INTERNATIONAL STANDARD

ISO 23539

CIE S 010/E

First edition
2005-08-01

Photometry — The CIE system of physical photometry

Photométrie — Le système CIE de photométrie physique

Reference number
ISO 23539:2005(E)
CIE S 010/E:2004

PDF disclaimer

This PDF file may contain embedded typefaces. In accordance with Adobe's licensing policy, this file may be printed or viewed but shall not be edited unless the typefaces which are embedded are licensed to and installed on the computer performing the editing. In downloading this file, parties accept therein the responsibility of not infringing Adobe's licensing policy. The ISO Central Secretariat accepts no liability in this area.

Adobe is a trademark of Adobe Systems Incorporated.

Details of the software products used to create this PDF file can be found in the General Info relative to the file; the PDF-creation parameters were optimized for printing. Every care has been taken to ensure that the file is suitable for use by ISO member bodies. In the unlikely event that a problem relating to it is found, please inform the Central Secretariat at the address given below.

ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

Published in Switzerland

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

ISO 23539 was prepared as Standard CIE S 010/E by the International Commission on Illumination, which has been recognized by the ISO Council as an international standardizing body. It was adopted by ISO under a special procedure which requires approval by at least 75 % of the member bodes casting a vote, and is published as a joint ISO/CIE edition.

The International Commission on Illumination (abbreviated as CIE from its French title) is an organization devoted to international cooperation and exchange of information among its member countries on all matters relating to the science and art of lighting.

ISO 23539 was prepared by CIE Technical Committee 2-35 *CIE Standard for* $V(\lambda)$ *and* $V'(\lambda)$.

CIE S 010/E:2004

COMMISSION INTERNATIONALE DE L'ECLAIRAGE
INTERNATIONAL COMMISSION ON ILLUMINATION
INTERNATIONALE BELEUCHTUNGSKOMMISSION

Standard

PHOTOMETRY - THE CIE SYSTEM OF PHYSICAL PHOTOMETRY

Photométrie – Le système CIE de photométrie physique

Photometrie - Das CIE-System der physikalischen Photometrie

CIE Central Bureau, Vienna
Kegelgasse 27, A-1030 Vienna, Austria

CIE S 010/E:2004

UDC: 635.24 Descriptor: Photometry

CIE Central Bureau
Kegelgasse 27
A-1030 Vienna
Austria
Tel.: +43 1 714 3187 0
Fax: +43 1 714 3187 18
e-mail: ciecb@ping.at
Web: www.cie.co.at

FOREWORD

Standards produced by the Commission Internationale de l'Eclairage (CIE) are a concise documentation of data defining aspects of light and lighting, for which international harmony requires such unique definition. CIE Standards are therefore a primary source of internationally accepted and agreed data, which can be taken, essentially unaltered, into universal standard systems.

This International Standard has been prepared by CIE Technical Committee 2-35[*)], "CIE Standard for $V(\lambda)$ and $V'(\lambda)$", and was approved by the National Committees of the CIE.

TABLE OF CONTENTS

FOREWORD vii

INTRODUCTION 1

1. SCOPE 1

2. PHOTOMETRIC QUANTITIES 1
   2.1 Luminous flux 1
   2.2 Other quantities 1

3. PHOTOMETRIC UNITS 2
   3.1 Candela 2
   3.2 Other units 2

4. PHOTOMETRIC STANDARDS 3
   4.1 CIE Standard spectral luminous efficiency functions for photopic and scotopic vision 3
   4.2 Maximum luminous efficacies for photopic and scotopic vision 3
   4.3 Fundamental equations relating photometric and radiometric quantities 4
   4.4 Measurement procedures 4

TABLES 5
   Table 1. Definitive values of the spectral luminous efficiency function for photopic vision $V(\lambda)$ 5
   Table 2. Definitive values of the spectral luminous efficiency function for scotopic vision $V'(\lambda)$ 10

ANNEX A (INFORMATIVE) 14
   Vocabulary of related terms 14

ANNEX B (INFORMATIVE) 16
   Background to the CIE system of physical photometry 16
   B.1 Evolution of the photometric base unit 16
   B.2 Spectral response of the human eye 16
   B.3 Supplementary remarks 17

ANNEX C (INFORMATIVE) 18
   Bibliography 18

[*)] Chairman of this TC was K. D. Mielenz (US), members were: J. Bastie (FR), J. L. Gardner (AU), F. Hengstberger (ZA), J. R. Moore (GB), Y. Ohno (US), A. C. Parr (US), A. R. Robertson (CA), G. Sauter (DE), J. Schanda (HU).

PHOTOMETRY - THE CIE SYSTEM OF PHYSICAL PHOTOMETRY

INTRODUCTION

The visual brightness of a light source depends not only on the amount of radiation it emits 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 the spectral luminous efficiency functions of two such standard observers. One, $V(\lambda)$, represents photopic vision and the other, $V'(\lambda)$, scotopic vision. Used in conjunction with the SI photometric base unit, the candela, these functions constitute a system that enables the values of photometric quantities for all types of luminous source to be precisely determined, regardless of the spectral composition of the radiation emitted.

1. SCOPE

This international Standard 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). They comprise:

– the definition of photometric quantities and units,
– the definition of CIE standard spectral luminous efficiency functions for photopic and scotopic vision,
– the definition of a CIE standard photometric observer that conforms to these functions,
– the definition of maximum luminous efficacies for photopic and scotopic vision.

An informative annex provides a vocabulary of related terms.

2. PHOTOMETRIC QUANTITIES

Photometric quantities are defined in the International Lighting Vocabulary (ILV) (CIE, 1987a).

2.1 Luminous flux

The fundamental physical quantity used in optical radiometry is the radiant flux or radiant power, Φ_e, measured in watts, which is emitted by a source of radiation, transmitted by a medium of propagation, or received at a surface. The corresponding photometric quantity is:

luminous flux (Φ_v) (see ILV 845-01-25)

quantity derived from radiant flux Φ_e by evaluating the radiation according to its action upon the CIE standard photometric observer

The procedure for deriving Φ_v from Φ_e is defined in 4.3, below.

2.2 Other quantities

The following are the photometric quantities that correspond to the most important radiometric quantities defined in the International Lighting Vocabulary.

luminous energy (also known as **quantity of light**) **(Q_v)** (see ILV 845-01-28)

time integral of the luminous flux Φ_v over a given duration Δt

$$Q_v = \int_{\Delta t} \Phi_v \mathrm{d}t$$

luminous intensity (of a source in a given direction) **(I_v)** (see ILV 845-01-31)

quotient of the luminous flux $\mathrm{d}\Phi_v$ leaving the source and propagated in the element of solid angle $\mathrm{d}\Omega$ containing the given direction, by the element of solid angle

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

luminance (in a given direction, at a given point of a real or imaginary surface) **(L_v)** (see ILV 845-01-35)

quantity defined by the formula

$$L_v = \frac{d\Phi_v}{dA \cdot \cos\theta \cdot d\Omega}$$

where dΦ_v is the luminous flux transmitted by an elementary beam passing through the given point and propagating in the solid angle dΩ containing the given direction; dA is the area of a section of that beam containing the given point; θ is the angle between the normal to that section and the direction of the beam

illuminance (at a point of a surface) **(E_v)** (see ILV 845-01-38)

quotient of the luminous flux dΦ_v incident on an element of the surface containing the point, by the area dA of that element

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

luminous exitance (at a point of a surface) **(M_v)** (see ILV 845-01-48)

quotient of the luminous flux dΦ_v leaving an element of the surface containing the point, by the area dA of that element

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

3. PHOTOMETRIC UNITS

3.1 Candela

The SI photometric base unit is the candela (cd), the unit of luminous intensity. It was defined by the Conférence Générale des Poids et Mesures (CGPM) in 1979 (CGPM, 1979), as follows:

> *The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540 x 10^{12} hertz and that has a radiant intensity in that direction of (1/683) watt per steradian.*

This definition of the candela applies equally to photopic, scotopic, and mesopic vision.

3.2 Other units

The SI units of other photometric quantities can be derived from the candela and the SI units of length (m), solid angle (sr) and time (s). Thus:

Quantity	Symbol	SI Unit
Luminous flux	Φ_v	lm = cd·sr
Luminous energy	Q_v	cd·sr·s
Luminance	L_v	cd·m^{-2}
Illuminance	E_v	lx = cd·sr·m^{-2}
Luminous exitance	M_v	cd·sr·m^{-2}

4. PHOTOMETRIC STANDARDS

4.1 CIE Standard spectral luminous efficiency functions for photopic and scotopic vision

This Standard defines two spectral luminous efficiency functions for photometric measurements:

- The $V(\lambda)$ function, which applies to photopic vision and should be used for measurements at luminance levels of at least several candelas per square metre. It is defined by the numerical values given in Table 1 of this Standard, the wavelength being measured in standard air (Birch, 1994). For numerical computations, the peak value of the $V(\lambda)$ function should be evaluated at 555 nm exactly. Linear interpolation should be used exclusively to evaluate $V(\lambda)$ at wavelengths intermediate to those given in Table 1;

- The $V'(\lambda)$ function, which applies to scotopic vision and should be used for measurements at luminance levels less than some hundredths of a candela per square metre. This function is defined by the numerical values in Table 2 of this Standard, the wavelength λ again being measured in standard air. For numerical computations, the peak value of the $V'(\lambda)$ function should be evaluated at 507 nm exactly. Linear interpolation should be used exclusively to evaluate $V'(\lambda)$ at wavelengths intermediate to those given in Table 2.

An ideal observer having a relative spectral responsivity curve that conforms to the $V(\lambda)$ function for photopic vision or the $V'(\lambda)$ function for scotopic vision, and that complies with the summation law implied in the definition of luminous flux, is known as a **CIE standard photometric observer**.

The CIE has not, so far, defined standard spectral luminous efficiency functions for the mesopic region, intermediate between the ranges of photopic and scotopic vision.

4.2 Maximum luminous efficacies for photopic and scotopic vision

The $V(\lambda)$ and $V'(\lambda)$ functions defined in this Standard supplement the 1979 candela definition in a manner that, taken together, these definitions 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 for photopic and scotopic vision,
– establishes precisely defined numerical relationships between radiometric and photometric quantities.

Based on the following definitions and considerations, these numerical relationships are defined by equations (1) to (4), below.

luminous efficacy (for monochromatic radiation of wavelength λ) ***K*(λ) and *K'*(λ)**

Quotient of the luminous flux Φ_v by the corresponding radiant flux Φ_e

$$K(\lambda) = K_m \cdot V(\lambda) = \frac{\Phi_v}{\Phi_e} \quad \left[\mathrm{lm} \cdot \mathrm{W}^{-1}\right] \qquad \text{(for photopic vision)} \qquad (1)$$

$$K'(\lambda) = K'_m \cdot V'(\lambda) = \frac{\Phi'_v}{\Phi_e} \quad \left[\mathrm{lm} \cdot \mathrm{W}^{-1}\right] \qquad \text{(for scotopic vision)} \qquad (2)$$

where the maximum values of $K(\lambda)$ and $K'(\lambda)$ are denoted by K_m and K'_m so that K_m = K(555 nm) and K'_m = K'(507 nm). The frequency 540 x 10^{12} Hz corresponds to a wavelength of 555,016 nm in standard air and it follows from the candela definition that K(555,016 nm) = K'(555,016 nm) = 683 lm·W^{-1}. Therefore, according to equations 1 and 2,

$$K_m = 683\ [\mathrm{lm} \cdot \mathrm{W}^{-1}] \,/\, V(555{,}016\ \mathrm{nm}) = 683{,}002\ \mathrm{lm} \cdot \mathrm{W}^{-1} \qquad (3)$$

$$K'_m = 683\ [\mathrm{lm} \cdot \mathrm{W}^{-1}] \,/\, V'(555{,}016\ \mathrm{nm}) = 1700{,}05\ \mathrm{lm} \cdot \mathrm{W}^{-1} \qquad (4)$$

For all practical photometric applications, K_m can be taken as equal to 683 lm·W^{-1} and K'_m as equal to 1700 lm·W^{-1}.