric units are not used for non-visual effects.[4] For non-visual effects, radiometric units are used.

NOTE See Annex D for guidance on the valid description of photometric values.

6.2 Photopic vision

Table 1 shows the quantity names, symbols and units that apply for photopic vision [using the spectral luminous efficiency function for photopic vision, $V(\lambda)$] and derivations of the units.

Table 1 — Photometric quantities for photopic vision with their associated symbol, SI unit and unit expressed in terms of other SI units

Quantity	Symbol	SI unit	Unit expressed in terms of other SI units
(Photopic) luminous flux	Φ_{v}	lm	cd·sr
(Photopic) luminous intensity	I_{v}	cd	$\mathrm{lm \cdot sr^{-1}}$
(Photopic) luminance	L_{v}	$\mathrm{cd \cdot m^{-2}}$	$\mathrm{lm \cdot sr^{-1} \cdot m^{-2}}$
(Photopic) illuminance	E_{v}	lx	$\mathrm{lm \cdot m^{-2}}$, $\mathrm{cd \cdot sr \cdot m^{-2}}$
NOTE 1 The descriptor “photopic” is used only when quantities other than photopic are reported or discussed in the same document and there is a possibility of confusion.			
NOTE 2 The steradian (symbol sr) is the unit for solid angle. 1 sr is the solid angle subtended at the centre of a sphere by an area of the surface that is equal to the squared radius. The steradian can be expressed in terms of the metre as $\mathrm{sr} = \mathrm{m^2/m^2}$.			

6.3 Scotopic vision

Table 2 shows the quantity names and symbols that apply for scotopic vision [using the spectral luminous efficiency function for scotopic vision, $V'(\lambda)$].

Table 2 — Photometric quantities for scotopic vision with their associated symbol and SI unit

Quantity	Symbol	SI unit
Scotopic luminous flux	Φ'_{v}	lm
Scotopic luminous intensity	I'_{v}	cd
Scotopic luminance	L'_{v}	$\mathrm{cd \cdot m^{-2}}$
Scotopic illuminance	E'_{v}	lx

6.4 Mesopic vision

Table 3 shows the quantity names and symbols that apply for mesopic vision[8] [using the spectral luminous efficiency function for mesopic vision, $V_{\mathrm{mes};m}(\lambda)$].

Table 3 — Photometric quantities for mesopic vision with their associated symbol and SI unit

Quantity	Symbol	SI unit
Mesopic luminous flux	$\Phi_{\mathrm{mes};\,m}$	lm
Mesopic luminous intensity	$I_{\mathrm{mes};\,m}$	cd
Mesopic luminance	$L_{\mathrm{mes};\,m}$	$\mathrm{cd \cdot m^{-2}}$
Mesopic illuminance	$E_{\mathrm{mes};\,m}$	lx

m is a coefficient ($0 \le m \le 1$) determined by the visual adaptation level. The value of m shall be specified as appendage to the quantity name, for example “mesopic luminous flux (m = 0,5)”, as well as subscript to the symbol, for example “$\Phi_{\mathrm{mes};\,0,5}$”. Further guidance is available in Reference [8].

NOTE Mesopic photometric quantities follow the law of additivity only within a scene at a certain adaptation luminance level. For $m = 1$ and $m = 0$, the mesopic photometric quantities are identical to the photopic and scotopic quantities, respectively (see 7.7).

6.5 10° Photopic vision

Table 4 shows the quantity names and symbols that apply for 10° photopic vision [using the spectral luminous efficiency function for 10° photopic vision, $V_{10}(\lambda)$].

Table 4 — Photometric quantities for 10° photopic vision with their associated symbol and SI unit

Quantity	Symbol	SI unit
10° luminous flux	Φ_{10}	lm
10° luminous intensity	I_{10}	cd
10° luminance	L_{10}	$cd \cdot m^{-2}$
10° illuminance	E_{10}	lx

6.6 Photometric quantities for other observers

For research purposes, photometric quantities for observers other than those introduced in 6.2 to 6.5 may be used, for example observers adapted from the cone-fundamental-based spectral luminous efficiency functions defined in CIE 170-2:2015[5] and the CIE 1988 modified 2° observer.[9] When one of these CIE observers is used, the respective spectral luminous efficiency function shall be specified to avoid any confusion with other CIE-defined photometric quantities. Additionally, an appropriate quantity name (e.g. CIE 2015 luminous flux or CIE 1988 luminous flux) and an appropriate symbol for the quantity (e.g. Φ_F or Φ_M) shall be used. The same SI units – cd, lm, lx, $cd \cdot m^{-2}$ – are used and these shall not be modified.

7 Basic formulae relating photometric quantities to radiometric quantities

7.1 General

The spectral luminous efficiency functions and the basic formulae relating radiometric and photometric quantities defined in this document supplement the reformulation of the definition of the candela approved in the 28th CGPM.[6] These definitions in conjunction constitute a rational system of physical photometry, which:

— correlates the radiant power of broadband radiation acting upon the human visual system with the physiological characteristics of the latter;

— is consistent with visual experience;

— establishes precisely defined numerical relationships between radiometric and photometric quantities.

In 7.2 the general formula linking radiometric and photometric quantities is presented; in 7.3 this relation is specified for luminous flux as an example; in 7.4 the formulae for the maximum luminous efficacies are given; and in 7.5 to 7.8 examples of relations between radiant flux and luminous flux are provided for each photometric condition.

7.2 General formula

Formula (2) forms the basis of the CIE system of physical photometry and provides a direct link between a given spectral radiometric quantity, $X_{e,\lambda}(\lambda)$, (e.g. spectral radiant intensity) and the corresponding photometric quantity, $X_{v,X}$, (e.g. luminous intensity) using:

$$X_{v,X} = \frac{K_{cd}}{V_X(\lambda_{cd})} \int_{\lambda} X_{e,\lambda}(\lambda) V_X(\lambda) \, d\lambda \qquad (2)$$

where

K_{cd} is the luminous efficacy of monochromatic radiation of frequency 540 × 10^{12} Hz (683 lm·W^{-1});

$V_X(\lambda)$ is the relevant spectral luminous efficiency function;

λ_{cd} is the wavelength at 540 × 10^{12} Hz according to the definition of the unit candela (555,017 nm in standard air);

$V_X(\lambda_{cd})$ is the value of the relevant spectral luminous efficiency function at the wavelength λ_{cd} in standard air.

7.3 General formula for luminous flux

For a specific spectral luminous efficiency function, $V_X(\lambda)$, the relationship between the photometric quantity luminous flux, $\Phi_{v,X}$, and its corresponding spectral radiant flux, $\Phi_{e,\lambda}(\lambda)$, is given according to Formula (3):

$$\Phi_{v,X} = \frac{K_{cd}}{V_X(\lambda_{cd})} \int_\lambda \Phi_{e,\lambda}(\lambda) V_X(\lambda)\, d\lambda \tag{3}$$

where

K_{cd} is the luminous efficacy of monochromatic radiation of frequency 540 × 10^{12} Hz (683 lm·W^{-1});

$V_X(\lambda)$ is the relevant spectral luminous efficiency function;

$\Phi_{v,X}$ is the luminous flux evaluated using a defined spectral luminous efficiency function $V_X(\lambda)$;

$\Phi_{e,\lambda}(\lambda) = \frac{d\Phi_e}{d\lambda}$ is spectral radiant flux, i.e. the spectral distribution of radiant flux, Φ_e;

λ_{cd} is the wavelength at 540 × 10^{12} Hz according to the definition of the unit candela (555,017 nm in standard air);

$V_X(\lambda_{cd})$ is the value of the relevant spectral luminous efficiency function at the wavelength λ_{cd} in standard air.

Formula (3) requires that the spectral luminous efficiency function has a non-zero value at wavelength λ_{cd}. The wavelengths for the spectral luminous efficiency functions are typically wavelengths in air.

7.4 Maximum luminous efficacy

7.4.1 General

The maximum luminous efficacy for a specified photometric condition, K_X, constitutes the link from the defining constant in the SI, K_{cd}, to the CIE standard observers and CIE observers according to Formula (4):

$$K_X = K_{cd} \frac{V_X(\lambda_X)}{V_X(\lambda_{cd})} \tag{4}$$

where

K_{cd} is the luminous efficacy of monochromatic radiation of frequency 540 × 10^{12} Hz (683 lm·W^{-1});

$V_X(\lambda)$ is the relevant spectral luminous efficiency function;

λ_{cd} is the wavelength at 540×10^{12} Hz according to the definition of the unit candela (555,017 nm in standard air);

λ_X is the wavelength of the maximum of $V_X(\lambda)$;

$V_X(\lambda_{cd})$ is the value of the relevant spectral luminous efficiency function at the wavelength λ_{cd} in standard air.

For the CIE standard observers and CIE observers the maximum luminous efficacies shown in 7.4.2 to 7.4.5 are defined (see also Table 5).

7.4.2 Photopic vision

The maximum luminous efficacy for photopic vision, K_m, i.e. the luminous efficacy at the peak of the $V(\lambda)$ function, which is at a wavelength of λ_m = 555 nm (exactly), is given by Formula (5):

$$K_m = K_{cd} \frac{V(\lambda_m)}{V(\lambda_{cd})} \tag{5}$$

(= 683,002 ... lm·W^{-1} ≈ 683 lm·W^{-1} in standard air).

7.4.3 Scotopic vision

The maximum luminous efficacy for scotopic vision, K'_m, i.e. the luminous efficacy at the peak of the $V'(\lambda)$ function, which is at a wavelength of λ'_m = 507 nm (exactly), is given by Formula (6):

$$K'_m = K_{cd} \frac{V'(\lambda_m)}{V'(\lambda_{cd})} \tag{6}$$

(= 1 700,13 ... lm·W^{-1} ≈ 1 700 lm·W^{-1} in standard air).

7.4.4 Mesopic vision

The maximum luminous efficacy for mesopic vision, $K_{m,mes;m}$, varies as a function of m and is given by Formula (7):

$$K_{m,mes;m} = \frac{K_{cd}}{V_{mes;m}(\lambda_{cd})} \tag{7}$$

The value of $K_{m,mes;m}$ varies from 683 lm·W^{-1} at m = 1 (photopic) to 1 700 lm·W^{-1} at m = 0 (scotopic)[1]. Figure 2 shows this relationship. Annex B provides the values of the maximum luminous efficacy for mesopic vision for specific values of m.

7.4.5 10° photopic vision

The maximum luminous efficacy for 10° photopic vision, $K_{m,10}$, i.e. the luminous efficacy at the peak of the $V_{10}(\lambda)$ function, which is at a wavelength of $\lambda_{m,10}$ = 557 nm (exactly), is given by Formula (8):

$$K_{m,10} = K_{cd} \frac{V_{10}(\lambda_{m,10})}{V_{10}(\lambda_{cd})} \tag{8}$$

(= 683,601... lm·W^{-1} ≈ 684 lm·W^{-1} in standard air).

1) The subscript m, in roman, in $K_{m,mes;m}$ refers to “maximum”, whereas the subscript m, in italic, represents a variable, referring to the adaptation coefficient.