



International Commission on Illumination
Commission Internationale de l'Eclairage
Internationale Beleuchtungskommission

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TECHNICAL REPORT

The Basis of Physical Photometry, 3rd Edition

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THE INTERNATIONAL COMMISSION ON ILLUMINATION

The International Commission on Illumination (CIE) is an organization devoted to international co-operation and exchange of information among its member countries on all matters relating to the art and science of lighting. Its membership consists of the National Committees in about 40 countries.

The objectives of the CIE are:

1. To provide an international forum for the discussion of all matters relating to the science, technology and art in the fields of light and lighting and for the interchange of information in these fields between countries.
2. To develop basic standards and procedures of metrology in the fields of light and lighting.
3. To provide guidance in the application of principles and procedures in the development of international and national standards in the fields of light and lighting.
4. To prepare and publish standards, reports and other publications concerned with all matters relating to the science, technology and art in the fields of light and lighting.
5. To maintain liaison and technical interaction with other international organizations concerned with matters related to the science, technology, standardization and art in the fields of light and lighting.

The work of the CIE is carried out by Technical Committees, organized in six Divisions. This work covers subjects ranging from fundamental matters to all types of lighting applications. The standards and technical reports developed by these international Divisions of the CIE are accepted throughout the world.

A plenary session is held every four years at which the work of the Divisions and Technical Committees is reported and reviewed, and plans are made for the future. The CIE is recognized as the authority on all aspects of light and lighting. As such it occupies an important position among international organizations.

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La Commission Internationale de l'Eclairage (CIE) est une organisation qui se donne pour but la coopération internationale et l'échange d'informations entre les Pays membres sur toutes les questions relatives à l'art et à la science de l'éclairage. Elle est composée de Comités Nationaux représentant environ 40 pays.

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1. De constituer un centre d'étude international pour toute matière relevant de la science, de la technologie et de l'art de la lumière et de l'éclairage et pour l'échange entre pays d'informations dans ces domaines.
2. D'élaborer des normes et des méthodes de base pour la métrologie dans les domaines de la lumière et de l'éclairage.
3. De donner des directives pour l'application des principes et des méthodes d'élaboration de normes internationales et nationales dans les domaines de la lumière et de l'éclairage.
4. De préparer et publier des normes, rapports et autres textes, concernant toutes matières relatives à la science, la technologie et l'art dans les domaines de la lumière et de l'éclairage.
5. De maintenir une liaison et une collaboration technique avec les autres organisations internationales concernées par des sujets relatifs à la science, la technologie, la normalisation et l'art dans les domaines de la lumière et de l'éclairage.

Les travaux de la CIE sont effectués par Comités Techniques, organisés en six Divisions. Les sujets d'études s'étendent des questions fondamentales, à tous les types d'applications de l'éclairage. Les normes et les rapports techniques élaborés par ces Divisions Internationales de la CIE sont reconnus dans le monde entier.

Tous les quatre ans, une Session plénière passe en revue le travail des Divisions et des Comités Techniques, en fait rapport et établit les projets de travaux pour l'avenir. La CIE est reconnue comme la plus haute autorité en ce qui concerne tous les aspects de la lumière et de l'éclairage. Elle occupe comme telle une position importante parmi les organisations internationales.

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Die Internationale Beleuchtungskommission (CIE) ist eine Organisation, die sich der internationalen Zusammenarbeit und dem Austausch von Informationen zwischen ihren Mitgliedsländern bezüglich der Kunst und Wissenschaft der Lichttechnik widmet. Die Mitgliedschaft besteht aus den Nationalen Komitees in rund 40 Ländern.

Die Ziele der CIE sind:

1. Ein internationales Forum für Diskussionen aller Fragen auf dem Gebiet der Wissenschaft, Technik und Kunst der Lichttechnik und für den Informationsaustausch auf diesen Gebieten zwischen den einzelnen Ländern zu sein.
2. Grundnormen und Verfahren der Messtechnik auf dem Gebiet der Lichttechnik zu entwickeln.
3. Richtlinien für die Anwendung von Prinzipien und Vorgängen in der Entwicklung internationaler und nationaler Normen auf dem Gebiet der Lichttechnik zu erstellen.
4. Normen, Berichte und andere Publikationen zu erstellen und zu veröffentlichen, die alle Fragen auf dem Gebiet der Wissenschaft, Technik und Kunst der Lichttechnik betreffen.
5. Liaison und technische Zusammenarbeit mit anderen internationalen Organisationen zu unterhalten, die mit Fragen der Wissenschaft, Technik, Normung und Kunst auf dem Gebiet der Lichttechnik zu tun haben.

Die Arbeit der CIE wird durch Technische Komitees geleistet, die in sechs Divisionen organisiert sind. Diese Arbeit betrifft Gebiete mit grundlegendem Inhalt bis zu allen Arten der Lichtanwendung. Die Normen und Technischen Berichte, die von diesen international zusammengesetzten Divisionen ausgearbeitet werden, sind auf der ganzen Welt anerkannt.

Alle vier Jahre findet eine Session statt, in der die Arbeiten der Divisionen berichtet und überprüft werden, sowie neue Pläne für die Zukunft ausgearbeitet werden. Die CIE wird als höchste Autorität für alle Aspekte des Lichtes und der Beleuchtung angesehen. Auf diese Weise unterhält sie eine bedeutende Stellung unter den internationalen Organisationen.

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This Technical Report has been prepared by CIE Joint Technical Committee JTC 2 (CIE-CCPR) of CIE Division 2 "Physical Measurement of Light and Radiation" in cooperation with the Consultative Committee for Photometry and Radiometry (CCPR) and has been approved by the Board of Administration and by Division 2 of the Commission Internationale de l'Eclairage. A harmonized document, Rapport BIPM-2019/05, Principles Governing Photometry, 2nd Edition, containing identical technical contents, has also been published by BIPM (Bureau International des Poids et Mesures). The document reports on current knowledge and experience within the specific field of light and lighting described, and is intended to be used by all with an interest in excellence in light and lighting. The information provided here is advisory, and not mandatory.

Ce rapport technique a été élaboré par le Comité Technique mixte JTC 2 (CIE-CCPR) de la CIE Division 2 "Mesures Physiques de la Lumière et des Radiations" conjointement avec le CCPR et a été approuvé par le Bureau et Division 2 de la Commission Internationale de l'Eclairage. Un document harmonisé, Rapport BIPM-2019/05, Principles Governing Photometry, 2nd Edition, avec content technique identique, a été publié par BIPM (Bureau International des Poids et Mesures). Le document expose les connaissances et l'expérience actuelles dans le domaine particulier de la lumière et de l'éclairage décrit ici. Il est destiné à être utilisé par tous ceux qui s'intéressent à l'excellence de la lumière et de l'éclairage. Les informations fournies ici sont données à titre indicatif et non obligatoire.

Dieser Technisch Bericht ist vom gemeinschaftlichen Technischen Komitee JTC 2 (CIE-CCPR) der CIE Division 2 "Physikalische Messungen von Licht und Strahlung" in Zusammenarbeit mit dem CCPR ausgearbeitet und vom Vorstand sowie Division 2 der Commission Internationale de l'Eclairage gebilligt worden. Ein harmonisiertes Dokument, Rapport BIPM-2019/05, Principles Governing Photometry, 2nd Edition, mit identischem technischen Inhalt, ist auch vom BIPM (Bureau International des Poids et Mesures) veröffentlicht worden. Das Dokument berichtet über den derzeitigen Stand des Wissens und Erfahrung in dem behandelten Gebiet von Licht und Beleuchtung. Es ist zur Verwendung durch alle an Licht- und Beleuchtungsqualität Interessierte bestimmt. Die in diesem Dokument gegebenen Informationen sind eine Empfehlung und keine Vorschrift.

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CONTENTS

Summary	v
Résumé	v
Zusammenfassung	v
1 Introduction	1
2 Photometric quantities	1
2.1 luminous flux	2
2.2 luminous intensity	2
2.3 luminance	3
2.4 illuminance	4
3 Photometric units	4
4 Spectral luminous efficiency functions	5
4.1 Photopic vision	5
4.2 Scotopic vision	6
4.3 Mesopic vision	6
4.4 10° photopic vision	6
4.5 Use of these spectral luminous efficiency functions	7
5 Photometric quantity names and symbols	7
5.1 Photometric quantities for photopic vision	7
5.2 Photometric quantities for scotopic vision	7
5.3 Photometric quantities for mesopic vision	8
5.4 Photometric quantities for 10° photopic vision	8
5.5 Photometric quantities for other observers	8
6 Basic equations relating photometric quantities to radiometric quantities	8
6.1 General equation	8
6.2 (Photopic) luminous flux	9
6.3 Scotopic luminous flux	9
6.4 Mesopic luminous flux	10
7 Relating photochemical and photobiological quantities to photometric quantities	12
8 Colorimetric quantities	12
8.1 CIE 1931 colour-matching functions	12
8.2 Tristimulus values and chromaticity coordinates	12
9 General notes	13
10 Tables	15
References	41

THE BASIS OF PHYSICAL PHOTOMETRY, 3RD EDITION

Summary

This publication supersedes CIE 18.2-1983. It presents the basic conventions and principles of physical photometry, with the definitions of the photometric units as reformulated in the International System of Units (SI) 2019 and the photometric quantities and spectral luminous efficiency functions for photopic, mesopic and scotopic vision, including 10° photopic vision. The relationships between the photometric quantities and the radiometric quantities based on the constant K_{cd} are described, as well as the relationships between photochemical and photobiological quantities and photometric quantities. The conventions of colorimetry are presented, with the definitions of the colour-matching functions for the 2° and 10° field of view, tristimulus values, and chromaticity coordinates.

LES BASES DE LA PHOTOMÉTRIE PHYSIQUE, 3ÈME EDITION

Résumé

Ce rapport remplace la publication CIE 18.2-1983. Il présente les conventions de base et les principes de la photométrie physique en tenant compte des unités photométriques définies dans le Système International des Unités (SI) 2019, des grandeurs photométriques et des fonctions d'efficacité lumineuse spectrale pour la vision photopique, mésopique et scotopique, y compris l'observateur photopique 10°. Le rapport décrit la relation entre les unités photométriques et radiométriques basée sur la constante K_{cd} . De plus, la relation entre les grandeurs photochimiques et photobiologiques et les grandeurs photométriques est décrite. Les conventions de la colorimétrie avec la définition des fonctions colorimétriques 2° et 10°, les composantes trichromatiques et les coordonnées trichromatiques sont présentées.

DIE BASIS DER PHYSIKALISCHEN PHOTOMETRIE, 3. EDITION

Zusammenfassung

Dieser Technische Bericht ersetzt die CIE Publikation 18.2-1983. Er enthält die grundlegenden Festlegungen und Prinzipien der physikalischen Photometrie. Er beinhaltet die photometrischen Einheiten gemäss dem Internationalen Einheitensystem (SI) 2019, sowie die photometrischen Messgrössen und die spektralen Hellempfindlichkeitsgrade für den photopischen, mesopischen, skoptischen Beobachter, inklusive dem 10° photopischen Beobachter. Die Beziehungen zwischen den photometrischen und radiometrischen Größen, basierend auf der Konstante K_{cd} , werden beschrieben, wie auch der Zusammenhang zwischen photochemischen und photobiologischen Messgrössen und photometrischen Messgrössen. Die Konventionen für die Farbmessung, mit Definitionen der Spektralwertfunktionen für den 2°- und 10°-Beobachter, der Farbwerte, und der Farbwertanteile werden vorgestellt.

1 Introduction

Photometric procedures are used to measure light, i.e. measuring the universal and essential attribute of all perceptions and sensations which are peculiar to the human visual system and which are produced through the agency of that system. Thus, photometric quantities must take into account both the purely physical characteristics of the radiant power stimulating the visual system and the spectral responsivity of the latter. The psychophysical nature of the second of these two factors sets photometric quantities apart from purely physical quantities.

The purpose of this document is to describe and explain the usage of the photometric quantities as well as their units, and to explain briefly the conventions relating them with the purely physical quantity, radiant power, and its unit, the watt. These definitions and conventions aim at enabling photometric measurements to be made by purely physical methods, but to yield results that correlate adequately with visual experience. The relationships between these photometric quantities and photobiological, photochemical, and colorimetric quantities are also given. The practical realization of the units for these photometric quantities is outside the scope of this document and is available in the *mise en pratique* for the definition of the candela and associated derived units for photometric and radiometric quantities (Zwinkels et al., 2016).

If electromagnetic radiation is of sufficient power and of wavelengths within the range 360 nm to 830 nm (approximately), it stimulates the visual organ, i.e. the eye. The retinal receptor elements involved may be principally the cones (photopic vision, eye adapted to higher levels of luminance), the rods (scotopic vision, eye adapted to lower levels of luminance), or a combination of the cones and rods (mesopic vision, intermediate between photopic and scotopic vision).

This 3rd edition of CIE 18 has been updated to include, in the definitions of photometric quantities and units, the spectral luminous efficiency functions for mesopic vision based on CIE 191:2010 (CIE, 2010), as well as the 10° spectral luminous efficiency functions based on CIE 165:2005 (CIE, 2005), and to introduce the defining constant for photometry, denoted K_{cd} , adopted in the International System of Units (SI) 2019 (BIPM, 2019).

2 Photometric quantities

The photometric quantities generally used are:

- luminous flux,
- luminous intensity,
- luminance,
- illuminance.

These quantities are defined by the International Commission on Illumination (CIE, 2016a) and their definitions, adopted by the Consultative Committee for Photometry and Radiometry (CCPR) of the International Committee for Weights and Measures (CIPM), are shown in this clause.

To avoid confusion, photometric and radiometric quantities are distinguished symbolically from each other by the subscript “v” or “e”, respectively. The same subscripts are applicable to photometric quantities other than those listed above (e.g. luminous exposure). For photometric quantities using spectral luminous efficiency functions other than that for 2° photopic vision, $V(\lambda)$, the notations described in Clause 5 are used.

Luminous flux is the most fundamental quantity in photometry because it has the simplest relationship with radiant power. The other three quantities are defined as follows in terms of luminous flux and appropriate geometric factors. The defining relationships for scotopic and

mesopic photometric quantities are formed from the formulae in definitions 2.1 to 2.4 below by replacing the quantity symbols by those defined in Clause 5.

2.1

luminous flux

Φ_v ; Φ

change of luminous energy with time

$$\Phi_v = \frac{dQ_v}{dt}$$

where Q_v is the luminous energy emitted, transferred or received and t is time

Note 1 to entry: Luminous flux is a quantity derived from the radiant flux Φ_e , by evaluating the radiation according to its action upon the CIE standard photometric observer. Luminous flux can be derived from the spectral radiant flux distribution by

$$\Phi_v = K_m \int_0^\infty \Phi_{e,\lambda}(\lambda) V(\lambda) d\lambda$$

where K_m is maximum luminous efficacy, $\Phi_{e,\lambda}(\lambda)$ is spectral radiant flux, $V(\lambda)$ is spectral luminous efficiency and λ is wavelength.

Note 2 to entry: The distribution of the luminous intensities as a function of the direction of emission, e.g. given by the polar angles (ϑ, φ) , is used to determine the luminous flux, Φ_v , within a certain solid angle, Ω , of a source:

$$\Phi_v = \iint_{\Omega} I_v(\vartheta, \varphi) \sin \vartheta \, d\vartheta \, d\varphi.$$

Note 3 to entry: The corresponding radiometric quantity is "radiant flux". The corresponding quantity for photons is "photon flux".

Note 4 to entry: The luminous flux is expressed in lumen (lm).

[SOURCE: CIE DIS 017:2016: Term 17-21-039, modified – ", expressed by" removed.]

2.2

luminous intensity

I_v ; I

density of luminous flux with respect to solid angle in a specified direction

$$I_v = \frac{d\Phi_v}{d\Omega}$$

where Φ_v is the luminous flux emitted in the given direction, and Ω is the solid angle containing that direction.

Note 1 to entry: For practical realization of the quantity the source is approximated by a point source.

Note 2 to entry: The distribution of the luminous intensities as a function of the direction of emission, e.g. given by the polar angles (ϑ, φ) , is used to determine the luminous flux, Φ_v , within a certain solid angle, Ω , of a source:

$$\Phi_v = \iint_{\Omega} I_v(\vartheta, \varphi) \sin \vartheta \, d\vartheta \, d\varphi.$$

Note 3 to entry: Luminous intensity can be derived from the spectral radiant intensity distribution by

$$I_v = K_m \int_0^{\infty} I_{e,\lambda}(\lambda) V(\lambda) d\lambda$$

where K_m is maximum luminous efficacy, $I_{e,\lambda}(\lambda)$ is the spectral radiant intensity at wavelength λ , and $V(\lambda)$ is spectral luminous efficiency.

Note 4 to entry: The corresponding radiometric quantity is "radiant intensity". The corresponding quantity for photons is "photon intensity".

Note 5 to entry: The luminous intensity is expressed in candela ($\text{cd} = \text{lm} \cdot \text{sr}^{-1}$).

[SOURCE: CIE DIS 017:2016, Term 17-21-045, modified – ", expressed by" removed, Note 1 to entry changed, formula in Note 3 to entry adjusted]

2.3 luminance

L_v ; L

density of luminous intensity with respect to projected area in a specified direction at a specified point on a real or imaginary surface

$$L_v = \frac{dI_v}{dA} \frac{1}{\cos \alpha}$$

where I_v is luminous intensity, A is area and α is the angle between the normal to the surface at the specified point and the given direction

Note 1 to entry: In a practical sense, the definition of luminance can be thought of as dividing a real or imaginary surface into an infinite number of infinitesimally small surfaces, which can be considered as point sources, each of which has a specific luminous intensity, I_v , in the specified direction. The luminance of the surface is then the integral of these luminance elements over the whole surface.

The equation in the definition can mathematically be interpreted as a derivative (i.e. a rate of change of luminous intensity with projected area) and could alternatively be rewritten in terms of the average luminous intensity $\bar{I}_v$ as

$$L_v = \lim_{A \rightarrow 0} \frac{\bar{I}_v}{A} \frac{1}{\cos \alpha}$$

Hence, luminance is often considered as a quotient of averaged quantities; the area, A , should be small enough that uncertainties due to variations in luminous intensity within that area are negligible, otherwise, the quotient $\bar{L}_v = \frac{\bar{I}_v}{A} \frac{1}{\cos \alpha}$ gives the average luminance and the specific measurement conditions must be reported with the result.

Note 2 to entry: For a surface being irradiated, an equivalent formula in terms of illuminance, E_v , and solid angle, Ω , is $L_v = \frac{dE_v}{d\Omega} \frac{1}{\cos \theta}$ where θ is the angle between the normal to the surface being irradiated and the direction of irradiation. This form is useful when the source has no surface (e.g. the sky, the plasma of a discharge).

Note 3 to entry: An equivalent formula is $L_v = \frac{d\Phi_v}{dG}$, where Φ_v is luminous flux and G is geometric extent.

Note 4 to entry: Luminous flux may be obtained by integrating luminance over projected area, $A \cos \alpha$, and solid angle, Ω : $\Phi_v = \iint L_v \cos \alpha dA d\Omega$.

Note 5 to entry: Since the optical extent, expressed by $G \cdot n^2$, where G is geometric extent and n is refractive index, is invariant, the quantity expressed by $L_v \cdot n^{-2}$ is also invariant along the path of the beam if the losses by absorption, reflection and diffusion are taken as 0. That quantity is called “basic luminance”.

Note 6 to entry: The equation in the definition can also be described as a function of luminous flux, Φ_v . In this case, it is mathematically interpreted as a second partial derivative of the luminous flux at a specified point (x, y) in space in a specified direction (ϑ, φ) with respect to projected area, $A \cdot \cos \alpha$, and solid angle, Ω ,

$$L_v(x, y, \vartheta, \varphi) = \frac{\partial^2 \Phi_v(x, y, \vartheta, \varphi)}{\partial A(x, y) \cdot \cos \alpha \cdot \partial \Omega(\vartheta, \varphi)}$$

where α is the angle between the normal to that area at the specified point and the specified direction.

Note 7 to entry: The corresponding radiometric quantity is “radiance”. The corresponding quantity for photons is “photon radiance”.

Note 8 to entry: The luminance is expressed in candela per square metre ($\text{cd} \cdot \text{m}^{-2} = \text{lm} \cdot \text{m}^{-2} \cdot \text{sr}^{-1}$).

[SOURCE: CIE DIS 017:2016, Term 17-21-050, modified – “, expressed by” removed, in Note 1 to entry “radiance” replaced by “luminance” at two places, and “radiant intensity” replaced by “luminous intensity”]

2.4 illuminance

E_v ; E

density of incident luminous flux with respect to area at a point on a real or imaginary surface

$$E_v = \frac{d\Phi_v}{dA}$$

where Φ_v is luminous flux and A is the area on which the luminous flux is incident

Note 1 to entry: Illuminance can be derived from the spectral irradiance distribution by

$$E_v = K_m \int_0^\infty E_{e,\lambda}(\lambda) V(\lambda) d\lambda$$

where K_m is maximum luminous efficacy, $E_{e,\lambda}(\lambda)$ is the spectral irradiance at wavelength λ , and $V(\lambda)$ is spectral luminous efficiency.

Note 2 to entry: The corresponding radiometric quantity is “irradiance”. The corresponding quantity for photons is “photon irradiance”.

Note 3 to entry: The illuminance is expressed in lux ($\text{lx} = \text{lm} \cdot \text{m}^{-2}$)

[SOURCE: CIE DIS 017:2016, Term 17-21-060, modified – “, expressed by” removed, formula in Note 1 to entry adjusted]

3 Photometric units

Historically the SI units have been presented in terms of a set of seven base units. All other units (“derived units”) are then constructed as products of powers of the base units. In the field of photometry, the definition of the unit of luminous intensity (based on a blackbody at the freezing point temperature of platinum), was adopted at the 9th meeting of the General Conference on Weights and Measures (CGPM) in 1948 (CGPM, 1948). The name “candela” was assigned to this unit by the CIPM in 1949. The candela was endorsed as one of the international base units at the 10th meeting of the CGPM in 1954 (CGPM, 1955). The “Système International d’unités”,

abbreviation “SI”, was established at the 11th meeting of the CGPM in 1960. In 1979, the candela was linked to radiometric quantities for monochromatic radiation of frequency 540×10^{12} Hz (CGPM, 1979). In 2018 the CGPM adopted a new approach for the SI based on seven defining constants (CGPM, 2018). In the International System of Units (SI) 2019 (BIPM, 2019) the definition of the candela is reformulated by introducing the constant $K_{cd} = 683 \text{ lm} \cdot \text{W}^{-1}$, which is the luminous efficacy of monochromatic radiation of frequency 540×10^{12} Hz.

The frequency in the candela definition of 540×10^{12} Hz, denoted as ν_{cd} , corresponds to a wavelength in standard air¹ (Ciddor, 1996) that is usually rounded to 555,017 nm, and denoted λ_{cd} . All wavelength values given in this document are in standard air. For photometric measurements in air under real environmental conditions, the influence of the variation of the refractive index of air on λ_{cd} with respect to standard air is typically in the range of a few picometres and can be neglected.

The above definition of the candela applies to photopic, scotopic and mesopic vision.

The definition of K_{cd} relates the unit of luminous flux (*lumen*, lm) to the unit of radiant flux (*watt*, W) at wavelength λ_{cd} . For wavelengths other than λ_{cd} , the luminous efficacy is proportional to one of the spectral luminous efficiency functions described in Clause 4.

The SI units of the three other photometric quantities, luminous intensity, luminance, and illuminance, defined in Clause 2 of this document, are derived directly from the unit of luminous flux, the *lumen*, and the units of the geometric quantities, area and solid angle.

The SI unit of luminous intensity is *lumen per steradian* ($\text{lm} \cdot \text{sr}^{-1}$), which is termed *candela* (cd).

The SI unit of luminance is *lumen per square metre per steradian* ($\text{lm} \cdot \text{sr}^{-1} \cdot \text{m}^{-2}$) or *candela per square metre* ($\text{cd} \cdot \text{m}^{-2}$).

The SI unit of illuminance is *lumen per square metre* ($\text{lm} \cdot \text{m}^{-2}$), which is termed *lux* (lx).

While the units above are defined independently of any luminous efficiency function, the corresponding quantities include the descriptor (photopic, mesopic, scotopic); where no descriptor is given, it is assumed that the quantity is for photopic vision (see Clause 5).

4 Spectral luminous efficiency functions

Photometric quantities are related to radiometric quantities through internationally agreed spectral weighting functions defined by the CIE as *spectral luminous efficiency functions*. These provide agreed 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 for the spectral distribution of the corresponding radiometric quantity (see Clause 6 for further details).

The most common spectral luminous efficiency functions are described in 4.1 to 4.4.

4.1 Photopic vision

The spectral luminous efficiency function for photopic vision is denoted by $V(\lambda)$; its values are given in Table 1, adopted from (ISO/CIE, 2005).

¹ The value of λ_{cd} is for standard air (dry air at 15 °C and 101 325 Pa, containing 0,045 % of carbon dioxide by volume), see Ciddor (1996). This value changes slightly if laboratory air conditions are different but such changes are negligible in practice.

4.2 Scotopic vision

The spectral luminous efficiency function for scotopic vision is denoted by $V'(\lambda)$; its values are given in Table 2, adopted from (ISO/CIE, 2005).

4.3 Mesopic vision

The spectral luminous efficiency function for mesopic vision is denoted by $V_{\text{mes};m}(\lambda)$, and is defined as

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

where

m is the adaptation coefficient, the value of which depends on the visual adaptation conditions (see 6.4);

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

Figure 1 shows the curves of the mesopic spectral luminous efficiency function $V_{\text{mes};m}(\lambda)$ at $m = 0,2, 0,4, 0,6, 0,8$ as examples, plotted with $V(\lambda)$ and $V'(\lambda)$. Table 3 shows the values of $V_{\text{mes};m}(\lambda)$ at $m = 0,8$ as an example, which corresponds to the visual adaptation condition for a typical road lighting luminance level ($\approx 1 \text{ cd m}^{-2}$).

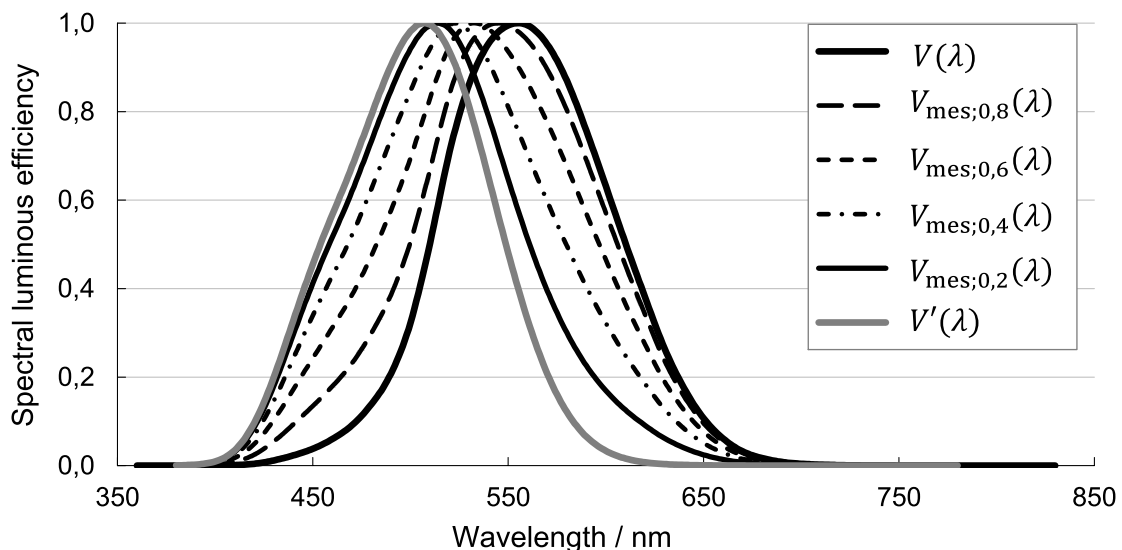


Figure 1 – The spectral luminous efficiency functions for mesopic vision, $V_{\text{mes};m}(\lambda)$, at $m = 0,2; 0,4; 0,6; 0,8$ as examples, plotted with $V(\lambda)$ and $V'(\lambda)$

4.4 10° photopic vision

The spectral luminous efficiency function for 10° photopic vision is denoted by $V_{10}(\lambda)$; its values are given in Table 5, adopted from (ISO/CIE, 2005).

4.5 Use of these spectral luminous efficiency functions

It is important to note that the $V(\lambda)$ function applies at all luminance levels for foveal view, i.e. for all on-axis visual tasks (where objects seen by the eye are in a narrow field of view in central vision). For visual tasks that are not on-axis (larger field of view and/or peripheral vision), the following specifications apply (CIE, 2010):

- Scotopic photometric quantities are applicable to the condition where the eye is adapted to an average luminance of $< 0,005 \text{ cd}\cdot\text{m}^{-2}$.
- Mesopic photometric quantities are applicable to the condition where the eye is adapted to average luminance levels between $0,005 \text{ cd}\cdot\text{m}^{-2}$ and $5 \text{ cd}\cdot\text{m}^{-2}$.
- Above $5 \text{ cd}\cdot\text{m}^{-2}$, photopic photometric quantities should be used. The $V(\lambda)$ function was determined on the basis of experimental studies for photopic vision with a narrow field of view (about 4° or less). For situations where the visual target has an angular subtense larger than 4° or is seen off-axis, the $V_{10}(\lambda)$ function, based on experimental studies for photopic vision with a 10° field of view (CIE, 2005), can be used.

For the purpose of practical photometry, and to avoid confusion, the relevant spectral luminous efficiency function used for the photometric quantities must be specified, either through use of an appropriate descriptor linked with the quantity (e.g. photopic, scotopic, mesopic) or by use of the appropriate symbol (see Clause 5). If the luminous efficiency function used is not specified, it is assumed to be the $V(\lambda)$ function.

5 Photometric quantity names and symbols

The names and symbols of photometric quantities listed in Clause 2, with the spectral luminous efficiency functions listed in Clause 4, are defined in the following subclauses. Similar names and symbols are used for photometric quantities other than those given below.

5.1 Photometric quantities for photopic vision

The following quantity names and symbols apply for photopic vision (using the $V(\lambda)$ function):

- (photopic) luminous flux, Φ_v
- (photopic) luminous intensity, I_v
- (photopic) illuminance, E_v
- (photopic) luminance, L_v

NOTE 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.

5.2 Photometric quantities for scotopic vision

The following quantity names and symbols apply for scotopic vision (using the $V'(\lambda)$ function):

- scotopic luminous flux, Φ'_v
- scotopic luminous intensity, I'_v
- scotopic illuminance, E'_v
- scotopic luminance, L'_v