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Characterization of the performance of illuminance meters and luminance meters

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The UK participation in its preparation was entrusted to Technical Committee EL/1, Light and lighting applications.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Characterization of the performance of illuminance meters and luminance meters

Caractérisation des performances des luxmètres et des luminancemètres

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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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ISO/CIE 19476 was prepared by CIE Technical Committee 2-40: *Characterizing the performance of illuminance and luminance meters*, as CIE S 023. The committee responsible for this document is ISO/TC 274, *Light and lighting.*

CIE S 023/E:2013

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

International Standard

Characterization of the Performance of Illuminance Meters and Luminance Meters

Caractérisation des performances des luxmètres et des luminancemètres

Kennzeichnung der Güte von Beleuchtungsstärke- und Leuchtdichtemessgeräten

CIE Central Bureau, Vienna
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Foreword

International Standards produced by the Commission Internationale de l'Eclairage are concise documents on aspects of light and lighting that require a unique definition. They are a primary source of internationally accepted and agreed data which can be taken, essentially unaltered, into universal standard systems.

This CIE International Standard has been prepared by CIE Technical Committee 2-40[1] "Characterizing the Performance of Illuminance and Luminance Meters". It has been approved by the Board of Administration and Division 2 of the Commission Internationale de l'Eclairage as well as by the CIE National Committees. It is supposed to supersede CIE Publication 69-1987.

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[1] This TC was chaired by R. Rattunde † (DE) and P. Blattner (CH).
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CONTENTS

Characterization of the Performance of Illuminance Meters and Luminance Meters

1 Scope

This CIE International Standard is applicable to illuminance and luminance meters. The Standard defines quality indices characterizing the performance of such devices in a general lighting measurement situation, as well as measurement procedures for the individual indices and standard calibration conditions.

Measurements of illuminance or luminance and their accuracy are influenced by various parameters, such as operational conditions, properties of light sources, as well as characteristics of the applied photometers. The characteristics of these photometers alone do not allow the determination of the measurement uncertainty for a specific measurement task. Nevertheless, it is generally true that instruments with “better” characteristics in most cases produce smaller uncertainties than instruments with “worse” properties. This Standard has been written to:

- give clear and unambiguous definitions for the individual quality indices;
- define measurement procedures and methods for numerical evaluation of these quality indices;
- define calibration conditions for illuminance meters and luminance meters.

Where different, the definitions of the quality indices and the associated measurement procedures and methods for numerical evaluation given in this Standard supersede those given in CIE Publication 53-1982. CIE publication 69-1987 shall be superseded by this Standard.

2 Normative References

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

CIE 202:2011 Spectral Responsivity Measurement of Detectors, Radiometers and Photometers

CIE S 017/E:2011 ILV: International Lighting Vocabulary

ISO 11664-2:2007/CIE S 014-2:2006 Colorimetry – Part 2: CIE Standard Illuminants

ISO 23539:2005/CIE S 010:2004 Photometry – The CIE System of Physical Photometry

CIE 198:2011 Determination of Measurement Uncertainties in Photometry

CIE 114/4-1994 CIE Collection in Photometry and Colorimetry - Distribution Temperature and Ratio Temperature

IEC 60051-1:1997 Direct acting indicating analogue electrical measuring instruments and their accessories – Part 1: Definitions and general requirements common to all parts

ISO/IEC Guide 98-3:2008[1] Uncertainty of measurement -- Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)

ISO/IEC Guide 99:2007[2] International Vocabulary of Metrology — Basic and General Concepts and Associated Terms (VIM).

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1 Also referred as JCGM 100:2008, available from BIPM webpage.

2 Also referred as JCGM 200:2008, available from BIPM webpage.

3 Definitions

For the purposes of this document, the terms and definitions given in CIE S 017/E:2011 (International Lighting Vocabulary) and the following apply.

3.1 General Definitions

3.1.1
measurement accuracy
closeness of agreement between a measured quantity value and a true quantity value of a measurand

Note 1 to entry: The concept 'measurement accuracy' is not a quantity and is not given a numerical quantity value. A measurement is said to be more accurate when it offers a smaller measurement error.

Note 2 to entry: The term "measurement accuracy" should not be used for measurement trueness and the term measurement precision should not be used for 'measurement accuracy', which, however, is related to both these concepts.

Note 3 to entry: 'Measurement accuracy' is sometimes understood as closeness of agreement between measured quantity values that are being attributed to the measurand.

[Source: ISO/IEC Guide 99:2007 (VIM), 2.13]

3.1.2
measurement error
measured quantity value minus a reference quantity value

Note 1 to entry: The concept of 'measurement error' can be used both

a) when there is a single reference quantity value to refer to, which occurs if a calibration is made by means of a measurement standard with a measured quantity value having a negligible measurement uncertainty or if a conventional quantity value is given, in which case the measurement error is known, and

b) if a measurand is supposed to be represented by a unique true quantity value or a set of true quantity values of negligible range, in which case the measurement error is not known.

Note 2 to entry: Measurement error should not be confused with production error or mistake.

[Source: ISO/IEC Guide 99:2007 (VIM), 2.16]

3.1.3
calibration
operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication

Note 1 to entry: A calibration may be expressed by a statement, calibration function, calibration diagram, calibration curve, or calibration table. In some cases, it may consist of an additive or multiplicative correction of the indication with associated measurement uncertainty.

Note 2 to entry: Calibration should not be confused with adjustment of a measuring system, often mistakenly called "self-calibration", nor with verification of calibration.

Note 3 to entry: Often, the first step alone in the above definition is perceived as being calibration.

[Source: ISO/IEC Guide 99:2007 (VIM), 2.39]

3.1.4
adjustment of a measuring system
set of operations carried out on a measuring system so that it provides prescribed indications corresponding to given values of a quantity to be measured

Note 1 to entry: Types of adjustment of a measuring system include zero adjustment of a measuring system, offset adjustment, and span adjustment (sometimes called gain adjustment).

Note 2 to entry: Adjustment of a measuring system should not be confused with calibration, which is a prerequisite for adjustment.

Note 3 to entry: After an adjustment of a measuring system, the measuring system must usually be recalibrated.

[Source: ISO/IEC Guide 99:2007 (VIM), 3.11]

3.1.5
(metrological) traceability
property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty

Note 1 to entry: For this definition, a 'reference' can be a definition of a measurement unit through its practical realization, or a measurement procedure including the measurement unit for a non-ordinal quantity, or measurement standard.

Note 2 to entry: Metrological traceability requires an established calibration hierarchy.

Note 3 to entry: Specification of the reference must include the time at which this reference was used in establishing the calibration hierarchy, along with any other relevant metrological information about the reference, such as when the first calibration in the calibration hierarchy was performed.

Note 4 to entry: For measurements with more than one input quantity in the measurement model, each of the input quantity values should itself be metrologically traceable and the calibration hierarchy involved may form a branched structure or a network. The effort involved in establishing metrological traceability for each input quantity value should be commensurate with its relative contribution to the measurement result.

Note 5 to entry: Metrological traceability of a measurement result does not ensure that the measurement uncertainty is adequate for a given purpose or that there is an absence of mistakes.

Note 6 to entry: A comparison between two measurement standards may be viewed as a calibration if the comparison is used to check and, if necessary, correct the quantity value and measurement uncertainty attributed to one of the measurement standards.

Note 7 to entry: The ILAC considers the elements for confirming metrological traceability to be an unbroken metrological traceability chain to an international measurement standard or a national measurement standard, a documented measurement uncertainty, a documented measurement procedure, accredited technical competence, metrological traceability to the SI, and calibration intervals (see ILAC P-10:2002).

Note 8 to entry: The abbreviated term "traceability" is sometimes used to mean 'metrological traceability' as well as other concepts, such as 'sample traceability' or 'document traceability' or 'instrument traceability' or 'material traceability', where the history ("trace") of an item is meant. Therefore, the full term of "metrological traceability" is preferred if there is any risk of confusion.

[Source: ISO/IEC Guide 99:2007 (VIM), 2.41]

3.1.6
photometer
instrument for measuring photometric quantities

[Source: CIE S 017/E:2011, 17-909]

Note 1 to entry: A photometer consists of a photometer head, a signal converter, an output device and a power supply. The different parts can be built to a single device or split into separate housings. Within this Standard, the term photometer refers to illuminance and luminance meters having a single detector that measures light spectrally integrated.

3.1.7
reference plane (of a photometer or light source)
plane associated with a photometer or a light source for the purpose of measuring the distance between them

Note 1 to entry: For a photometer this is the plane perpendicular to the optical axis of the photometer head at which the photometer or photometer head is calibrated. The reference plane of a photometer should ideally coincide with the effective reference plane.

3.1.8
effective reference plane (of a photometer)
plane perpendicular to the optical axis of the photometer head where the inverse square law holds when illuminance from a point source is measured and the distance to the source is measured from this plane

Note 1 to entry: The effective reference plane may vary with wavelength. In such a case the type of light source (i.e. CIE Standard Illuminant A) shall be stated together with the effective reference plane.

3.1.9
limiting photometric distance
shortest distance between the reference plane of a light source and the effective reference plane of a photometer, for a given acceptable error considering the photometric inverse square law

Note 1 to entry: The limiting photometric distance is determined mainly from the geometrical properties of the photometer and the source.

3.1.10
acceptance aperture
acceptance area of the photometer head of an illuminance meter or the measurement field of a luminance meter

Note 1 to entry: Usually the acceptance aperture is at the effective reference plane of the photometer.

3.2 Quality Indices

A set of quality indices is used to characterize the performance of photometers. Quality indices are physical quantities characterizing selected properties of a photometer. They are normalized response values, which do not describe errors directly and thus cannot be used for correction. The name for each index has been taken from the physical effect influencing its value to make it easier to memorize and understand its meaning

A quality index is symbolized by the symbol "f_x" where the subscript "x" specifies the considered property. The values are:

- evaluated by formulas specific for each property, from data determined under specified measurement conditions;
- stated as a percentage, with associated uncertainties; and
- ideally zero.

The quality indices of these photometers alone do not allow the estimation of the measurement uncertainty for a specific measurement task. Nevertheless, it is generally true that instruments with smaller f_x-values, in most cases, allow smaller measurement uncertainties than instruments with larger values.

3.2.1
initial adjustment index
f_{adj}
index describing the absolute relative deviation of the photometer indication from the corresponding reference value

3.2.2
general $V(\lambda)$ mismatch index
f_1'
index describing the deviation of the relative spectral responsivity of the photometer from the $V(\lambda)$ function

3.2.3
UV response index
f_{UV}
index describing the responsivity of the photometer to UV radiation

3.2.4
IR response index
f_{IR}
index describing the responsivity of the photometer to IR radiation

3.2.5 (illuminance meter only)
directional response index for illuminance
f_2
index describing the responsivity of the photometer to light incident at an angle other than normal (the cosine law for general purpose illuminance meters)

3.2.6 (illuminance meter only)
directional response index for spherical illuminance
$f_{2,0}$
index describing the responsivity of the photometer to light incident at an angle other than normal

3.2.7 (illuminance meter only)
directional response index for cylindrical illuminance
$f_{2,c}$ [1]
index describing the responsivity of the photometer to light incident at an angle other than normal

3.2.8 (illuminance meter only)
directional response index for semi-cylindrical illuminance
$f_{2,sc}$
index describing the responsivity of the photometer to light incident at an angle other than normal

3.2.9 (illuminance meter only)
directional response index for semi-spherical illuminance
$f_{2,2\pi}$
index describing the responsivity of the photometer to light incident at an angle other than normal

3.2.10 (luminance meter only)
directional response index for luminance
$f_{2,g}$
index describing the responsivity of the photometer to light incident at an angle other than normal

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1 Previously used symbol $f_{2,z}$.

3.2.11 (luminance meter only)
directional symmetry index
$f_{2,s}$
index describing the influence of the angle of light incidence within the measuring field of a luminance meter

3.2.12 (luminance meter only)
surrounding field effect index
$f_{2,u}$
index describing the influence of the ambient luminance outside the measuring field of a luminance meter

3.2.13
linearity index
f_3
index describing the deviation of the photometer response to illuminance or luminance at different levels

3.2.14
display-unit index
f_4
index describing the influence of the analogue or digital display of photometers

3.2.15
fatigue index
f_5
index describing the stability of the photometer responsivity for constant illumination over long periods

3.2.16
temperature dependence index
$f_{6,T}$
index describing the influence of ambient temperature on the photometer responsivity when the ambient temperature differs from that at the time of calibration

3.2.17
humidity test index
$f_{6,H}$
index describing the stability of the photometer with respect to humidity

3.2.18
modulated light index
f_7
index describing the influence of modulated light at various frequencies, compared to the response for a constant illumination condition

3.2.19
polarization response index
f_8
index describing the influence of polarized light on the responsivity of the photometer

3.2.20
spatial response index
f_9
index describing the influence of non-uniform illumination incident on the photometer within the acceptance aperture

3.2.21
range change index
f_{11}
index describing the influence of range settings of display-units or amplifiers

3.2.22 (luminance meter only)
focusing distance index
f_{12}
index describing the influence of deviations of the test distance from the focus distance for luminance meters

4 Calibration

4.1 Conditions

Photometers shall be calibrated by sources or detectors certified as reference standards and whose calibration is traceable to the International System of Units (SI). Traceability means an unbroken chain of calibrations or comparisons, linking them to relevant primary standards of the SI-units of the measurement as published in the CMC lists of the BIPM and carried out by laboratories with accredited competence.

Photometers shall be calibrated at an ambient temperature of 25 °C with unpolarized light from an incandescent lamp with a correlated colour temperature of 2 856 K (CIE Source A). Prior to commencing calibration, the photometer shall be allowed to thermally stabilize in the ambient conditions for at least one hour. The entrance window of the photometer shall be uniformly illuminated and overfilled.

Photometers shall be regularly recalibrated:

- at the interval recommended by the manufacturer; or
- at least every 2 years; or
- if it is suspected that the instrument's performance has changed.

NOTE In practical terms, correlated colour temperature and distribution temperature are equivalent when establishing a lamp as CIE Source A.

4.2 Illuminance Meters

4.2.1 General

Illuminance meters shall be calibrated with light incident normal to the effective reference plane where the light source is located at a distance greater than the limiting photometric distance.

If the illuminance meter is calibrated against a reference photometer, the effective reference plane of the illuminance meter shall be positioned at the identical location and orientation as was the effective reference plane of the reference photometer. If the illuminance meter is calibrated using a standard lamp, the calibration distance is given by the distance from the reference plane of the standard lamp to the effective reference plane of the illuminance meter.

4.2.2 (Planar) Illuminance E

$$E = E_{\mathrm{x}} \quad (1)$$

where

E_{x} is the illuminance on the effective reference plane.

The location of the effective reference plane with respect to the front area of the photometer shall be declared by the manufacturer. For illuminance meters with flat diffusers, the effective reference plane is usually at the front plane of the diffuser.

4.2.3 Spherical Illuminance E_0[1]

$$E_0 = E_x \tag{2}$$

where

E_x is the illuminance on the effective reference plane.

The effective reference plane is located within the spherical adapter, at a distance of γ_0 = 0,146 times the diameter, d, of the spherical adapter from the sphere zenith.

NOTE The factor γ_0 is determined such that the area cut out from the effective reference plane is just half the area of the projected entrance window of the photometer. The solution is found from geometrical relations: $\gamma_0 = \left(1 - \cos\left(\arcsin\left(1/\sqrt{2}\right)\right)\right)/2 = 0{,}146$.

4.2.4 Cylindrical Illuminance E_c[2,3]

$$E_c = \frac{1}{\pi} E_x \tag{3}$$

where

E_x is the illuminance on the effective reference plane.

The effective reference plane is located within the cylindrical adapter, parallel to the entrance window of the photometer, at a distance of γ_c = 0,067 times the diameter, d, of the cylindrical adapter from the lateral area (see Figure 1).

NOTE The factor γ_c is determined such that the area taken out of the effective reference plane is just half the area of the projected entrance window of the photometer. The solution is found from geometrical relations: $\gamma_c = \left(1 - \cos\left(\arcsin\left(1/2\right)\right)\right)/2 = 0{,}067$.

4.2.5 Semi-Cylindrical Illuminance E_{sc}[4]

$$E_{sc} = \frac{2}{\pi} E_x \tag{4}$$

where

E_x is the illuminance on the effective reference plane.

The effective reference plane is located within the semi-cylindrical adapter, parallel to the entrance window of the photometer, at a distance of γ_c = 0,067 times the diameter, d, of the semi-cylindrical adapter from the lateral area (see Figure 1).

NOTE The factor γ_c is determined such that the area taken out of the effective reference plane is just half the area of the projected entrance window of the photometer. The solution is found from geometrical relations: $\gamma_c = \left(1 - \cos\left(\arcsin\left(1/2\right)\right)\right)/2 = 0{,}067$.

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[1] For the definition of "spherical illuminance" see CIE S 017/E:2011, 17-1244 and 17-1245 respectively.

[2] Previously used symbol E_z .

[3] For the definition of "cylindrical illuminance" see CIE S 017/E:2011, 17-273 and 17-274 respectively.

[4] For the definition of "semi-cylindrical illuminance" see CIE S 017/E:2011, 17-1160.

ISO/CIE 19476:2014(E)

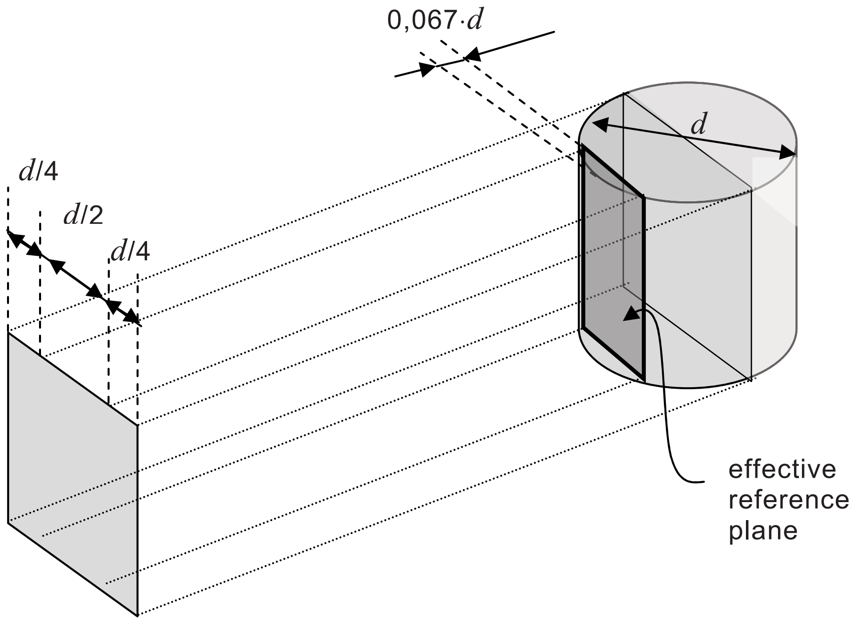

Figure 1 — Effective reference plane for a (semi-)cylindrical illuminance meter

4.2.6 Semi-Spherical Illuminance $E_{2\pi}$

$$E_{2\pi} = \frac{1}{2} E_{\mathrm{x}} \tag{5}$$

where

E_{x} is illuminance on the effective reference plane.

The effective reference plane is located within the semi-spherical adapter, parallel to the entrance window of the photometer, at a distance of γ_0 = 0,146 times the diameter, d ,of the semi-spherical adapter from the sphere zenith.

NOTE The factor γ_0 is determined such that the area cut out from the effective reference plane is just half the area of the projected entrance window of the photometer. The solution is found from geometrical relations: $\gamma_0 = \left(1 - \cos\left(\arcsin\left(1/\sqrt{2}\right)\right)\right)/2 = 0{,}146$.

4.3 Luminance Meters

Luminance meters shall be calibrated with a luminance standard using a uniform luminous surface significantly larger than the measuring field of the luminance meter. Uniformity of the luminance standard shall be such that any non-uniformity does not significantly affect the calibration or is corrected for.

4.4 Calibration Uncertainties

The uncertainty associated with the calibration factor of a photometer is a combination of the uncertainties arising from the measurement process and the uncertainties associated with the certified value of the reference standard. The overall uncertainty associated with the calibration factor of the photometer shall be stated.

The uncertainty associated with the certified value of the reference standard shall be taken from the calibration certificate of the standard. Additional uncertainty contributions arising during the measurement process can result from:

- uncertainty associated with the value of the working standard;
- ageing of the standard;
- the spectral mismatch to the $V(\lambda)$ function for the source being measured (in the case of the source used for calibration of the photometer, which, as stated in 4.1, is an incandescent lamp with a correlated colour temperature of 2 856 K, this can be characterized, for example, by the mismatch exponent m in Equation (9));
- uncertainties associated with the measured values of the electrical quantities of both the standard and the device under test;
- uncertainties associated with the geometrical adjustments (the mutual position of the effective reference planes and angular alignments);
- stray light;
- ambient temperature change;
- temperature change of the photometer due to heating from the radiance of the source; and
- finite resolution of the display.

As in general corrections, if any of the parameters mentioned above or other contributions to uncertainty can be quantified, and if the change of the photometer signal resulting from the change of the parameter is known (e.g. through a sensitivity coefficient), then the reading shall be corrected and the overall uncertainty decreased accordingly.

Uncertainties shall be estimated in accordance with the procedures given in the ISO/IEC Guide 98-3:2008 (GUM) and its supplements. Detailed considerations of measurement uncertainties can be found in CIE 198:2011.

4.5 Initial Adjustment

The initial adjustment index is the absolute value of the relative deviation of the photometer indication from the corresponding reference value. The quality index for initial adjustment $f_{\text{adj}} = \left| Y'_{\text{cal}} / Y_{\text{cal}} - 1 \right|$ is the absolute value of the relative deviation of the photometer indication Y'_{cal} from the corresponding reference value Y_{cal}.

The manufacturer will usually adjust the photometer indication to the reference value, and in this case $f_{\text{adj}} = 0$, but the associated uncertainty of f_{adj} will correspond to the uncertainty of the initial calibration process; this uncertainty shall be stated together with the value of the index f_{adj} (see 4.4).

NOTE For low cost photometers, the procedures for the adjustment of their indications are often simplified, and the uncertainties associated with the values of the reference standards are larger, which significantly increases the value of this quality index.

4.6 Checking of Photometers

The spectral match of the photometer to the $V(\lambda)$ function shall be regularly checked. A simple method of verification is to first calibrate the photometer using a CIE Source A and then compare the luminous response of the photometer due to a 3-band lamp (fluorescent lamp or RGB-LED) to the luminous response of a reference meter.

However, it is usually not necessary to check any of the other quality indices for a photometer, unless it has been damaged or it is suspected that the meter is not functioning correctly.

If during regular maintenance check by the manufacturer or a calibration laboratory the instrument is adjusted, the user shall be informed and the calibration factor prior and after the adjustment shall be reported to the user.

5 Properties of Illuminance Meters and Luminance Meters

5.1 General Considerations

The present Standard defines specific measurement conditions, for example spectral wavelength region and bandwidths. If, for any reason, the specific conditions cannot be applied, alternative procedures can be applied. In this case the influence of choosing a different procedure shall be evaluated, but the results shall be reported as specified in the Standard. The uncertainty analysis will depend on the measurement procedure. For example, 5.3.2 gives requirements for the light source to be used when determining the UV response of the photometer. The user of the Standard is allowed to use a different type of illumination, for example a spectral scanning light source, and then perform calculations to determine the UV response for the required source numerically. However, the influence of choosing a different source shall be evaluated, and the uncertainty analysis adjusted correspondingly.

Most quality indices are based on absolute comparisons between the ideal property and the measured property. Special considerations shall be applied for photometers with quality indices that are close to ideal. In these cases, the equations defining the quality indices cannot be applied directly and Monte Carlo analysis must be applied. Consequently, the value of a specific quality index (e.g. f_1') may not only depend on the input quantities $s(\lambda)$ but also on the uncertainties of the input quantities and their possible correlations.

Unless specified otherwise, the quality indices shall be reported for a CIE Standard Illuminant A according to ISO 11664-2:2007/CIE S 014-2:2006 (or CIE Source A for real measurements).

5.2 Spectral Properties

5.2.1 General

The relative spectral responsivity, $s_{\mathrm{rel}}(\lambda)$, of a photometer shall match the spectral luminous efficiency function for photopic vision $V(\lambda)$ [1,2]. Different parameters exist to describe the quality of the spectral match. If the relative spectral distribution of the source, $S_{\mathrm{Z}}(\lambda)$, and the relative spectral responsivity of the detector is known, the reading of the photometer shall be corrected by the spectral mismatch correction factor $F\left(S_{\mathrm{Z}}(\lambda)\right)$. If no information about the relative spectral distribution of the source is available, the concept of the general $V(\lambda)$ mismatch index f_1' can be used to characterize the photometer.

5.2.2 Measurement

In order to characterize the quality of the photometer in respect to light sources of different spectral distribution, it is essential to know the spectral responsivity of the photometer. The spectral measurement shall be done in agreement with the recommendations given in CIE 202:2011. The definition of the $V(\lambda)$ function covers the complete photometric spectral range from 360 nm to 830 nm. In practice measurements at the limits of the spectral range are very difficult. For the evaluation of f_1', the measurement of the relative spectral responsivity in the wavelength range from 380 nm to 780 nm is sufficient as this Standard covers only the general lighting measurement situation.

The contribution to the luminous responsivity due to the spectral responsivity at the borders of the visible wavelength range is small and the measurement uncertainties increase substantially. Nevertheless, for the determination of the luminous responsivity and the spectral mismatch correction factor, the measurement range shall cover the full sensitive wavelength range of the photometer. The measurements shall be done with a tuneable

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1 This Standard covers only photometers for photopic vision. For non- photopic vision, similar concepts and parameters might be derived.

2 The spectral luminous efficiency function is defined in ISO 23539:2005/CIE S 010:2004.

monochromatic light source in wavelength steps equal to or smaller than 5 nm. The spectral bandwidth shall be equal or smaller than 5 nm. For as ymmetrical band pass functions or bandwidths larger than 5 nm, a spectral band pass correction method shall be applied.

5.2.3 Luminous Responsivity

The responsivity of a photometer is usually defined as the quotient of the detector output by the detector input. In photometry the input radiation is spectrally weighted by the spectral luminous efficiency function $V(\lambda)$. The resulting responsivity is called the absolute luminous responsivity, s_{v} , and is defined as follows:

$$s_{\mathrm{v}} = \frac{\int_{\lambda_{\min}}^{\lambda_{\max}} S_{\mathrm{Z}}(\lambda) \cdot s(\lambda)\, \mathrm{d}\lambda}{K_{\mathrm{m}} \int_{360\,\mathrm{nm}}^{830\,\mathrm{nm}} S_{\mathrm{Z}}(\lambda) \cdot V(\lambda)\, \mathrm{d}\lambda} \tag{6}$$

where $K_{\mathrm{m}} \cong$ 683 lm·W^{-1} (in standard air), and $s(\lambda)$ is the spectral responsivity of the photometer, and $S_{\mathrm{Z}}(\lambda)$ is the relative spectral distribution of the light source being measured. Luminous responsivity includes illuminance responsivity and luminance responsivity and is usually expressed in the units of A·lx^{-1}, V·lx^{-1}, A·(cd·m^{-2})$^{-1}$, etc. For example, s_{v} will be illuminance responsivity in A·lx^{-1} if $s(\lambda)$ is spectral irradiance responsivity in th e units of $\left[s(\lambda)\right] = \mathrm{A} \cdot \mathrm{W}^{-1} \cdot \mathrm{m}^2$.

The lower and upper integration limits ($\lambda_{\min}, \lambda_{\max}$) should cover the entire range where $S_{\mathrm{Z}}(\lambda) \cdot s(\lambda) \cdot$ has non-zero values. Photometers are normally calibrated with a CIE Source A lamp. In this case, the luminous responsivity for CIE Standard Illuminant A is expressed as

$$s_{v}^{*} = \frac{\int_{\lambda_{\min}}^{\lambda_{\max}} S_{\mathrm{A}}(\lambda) \cdot s(\lambda)\, \mathrm{d}\lambda}{K_{\mathrm{m}} \int_{360\,\mathrm{nm}}^{830\,\mathrm{nm}} S_{\mathrm{A}}(\lambda) \cdot V(\lambda)\, \mathrm{d}\lambda} \tag{7}$$

where

$S_{\mathrm{A}}(\lambda)$ is the relative spectral power distribution of CIE Standard Illuminant A.

5.2.4 Relative Luminous Responsivity and Spectral Mismatch Correction Factor

For a photometric measurement using a photometer whose spectral responsivity differs in certain spectral ranges from the prescribed weighting function, incorrect measurement results are obtained. When using the spectrally integrated responsivity function, such differences may compensate each other to some extent when comparing two spectral distributions, e.g. light source Z and CIE Standard Illuminant A. To calculate this, the knowledge of the *relative* spectral responsivity of the photometer, $s_{\mathrm{rel}}(\lambda)$, and the *relative* spectral distribution of the light source Z, $S_{\mathrm{Z}}(\lambda)$, is sufficient. The relative luminous responsivity, $a^{*}\left(S_{\mathrm{Z}}(\lambda)\right)$, is the ratio of the luminous responsivity s_{Z} when the detector is illuminated with light source Z to the luminous responsivity s_{A} when it is illuminated with CIE Standard Illuminant A:

$$a^*\left(S_Z(\lambda)\right)=\frac{s_Z}{s_A}=\frac{\int_{\lambda_{min}}^{\lambda_{max}} S_Z(\lambda)\cdot s_{rel}(\lambda)\,d\lambda}{\int_{360\text{ nm}}^{830\text{ nm}} S_Z(\lambda)\cdot V(\lambda)\,d\lambda}\Bigg/\frac{\int_{\lambda_{min}}^{\lambda_{max}} S_A(\lambda)\cdot s_{rel}(\lambda)\,d\lambda}{\int_{360\text{ nm}}^{830\text{ nm}} S_A(\lambda)\cdot V(\lambda)\,d\lambda} \tag{8}$$

where

s_Z is the luminous responsivity of the photometer using light source Z; and

s_A is the luminous responsivity of the photometer using CIE Standard Illuminant A.

The lower and upper integration limits ($\lambda_{min}, \lambda_{max}$) should refer to the entire wavelength range where $s_{rel}(\lambda)$ has non-zero values. The reciprocal of $a^*\left(S_Z(\lambda)\right)$ is called the spectral mismatch correction factor $F^*\left(S_Z(\lambda)\right)=\left(a^*\left(S_Z(\lambda)\right)\right)^{-1}$ (sometimes also abbreviated to SMCF). If the relative spectral responsivity of the photometer and the relative spectral distribution of the source are known, the measurement shall be corrected according to Equation (8). For spectrally narrow light sources (e.g. LEDs), applying a spectral mismatch correction factor is most important.

5.2.5 Colour Correction Factor and Mismatch Exponent

The relative spectral power distribution of an incandescent or halogen lamp is similar to a Planckian distribution $P(T_d,\lambda)$ and characterized by a distribution temperature T_d, which is defined in CIE 114/4-1994. In this case the spectral mismatch correction factor can be approximated by a ratio of temperatures and a mismatch exponent m:

$$F^*(T_d)=\left(a^*\left(P(T_d,\lambda)\right)\right)^{-1}\approx\left(\frac{T_d}{T_A}\right)^m \tag{9}$$

where

$T_A = 2\,856\text{ K}$ refers to CIE Standard Illuminant A,

T_d is the distribution temperature of the source,

m is the mismatch exponent which is determined experimentally for the photometer.

Equation (9) is typically used in the uncertainty evaluation of the calibration procedure of photometers.

5.2.6 Specific Mismatch Index

The quality of the spectral match of the photometer to the $V(\lambda)$ function for a *specific* light source can be expressed by $f_1\left(S_Z(\lambda)\right)=a\left(S_Z(\lambda)\right)-1$. However if the relative spectral distribution of the source and the spectral responsivity of the photometer are known, the result of the photometer should be corrected.

5.2.7 General $V(\lambda)$ Mismatch Index f_1'

The specific mismatch index $f_1\left(S_Z(\lambda)\right)$ is less suited for a general description of the photometer performance, as it is at least theoretically possible to minimize $f_1\left(S_Z(\lambda)\right)$ for a specific spectral distribution – even if the relative spectral responsivity of the photometer differs considerably from the $V(\lambda)$ function, and therefore might lead to large $f_1\left(S_Z(\lambda)\right)$ values for other light sources. For general lighting conditions – in particular, white-light light source – the quality of the spectral mismatch can be best expressed by the general $V(\lambda)$ mismatch index f_1'. For this purpose the relative spectral responsivity $s_{\mathrm{rel}}(\lambda)$ shall be represented by means of the normalized spectral responsivity function:

$$s_{\mathrm{rel}}^{*}(\lambda) = s_{\mathrm{rel}}(\lambda) \cdot \frac{\int_{380\,\mathrm{nm}}^{780\,\mathrm{nm}} S_{\mathrm{A}}(\lambda) \cdot V(\lambda)\,\mathrm{d}\lambda}{\int_{380\,\mathrm{nm}}^{780\,\mathrm{nm}} S_{\mathrm{A}}(\lambda) \cdot s_{\mathrm{rel}}(\lambda)\,\mathrm{d}\lambda} \tag{10}$$

where $S_{\mathrm{A}}(\lambda)$ is the spectral distribution function of the CIE Standard Illuminant A, which, in principle, is used for the calibration of a photometer.

The index f_1' is then defined by:

$$f_1' = \frac{\int_{380\,\mathrm{nm}}^{780\,\mathrm{nm}} \left| s_{\mathrm{rel}}^{*}(\lambda) - V(\lambda) \right| \mathrm{d}\lambda}{\int_{380\,\mathrm{nm}}^{780\,\mathrm{nm}} V(\lambda)\,\mathrm{d}\lambda}. \tag{11}$$

NOTE 1 f_1' cannot be applied as a correction factor.

NOTE 2 For very closely matched photometers the uncertainty associated with the normalized spectral responsivity values influences the value of f_1'. In this case, Equation (11) cannot be directly applied and Monte Carlo simulation is necessary.

NOTE 3 It is essential to know the values of the responsivity function and its uncertainty with sufficiently high resolution in order to determine the $V(\lambda)$ mismatch index f_1', spectral mismatch correction factor and the associated measurement uncertainties.

5.3 UV Response

5.3.1 General

Photometers shall not be sensitive to UV radiation. UV sensitivity may be caused by non-perfect UV blocking or some fluorescence effects.

5.3.2 Measurement

The UV response is determined by irradiating the photometer using a UV lamp, which provides radiation mainly within the UV-A region, and a UV band-pass filter with the given spectral transmittance $\tau_{\mathrm{UV}}(\lambda)$, as defined below.

The lamp shall have a relative spectral distribution function of the type as shown in Figure 2. The ratio of the visible radiation (illuminance) to the UV-A irradiance shall be 35 $\mathrm{lx} \cdot (\mathrm{W} \cdot \mathrm{m}^{-2})^{-1}$. The tabulated data of the nominal relative spectral power distribution are given in Table A.2 in Annex A.

The UV band-pass filter shall have a spectral transmittance as close as possible to that shown in Figure 3, the spectral data are given in Table A.1 in Annex A.

If a different spectral distribution or transmittance is used the influence of the difference shall be evaluated, but the results shall be corrected and reported as specified by the nominal values.

The irradiation of the photometer by the UV lamp without the filter shall cause a signal at least 1 000 times as large as the smallest resolvable signal.

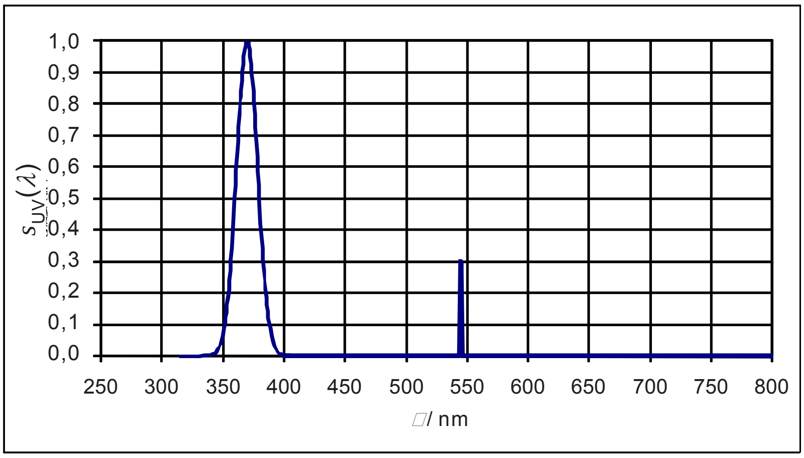


Figure 2 — Relative spectral distribution of the irradiance S_{UV} for determination of the UV response f_{UV}

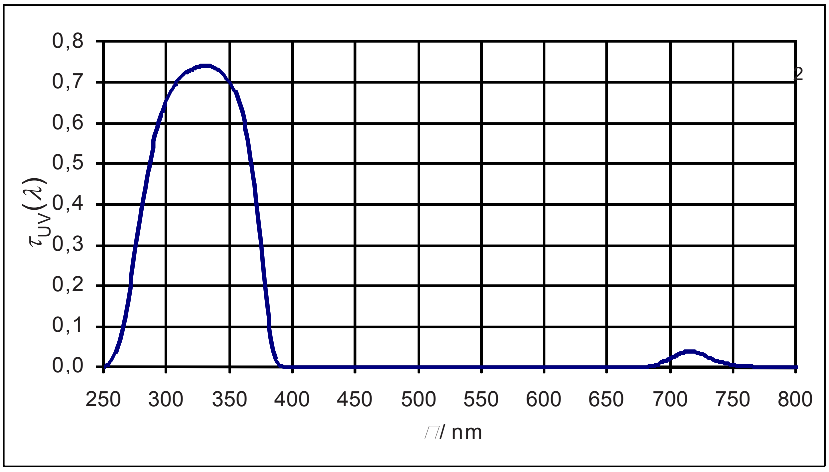


Figure 3 — Spectral transmittance $\tau_{UV}(\lambda)$ of the UV filter for determination of the UV response f_{UV}

5.3.3 Characterization

The UV response f_{UV} of a photometer is the ratio of the signal Y_{UV}, when the photometer is irradiated by the UV source defined in 5.3.2 in combination with the specified UV filter, to the signal Y when it is irradiated by the same source without the filter, according to Equation (12):

$$f_{UV} = \left| \frac{Y_{UV}}{Y} - u_0 \right| \quad \text{with} \quad u_0 = \frac{\int_{360\,\text{nm}}^{830\,\text{nm}} S_{UV}(\lambda) \cdot \tau_{UV}(\lambda) \cdot V(\lambda)\, d\lambda}{\int_{360\,\text{nm}}^{830\,\text{nm}} S_{UV}(\lambda) \cdot V(\lambda)\, d\lambda} \qquad (12)$$

where

$\tau_{UV}(\lambda)$ is the spectral transmittance of the filter for determining the UV response; and

$S_{UV}(\lambda)$ is the relative spectral distribution of the irradiance for determining the UV response.

5.4 IR Response

5.4.1 General

Photometers shall not be sensitive to IR radiation.

5.4.2 Measurement

The IR response shall be measured by illuminating the photometer with a tungsten filament CIE Source A lamp combined with an IR filter whose spectral transmittance is specified in Table A.3 in Annex A and illustrated in Figure 4. If a different spectral distribution or transmittance is used the influence of the difference shall be evaluated, but the results shall be corrected and reported as specified by the nominal values.

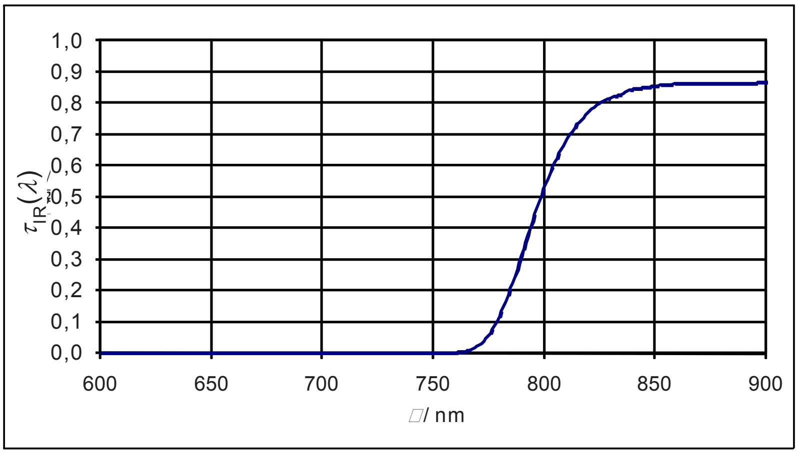


Figure 4 — Spectral transmittance $\tau_{IR}(\lambda)$ of the IR filter for determination of the IR response f_{IR}

The applied lamp shall be without reflector, will have an untreated envelope and shall not be reduced in respect of infrared radiation level. The illumination of the photometer without the filter shall cause a signal at least 10 000 times as large as the smallest resolvable signal.

5.4.3 Characterization

The IR response of a photometer is the ratio of the signal Y_{IR}, when the photometer is illuminated by an incandescent lamp with a correlated colour temperature of 2 856 K (CIE Source A), and combined with a specified IR filter, to the signal Y, when it is illuminated by the same source without the filter. This is defined in Equation (13):

$$f_{IR} = \left| \frac{Y_{IR}}{Y} - r_0 \right| \quad \text{with} \quad r_0 = \frac{\int_{360\,\text{nm}}^{830\,\text{nm}} S_{IR}(\lambda) \cdot \tau_{IR}(\lambda) \cdot V(\lambda)\, d\lambda}{\int_{360\,\text{nm}}^{830\,\text{nm}} S_{IR}(\lambda) \cdot V(\lambda)\, d\lambda} \tag{13}$$

where

$\tau_{IR}(\lambda)$ is the spectral transmittance of the filter for determining the IR response; and

$S_{IR}(\lambda)$ is the relative spectral distribution of the irradiance used for determining the IR response.

NOTE In practical terms, correlated colour temperature and distribution temperature are equivalent when establishing a lamp as CIE Source A.

5.5 Directional Response for Illuminance Meters

5.5.1 General

The effect of light incident on the acceptance area of the photometer depends on the angle of incidence. The directional response function (evaluation of the incident light as a function of the angle of incidence) is determined by the form and the optical construction of the photometer head.

By equipping the photometer head with directionally selective optical elements (e.g. diffusing adaptors of various shapes and special optical components) special evaluation functions can be realized. These include:

- cosine adaptors for the measurement of the (planar) illuminance E;
- E_0 adaptors for the measurement of spherical illuminance;
- E_{sc} and E_c [1] adaptors for the measurement of semi-cylindrical and cylindrical illuminance;
- $E_{2\pi}$ adaptors for the measurement of semi-spherical illuminance.

NOTE In Equations (15), (17), (21), (25) and (29) of Clauses 5.5.3 to 5.5.7 the variable of integration is expressed in the units of radian, [dε] = rad and [dφ] = rad.

5.5.2 Measurement

For the measurement of directional response, a small light source (CIE Source A) shall be set up at a distance corresponding to at least 2 times the limiting photometric distance of the photometer and the light source.

Special precautions shall be taken to exclude stray light from the acceptance area of the photometer head. For a light source with a horizontal beam, the rotation of the photometer head around a horizontal or vertical axis varies the angle of incidence with respect to the centre of the acceptance area of the photometer head. The centre of rotation shall coincide with the centre of the acceptance area, which is specified by the manufacturer. Measurements of the signal as a function of the angle of incidence shall be carried out in at least two mutually perpendicular planes, and the average deviation from the specified angular weighting function shall be used for the characterization. For the evaluation of the quality indices for the directional response the measurements shall be evaluated in angular steps of 5° in the minimum range 0° to 80°. However the measurements shall be performed and reported in the full sensitive angular range of the photometer. Thus for cosine-corrected illuminance meters with hemispherical diffuser it may go to beyond 90°. The angular size of the detector as subtended from the lamp shall be smaller or equal than 1°.

NOTE For photometer with a nonlinear relationship between input quantity and signal output, the measurement should be conducted at a constant signal level or the result should be corrected via the measured input-output characteristic of the photometer. In the first case the illuminance should be changed in a defined way (e.g. change of distance).

5.5.3 Characterization for (Planar) Illuminance Meters

For a photometer with a plane input window measuring planar illuminances, the deviation in directional response to the incident radiation is given by:

$$f_2(\varepsilon,\varphi) = \frac{Y(\varepsilon,\varphi)}{Y(0,\varphi)\cdot\cos\varepsilon} - 1 \tag{14}$$

where

---

1 Previously used symbol E_z.

$Y(\varepsilon,\varphi)$ is the output signal as a function of the angle of incidence ε and azimuth angle φ;

ε is the angle measured with respect to the normal to the measuring plane or optical axis;

φ is the azimuth angle

(see Figure 5).

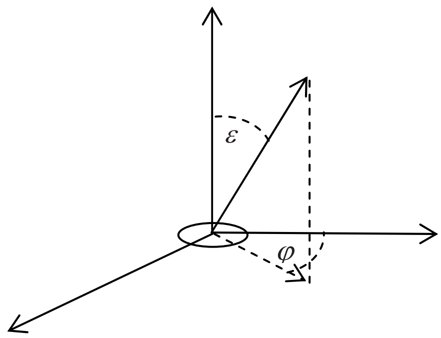


Figure 5 — Coordinates for the definition of the function $f_2(\varepsilon,\varphi)$

For characterizing the directional response, $f_2(\varepsilon,\varphi)$ is measured in four orthogonal planes of azimuth $\varphi = \{0, \pi/2, \pi, 3\pi/2\}$. The index f_2 is calculated as:

$$f_2 = \frac{1}{4}\sum_{j=0}^{3} f_2(\varphi = j\frac{\pi}{2}), \quad \text{with} \quad f_2(\varphi) = \int_0^{80°\cdot\frac{\pi}{180°}} \left| f_2(\varepsilon,\varphi)\right| \cdot \sin 2\varepsilon \, \mathrm{d}\varepsilon \tag{15}$$

5.5.4 Characterization for Spherical Illuminance Meter

For a spherical illuminance meter, the deviation in directional response is characterized by:

$$f_{2,0}(\varepsilon,\varphi) = \frac{Y(\varepsilon,\varphi)}{Y(0,0)} - 1 \tag{16}$$

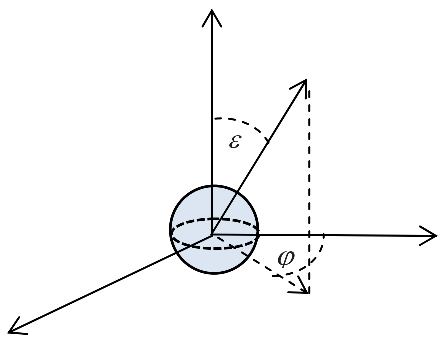


Figure 6 — Coordinates for the definition of the function $f_{2,0}(\varepsilon,\varphi)$

For characterizing the directional response, $f_{2,0}(\varepsilon,\varphi)$ is measured in four orthogonal planes of azimuth $\varphi = \{0, \pi/2, \pi, 3\pi/2\}$. The index $f_{2,0}$ is calculated as

$$f_{2,0} = \frac{1}{4}\sum_{j=0}^{3} f_{2,0}(\varphi = j\frac{\pi}{2}), \qquad \text{with} \quad f_{2,0}(\varphi) = \frac{1}{2}\int_0^{\pi} \left| f_{2,0}(\varepsilon,\varphi)\right| \cdot \sin\varepsilon \, \mathrm{d}\varepsilon \tag{17}$$

5.5.5 Characterization for Cylindrical Illuminance Meter[1]

For a cylindrical illuminance meter, the deviation in directional response is characterized by:

$$f_{2,\mathrm{c}}(\varepsilon,\varphi) = \frac{Y(\varepsilon,\varphi)}{Y\left(\frac{\pi}{2},0\right)\cdot\sin\varepsilon} - 1 \tag{18}$$

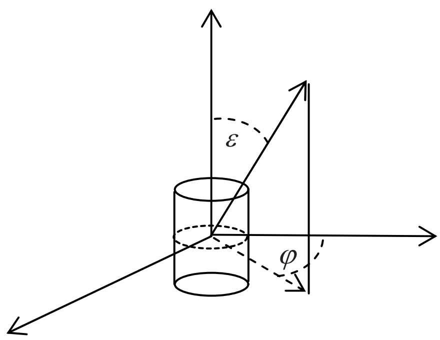


Figure 7 — Coordinates for the definition of the function $f_{2,\mathrm{c}}(\varepsilon,\varphi)$

NOTE It is advisable to give the function for the horizontal plane ($\varepsilon = \pi/2$) and the vertical plane ($\varphi = 0$) separately:

Horizontal plane:

$$f_{2,\mathrm{c}}\left(\frac{\pi}{2},\varphi\right) = \frac{Y\left(\frac{\pi}{2},\varphi\right)}{Y\left(\frac{\pi}{2},0\right)} - 1 \tag{19}$$

Vertical plane:

$$f_{2,\mathrm{c}}(\varepsilon,0) = \frac{Y(\varepsilon,0)}{Y\left(\frac{\pi}{2},0\right)\cdot\sin\varepsilon} - 1 \tag{20}$$

For characterizing the directional response by a single value, the index $f_{2,\mathrm{c}}$ is used:

$$f_{2,\mathrm{c}} = \frac{2}{\pi}\int_{10^\circ\cdot\frac{\pi}{180^\circ}}^{170^\circ\cdot\frac{\pi}{180^\circ}} \left|f_{2,\mathrm{c}}(\varepsilon,0)\right|\cdot\sin^2\varepsilon\,\mathrm{d}\varepsilon + \frac{1}{2\pi}\int_{-\pi}^{\pi}\left|f_{2,\mathrm{c}}\left(\frac{\pi}{2},\varphi\right)\right|\cdot\mathrm{d}\varphi \tag{21}$$

It is recommended that the two components in Equation (21) are given separately, i.e. $f_{2,\mathrm{c},\varepsilon} = \frac{2}{\pi}\int_{10^\circ\cdot\frac{\pi}{180^\circ}}^{170^\circ\cdot\frac{\pi}{180^\circ}} \left|f_{2,\mathrm{c}}(\varepsilon,0)\right|\cdot\sin^2\varepsilon\,\mathrm{d}\varepsilon$ and $f_{2,\mathrm{c},\varphi} = \frac{1}{2\pi}\int_{-\pi}^{\pi}\left|f_{2,\mathrm{c}}\left(\frac{\pi}{2},\varphi\right)\right|\cdot\mathrm{d}\varphi$.

———————————

1 Previously used symbol for cylindrical illuminance: $f_{2,\mathrm{z}}$

5.5.6 Characterization for Semi-Cylindrical Illuminance Meter

For a semi-cylindrical illuminance meter, the deviation $f_{2,\mathrm{sc}}(\varepsilon,\varphi)$ in directional response is given by:

$$f_{2,\mathrm{sc}}(\varepsilon,\varphi) = \frac{2\,Y(\varepsilon,\varphi)}{Y\left(\frac{\pi}{2},0\right)\sin\varepsilon\,(1+\cos\varphi)} - 1 \tag{22}$$

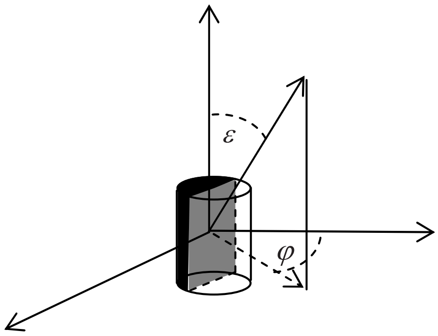


Figure 8 — Coordinates for the definition of the function $f_{2,\mathrm{sc}}(\varepsilon,\varphi)$

NOTE It is advisable to give the function for the horizontal plane ($\varepsilon = \pi/2$) and the vertical plane ($\varphi = 0$) separately:

Horizontal plane:

$$f_{2,\mathrm{sc}}\left(\frac{\pi}{2},\varphi\right) = \frac{2\,Y\left(\frac{\pi}{2},\varphi\right)}{Y\left(\frac{\pi}{2},0\right)(1+\cos\varphi)} - 1 \tag{23}$$

Vertical plane:

$$f_{2,\mathrm{sc}}(\varepsilon,0) = \frac{Y(\varepsilon,0)}{Y\left(\frac{\pi}{2},0\right)\sin\varepsilon} - 1 \tag{24}$$

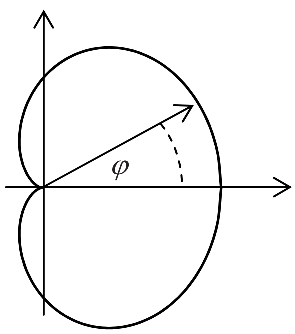


Figure 9 — Ideal responsivity of a semi-cylindrical illuminance meter in horizontal plane

For characterizing the directional response, the index $f_{2,\mathrm{sc}}$ is used:

$$f_{2,\mathrm{sc}} = \frac{2}{\pi} \int_{10^\circ \cdot \frac{\pi}{180^\circ}}^{170^\circ \cdot \frac{\pi}{180^\circ}} \left| f_{2,\mathrm{sc}}(\varepsilon,0) \right| \cdot \sin^2 \varepsilon \, \mathrm{d}\varepsilon + \frac{1}{2\pi} \int_{-170^\circ \cdot \frac{\pi}{180^\circ}}^{170^\circ \cdot \frac{\pi}{180^\circ}} \left| f_{2,\mathrm{sc}}\left(\frac{\pi}{2},\varphi\right) \right| \cdot (1+\cos\varphi) \, \mathrm{d}\varphi \qquad (25)$$

It is recommended that the two components in Equation (25) are given separately, i.e. $f_{2,\mathrm{sc},\varepsilon} = \frac{2}{\pi} \int_{10^\circ \cdot \frac{\pi}{180^\circ}}^{170^\circ \cdot \frac{\pi}{180^\circ}} \left| f_{2,\mathrm{sc}}(\varepsilon,0) \right| \cdot \sin^2 \varepsilon \, \mathrm{d}\varepsilon$ and $f_{2,\mathrm{sc},\varphi} = \frac{1}{2\pi} \int_{-170^\circ \cdot \frac{\pi}{180^\circ}}^{170^\circ \cdot \frac{\pi}{180^\circ}} \left| f_{2,\mathrm{sc}}\left(\frac{\pi}{2},\varphi\right) \right| \cdot (1+\cos\varphi) \, \mathrm{d}\varphi$.

5.5.7 Characterization for Semi-Spherical Illuminance Meter

For a semi-spherical illuminance meter, the systematic deviation $f_{2,2\pi}(\varepsilon,\varphi)$ in directional response is given by:

$$f_{2,2\pi}(\varepsilon,\varphi) = \frac{2\,Y(\varepsilon,\varphi)}{Y(0,0)\cdot(1+\cos\varepsilon)} - 1 \qquad (26)$$

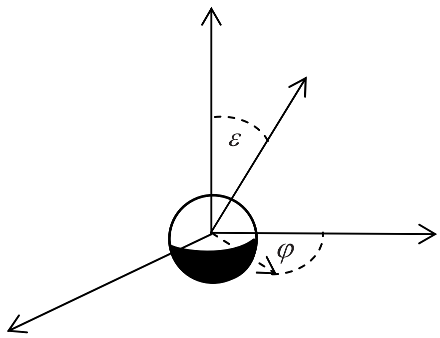


Figure 10 — Coordinates for the definition of the function $f_{2,2\pi}(\varepsilon,\varphi)$

NOTE It is advisable to give the function for the horizontal plane ($\varepsilon = \pi/2$) and the vertical plane ($\varphi = 0$) separately:

Horizontal plane:

$$f_{2,2\pi}\left(\frac{\pi}{2},\varphi\right) = \frac{2\,Y\left(\frac{\pi}{2},\varphi\right)}{Y(0,0)} - 1 \qquad (27)$$

Vertical plane:

$$f_{2,2\pi}(\varepsilon,0) = \frac{2\,Y(\varepsilon,0)}{Y(0,0)\cdot(1+\cos\varepsilon)} - 1 \qquad (28)$$

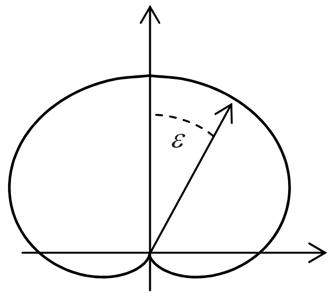


Figure 11 — Ideal responsivity of a semi-spherical illuminance meter in vertical plane

For characterizing the directional response, the index $f_{2,2\pi}$ is used:

$$f_{2,2\pi} = \frac{1}{\pi} \int_{0}^{170^\circ \cdot \frac{\pi}{180^\circ}} \left| f_{2,2\pi}(\varepsilon,0) \right| \cdot (1+\cos\varepsilon) \cdot \mathrm{d}\varepsilon + \frac{1}{2\pi} \int_{-\pi}^{\pi} \left| f_{2,2\pi}\left(\frac{\pi}{2},\varphi\right) \right| \cdot \mathrm{d}\varphi \quad (29)$$

It is recommended that the two components in Equation (29) are given separately, i.e. $f_{2,2\pi,\varepsilon} = \frac{1}{\pi} \int_{0}^{170^\circ \cdot \frac{\pi}{180^\circ}} \left| f_{2,2\pi}(\varepsilon,0) \right| \cdot (1+\cos\varepsilon) \cdot \mathrm{d}\varepsilon$ and $f_{2,2\pi,\varphi} = \frac{1}{2\pi} \int_{-\pi}^{\pi} \left| f_{2,2\pi}\left(\frac{\pi}{2},\varphi\right) \right| \cdot \mathrm{d}\varphi$.

5.6 Directional Response for Luminance Meter

5.6.1 General

Luminance meters shall evaluate the luminance of the assessed surface within a measurement field of uniform responsivity. Luminous areas outside the measurement field shall not influence the measurement results. The directional response function can be used to describe the directionally dependent evaluation and the influence of the surrounding luminance outside the measurement field. The response to incident light on the acceptance area of the photometer head is a function of the incidence angle. The directional response function (evaluation of the incident light as a function of the angle of incidence) is determined by the geometric optics, construction of the photometer head and stray light in the optical system. Special directional response functions can be generated by fitting the photometer head with special lenses or other such accessories (e.g. interchangeable objectives). One example is the measurement of the equivalent veiling luminance.

5.6.2 Measurement

In order to measure the directional response function, a light source shall be positioned at a sufficiently large distance from the acceptance area in order that the extent of the luminous area of the source shall not be greater than 5 % of the measurement field angle, α, i.e. the maximum angle of the outer limits of the measured field to the central optical axis. Focusing luminance meters shall be focused on the light source. The luminance meter shall be rotated around the centre of the entrance pupil. As an alternative technique, the light is moved in the plane perpendicular to the optical axis of the photometer, keeping the photometer head fixed. The measurement of the output signal as a function of the angle of incidence shall be obtained in at least four equally spaced directions of φ angles. Stray light shall be prevented from falling on the acceptance area.

5.6.3 Characterization

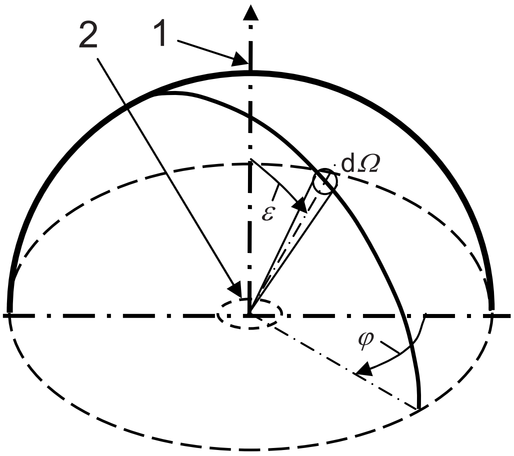
The directional response of a luminance meter is characterized by the directional response function $f_2(\varepsilon,\varphi)$:

$$f_2\left(\varepsilon,\varphi\right)=\frac{Y\left(\varepsilon,\varphi\right)}{Y\left(0,\varphi\right)} \tag{30}$$

where

$Y\left(\varepsilon,\varphi\right)$ is the output signal at angle of incidence ε and azimuth angle φ (Figure 12);

$Y\left(0,\varphi\right)$ is the output signal at azimuth angle φ for light incident in the direction of the optical axis of the photometer head.



Key:
1 Optical axis
2 Entrance pupil
ε Angle of incidence, measured from the optical axis
φ Azimuth angle

Figure 12 — Coordinates for the definition of the function $f_2\left(\varepsilon,\varphi\right)$

The directional response index $f_{2,\text{g}}$ is given by:

$$f_{2,\text{g}}=1-\frac{Y_{\text{min}}}{Y_{\text{max}}} \tag{31}$$

where

Y_{min} is the smallest output signal for an angle of incidence within 90 % of the measurement field using the measurement arrangement given in 5.6.2;

Y_{max} is the largest output signal for an angle of incidence within 90 % of the measurement field using the measurement arrangement given in 5.6.2.

The index functions $f_2\left(\varepsilon_{9/10}\right)$ and $f_2\left(\varepsilon_{1/100}\right)$ are defined as:

$$f_2\left(\varepsilon_{9/10}\right)=1-\frac{\bar{\varepsilon}_{9/10}}{\bar{\varepsilon}_{1/100}} \tag{32}$$

$$f_2\left(\varepsilon_{1/100}\right)=1-\frac{\bar{\varepsilon}_{1/10}}{\bar{\varepsilon}_{1/100}} \tag{33}$$

where

$\bar{\varepsilon}_{9/10}$	is the average angle within which the output is equal to or greater than 0,9 times the value of the incident light in the direction of the optical axis;
$\bar{\varepsilon}_{1/10}$	is the average angle within which the output is equal to or greater than 0,1 times the value of the incident light in the direction of the optical axis;
$\bar{\varepsilon}_{1/100}$	is the average angle within which the output is equal to or greater than 0,01 times the value of the incident light in the direction of the optical axis.

These values are the average of at least four equally separated plane measurements.

The directional symmetry of the measurement is characterized by the index function $f_{2,s}$ given by:

$$f_{2,s} = \frac{Y_{max}\left(\bar{\varepsilon}_{1/10}, \varphi_1\right) - Y_{min}\left(\bar{\varepsilon}_{1/10}, \varphi_2\right)}{Y_{max}\left(\bar{\varepsilon}_{1/10}, \varphi_1\right) + Y_{min}\left(\bar{\varepsilon}_{1/10}, \varphi_2\right)} \tag{34}$$

where

Y_{max}	is the maximum output signal at $\bar{\varepsilon}_{1/10}$;
Y_{min}	is the minimum output signal at $\bar{\varepsilon}_{1/10}$;
φ_1	is the angle for output Y_{max};
φ_2	is the angle for output Y_{min};
$\bar{\varepsilon}_{1/10}$	is the average angle within which the output is equal to or greater than 0,1 times the value of the incident light in the direction of the optical axis.

For an abbreviated characterization of the directional response function $f_2\left(\varepsilon,\phi\right)$ the following shall be given:

- the measurement field angle α (see 5.6.2),
- the directional response index $f_{2,g}$,
- the index function $f_2\left(\varepsilon_{9/10}\right)$,
- the index function $f_2\left(\varepsilon_{1/100}\right)$,
- the index function $f_{2,s}$ for characterizing the directional symmetry. Additionally, the corresponding value, $f_{2,s,1/100}$, may also be given for the equivalent angle for 0,01 times the value of the incident light.

5.6.4 Measurement of the Effect of the Surrounding Field

For the measurement of the effect of the surrounding luminance, or veiling glare, a specific illumination arrangement is necessary. A uniform luminous surface at least ten times as large as the measurement field shall be used. The luminance of this luminous surface shall be set such that it is at least 10 times the maximum signal on the most sensitive output range.

A gloss trap ("black" surface of negligibly small luminance) shall be fitted in front of the luminous surface and centred on the measurement field. The gloss trap shall exceed the dimensions of the measurement field in the image plane by 10 % (Figure 13). Measurements shall be made with and without the gloss trap, with the luminous surface present for both measurements.

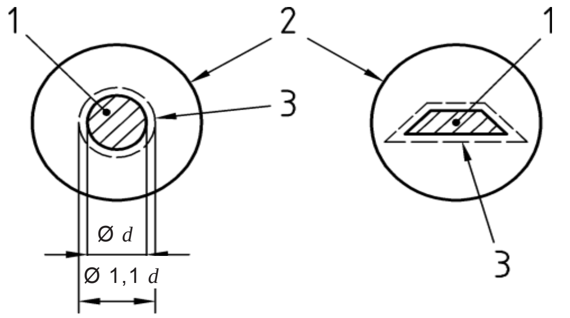
The characterization of the effect of the surrounding luminance is given by function $f_{2,u}$:

$$f_{2,u} = \frac{Y_{Surround}}{Y_{Total} - Y_{Surround}} \quad (35)$$

where

$Y_{Surround}$ is the output signal for measurement with the gloss trap, i.e. with black measurement field and bright surround; and

Y_{Total} is the output signal for measurement without the gloss trap, i.e. with bright measurement field and bright surround.



Key: 1 Measurement field (diameter d)
2 Field of view
3 Gloss trap

Figure 13 — Diagram showing the size of the gloss trap used in determining $f_{2,u}$

5.7 Linearity

5.7.1 General

Linearity of a photometer is the property whereby the change of the output quantity of the photometer is proportional to a change of the input quantity – that is, the responsivity is constant over a specified range of inputs.

NOTE 1 A detector is usually linear over a certain range of input levels only. Outside this range it can become nonlinear.

NOTE 2 The range of linearity of a photometer can be affected by the use of unsuitable electronic circuitry.

5.7.2 Measurement

The most convenient method for measuring the linearity of photometers is by comparison with a reference photometer of known linearity.

NOTE Characterization of linearity of a reference photometer can be evaluated by the most accurate measuring method using the principle of additivity of luminous fluxes by the technique of multiple sources or apertures.

5.7.3 Characterization

The characterization of the proportionality (not linearity) deviation of a photometer is given by:

$$f_3(Y) = \left| \frac{Y}{Y_{max}} \cdot \frac{X_{max}}{X} - 1 \right| \quad (36)$$

where

Y is the output signal due to illumination of the photometer with input quantity X;

X_{max} is the input value corresponding to the maximum output signal Y_{max} (largest value of the measurement range);

Y_{max} is the output signal due to illumination of the photometer due to the input X_{max}.

The index $f_3(Y)$ is used to characterize the linearity deviation in each range according to Equation (37). It corresponds to the largest value of the function $f_3(Y)$ within the measurement from 10 % of the range value to the full range value for all but the highest sensitive range and from the lowest specified value to the full range value at the highest sensitive range.

$$f_3 = \max\left[f_3(Y)\right] \tag{37}$$

The index f_3 shall be given for each measurement range.

5.8 Display-Unit

5.8.1 General

The accuracy of the reading of analogue-display photometers depends on the class index of analogue apparatus (classification by IEC 60051), the accuracy of the reading of digital-display photometers depends on the resolution.

NOTE The class index gives the maximum output error with respect to the full-scale reading.

5.8.2 Characterization

For analogue displays the quality index for a display unit, f_4, is given by Equation (38):

$$f_4 = k \cdot i_\text{c} \tag{38}$$

where

- k is the factor due to changing output range (e.g. $k = 10$ when the switching of the measurement range is at the ratio of 1:10);
- i_c is the class index as defined in IEC 60051.

k is given by:

$$k = \frac{Y_\text{B,max}}{Y_\text{A,max}} \tag{39}$$

where

- $Y_\text{B,max}$ is the full scale reading of the less sensitive range B;
- $Y_\text{A,max}$ is the full scale reading of the more sensitive range A.

NOTE The characterization by the parameter f_4 from Equation (38) is chosen in order to produce the largest error, which occurs at the boundary of the range change.

The uncertainty of digital-display photometers is determined by the deviations in the display-unit and the conversion deviations (in general ± 1 digit). The index is given by:

$$f_4 = \left| f_\text{display} \right| + \left| \frac{k \cdot D}{P_\text{max}} \right| \tag{40}$$

where

- f_display is the relative deviation, related to the display-unit;
- k is the factor for range changing;
- P_max is the maximum display capability of the digital instrument (e.g. for a 3 ½ digit display, $P_\text{max} = 1{,}999$);
- D is the possible deviation of the least significant digit (e.g. ± 1 digit).

The characterization by Equation (40) and the resulting index f_4 from Equation (38) are designed to produce the largest deviation, which occurs at the boundary of the range change.

5.9 Fatigue

5.9.1 General

Fatigue is the temporary change in the responsivity, under constant operating conditions, caused by incident illumination. The change in re sponsivity characterized by fatigue is reversible, which means that the responsivity gradually returns to normal when the incident illumination is removed.

NOTE 1 During the operation of phot ometers, reversible changes can occur in the spectral responsivity as well as in the luminous responsivity. These changes are both designat ed fatigue. However the change in spectral responsivity is difficult to quantify and so no test for such influence is given here – onl y the absolute luminous responsivity has a charact eristic index.

NOTE 2 Fatigue is generally greater for higher illu mination levels incid ent on the light-sensitive detector. Fatigue cannot be separated from the temperature effect caused by irradiation of the photometer head. Temperature changes induced by irradiation of the light-sensitive detector are likewise not necessarily completely eliminated with thermostatic control.

5.9.2 Measurement

Fatigue shall be measured with temporally-stable illumination, at a level of 5 000 lx. The operating conditions (ambient temperature, supply voltage, etc.) shall be held constant. The output signal shall be measured as a function of the illumination period. Before beginning the constant illumination, the photometer head shall not be exposed to light for at least 24 h.

5.9.3 Characterization

Fatigue is evaluated using the function of systematic deviation $f_5(t)$. It is given by:

$$f_5(t) = \frac{Y(t)}{Y(t_0)} - 1 \tag{41}$$

where

t is the elapsed time since the beginning of the illumination of t he photometer head with constant illuminance;

$Y(t)$ is the output signal at time t;

t_0 is the reference time, e.g. 10 s.

For characterizing fatigue, the index f_5 is used:

$$f_5 = \left| \frac{Y(t = 30\ \text{min})}{Y(t_0 = 10\ \text{s})} - 1 \right| \tag{42}$$

where

$Y(t = 30\ \text{min})$ is the output signal 30 min after the beginning of the illumination;

$Y(t_0 = 10\ \text{s})$ is the output signal 10 s after the beginning of the illumination.

5.10 Temperature

5.10.1 General

Temperature dependence characterizes the influence of the ambient temperature on the absolute responsivity and the relative spectral responsivity of th e photometer. If th e photometer is operated at an ambient temperature different from that used during calibration, measurement errors can occur.

Although the relative spectral responsivity of the photometer may change with different ambient temperatures, this is difficult to quantify and so no test for such influence is given here – only the absolute luminous responsivity has a characteristic index.

5.10.2 Measurement

In order to measure temperature dependence, the entire photometer shall be exposed to the desired temperature. The instrument shall attain thermal equilibrium before starting the measurement.

The measurement shall be performed, at minimum, for ambient temperatures of 5 °C, 25 °C (reference temperature) and 40 °C. The measurement shall be performed at an illumination level on the photometer head that approaches the largest value of an arbitrary measurement range (this range should be selected taking account of the requirement to use a sufficiently low illumination level as to minimize fatigue – see NOTE 2).

NOTE 1 In general, it can be assumed that the photometer will attain thermal equilibrium at the desired temperature in about one hour. However if the photometer has been stored at a temperature significantly different to the desired ambient temperature then the stabilization may take longer.

NOTE 2 In case there is a fatigue effect, the photometer head should be illuminated only during the measurement and the illuminance level should be sufficiently reduced to minimize fatigue.

5.10.3 Characterization

The characterization of temperature dependence is given by the function $f_{6,T}(T)$:

$$f_{6,T}(T) = \frac{Y(T)}{Y(T_0)} - 1 \qquad (43)$$

where

$Y(T)$ is the output signal at temperature T;

$Y(T_0)$ is the output signal at 25 °C reference ambient temperature.

The index $f_{6,T}$ for temperature dependence is given by:

$$f_{6,T} = \left| \frac{Y(T_2) - Y(T_1)}{Y(T_0)} \cdot \frac{\Delta T}{T_2 - T_1} \right| \qquad (44)$$

The following values shall be used:

T_2 = 40 °C; T_1 = 5 °C; T_0 = 25 °C; ΔT = 10 °C.

5.11 Humidity Resistance

5.11.1 General

The photometer shall resist humidity within a certain range. The quality index $f_{6,H}$ describes the durability against humidity by comparing the response before and after humidity exposure. However, $f_{6,H}$ is not the sensitivity coefficient of photometers to humidity changes.

5.11.2 Measurement

In order to evaluate the humidity resistance, the entire photometer shall be exposed to the desired humidity and temperature. The instrument shall attain thermal equilibrium at ambient environmental conditions before starting the measurement. The ambient temperature shall be set between 21 °C and 27 °C for the duration of the test, and shall be maintained within 2 °C throughout. The relative humidity shall be set between 45 % and 75 % and the photometer shall be allowed to acclimatize for at least 3 hours. The photometer shall be illuminated by a luminous intensity standard lamp on a photometric bench at a fixed photometric distance, generating the photometer signal Y_{before}. The relative humidity shall then be increased to between 85 % and 95 % noncondensing and the photometer shall be subjected to that condition for 3 hours. The relative humidity shall finally be set back to the original condition and, just after the relative humidity is set back to the original condition, the photometer signal Y_{after} shall be measured when illuminated by the same standard lamp.

5.11.3 Characterization

The characterization of humidity resistance is given by the index $f_{6,H}$:

$$f_{6,H} = \left| \frac{Y_{\text{after}}}{Y_{\text{before}}} - 1 \right| \quad (45)$$

where

Y_{before} is the output signal before exposure to high humidity;

Y_{after} is the output signal after exposure to high humidity.

5.12 Modulated Light

5.12.1 General

When measuring modulated light, the meter reading of a photometer can deviate from the arithmetic mean value if the frequency of the modulated light is below the lower frequency limit or above the upper frequency limit (see below), if the peak overload capability is exceeded, or if the settling time is not completed.

The lower frequency limit v_{l} (or upper frequency limit v_{u}) of sinusoidally modulated light (modulation degree 1, see Figure 14) is the frequency above (or below) which the meter reading does not differ more than 5 % from the reading for unmodulated light of the same arithmetic mean.

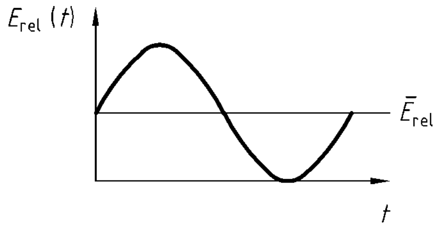


Figure 14 — Sinusoidally modulated light of modulation degree 1

5.12.2 Measurement

In order to characterize the frequency dependence of a photometer it is necessary to make measurements at different modulation frequencies of the incident radiation. For these measurements it is not necessary for the measurement area to be illuminated homogeneously. However it is important that suitable means shall be employed to ensure that the arithmetic mean output of the light source used for the measurement remains constant when the modulation frequency is varied.

The measurement of the upper and lower frequency limits can be performed by means of light emitting diodes (LEDs), the luminous intensities of which are modulated sinusoidally using a suitable power supply.

Alternatively a rotating-sector disk in combination with a DC-powered lamp can be used, although experience shows that the generation of modulated (not sinusoidal) light can only be used for frequencies up to the order of 10^4 Hz. Higher illuminance values can be achieved by this method than with a LED, however. For a 50 % duty-cycle sector disk the signal level for the measurement of modulated radiation shall be less than half of the full scale of the measuring range used. The measuring range shall be stated.

5.12.3 Characterization

The characterization of the frequency effects is given by the function $f_7(\upsilon)$:

$$f_7(\upsilon) = \frac{Y(\upsilon)}{Y(\upsilon_0 = 0\ \text{Hz})} - 1 \tag{46}$$

where

$Y(\upsilon = 0\ \text{Hz})$ is the output signal for illumination with unmodulated light;

$Y(\upsilon)$ is the output signal for illumination, modulated with frequency υ, with the same arithmetic mean value as for illumination with steady-state light.

To characterize the effect of modulation using only a single numerical value, the following shall be used:

$$f_7 = \left| \frac{Y(\upsilon = 100\ \text{Hz or } \upsilon = 120\ \text{Hz})}{Y(\upsilon_0 = 0\ \text{Hz})} - 1 \right| \tag{47}$$

For photometers intended for use with high frequency sources, such as high frequency fluorescent lamps and pulsed LEDs, the value of $f_7(\upsilon)$ at higher frequencies shall additionally be stated.

5.13 Polarization Dependence

5.13.1 General

The output signal of a photometer can depend on the polarization condition of the measured light. In this case, the output signal Y changes when the linearly polarized quasi-parallel incident light is rotated around the direction of incidence.

NOTE Photometer heads of illuminance meters may show a polarization dependence within certain angles of light incidence. With photometer heads for the measurement of other quantities (e.g. cylindrical illuminance, semi-cylindrical illuminance and luminance) such dependence may also be observed with normal light incidence.

5.13.2 Measurement

In order to measure the polarization dependence, unpolarized light from a point source is required, e.g. following the arrangement described in 5.5.2 (illuminance) or 5.6.2 (luminance). The radiation from this unpolarized source is then completely polarized by placing a polarizer (e.g. two sheet-polarizers placed back-to-back with their axes parallel) in front of the light source. The polarizer can be rotated around the direction of incidence in order to change the position of the plane of polarization. The maximum (Y_{max}) and minimum (Y_{min}) output signals of the photometer are measured while rotating the polarizer.

NOTE 1 The light from an incandescent filament source is generally polarized. Depolarization can be achieved by placing a glass plate, slightly tilted, in front of the light source. In order to achieve complete depolarization, the optimum position of the glass plate is determined with the aid of a polarization-independent detector, e.g. a windowless silicon planar photodiode perpendicular to the incident light, which is placed behind a polarization filter.

NOTE 2 To determine whether the polarizer is completely polarizing the transmitted light, a second polarizer (analyser) is used. After ascertaining complete polarization of the incident radiation and prior to making measurements of Y_{max} and Y_{min}, the second polarizer is removed.

5.13.3 Characterization

To characterize the polarization dependence, the index function $f_8(\varepsilon,\varphi)$ is given according to Equation (48):

$$f_8(\varepsilon,\varphi) = \frac{Y_{\text{max}}(\varepsilon,\varphi) - Y_{\text{min}}(\varepsilon,\varphi)}{Y_{\text{max}}(\varepsilon,\varphi) + Y_{\text{min}}(\varepsilon,\varphi)} \tag{48}$$

where

Y_{max} is the maximum output signal;

Y_{min} is the minimum output signal;

ε is the angle of incidence, measured from the optical axis

φ is the azimuth angle

To characterize the polarization dependence, the index f_8 is stated for a photometer head with measurement parameters depending on its application:

- Illuminance: $\varepsilon = 30°$, $\varphi = 0°$, and $\varepsilon = 30°$, $\varphi = 90°$, the mean value shall be reported.
- Spherical illuminance: $\varphi = 0°$.
- Cylindrical illuminance and semi-cylindrical illuminance: $\varepsilon = 60°$, $\varphi = 30°$, and $\varepsilon = 160°$, $\varphi = 150°$, the mean value shall be reported.
- Luminance: $\varepsilon = 0°$.

5.14 Spatial Non-Uniformity Response

5.14.1 General

The construction of some photometer heads can lead to their responsivity and relative spectral responsivity having a significant dependence on the position of the incident light within the acceptance aperture. This dependence disappears when the acceptance aperture is uniformly illuminated.

5.14.2 Measurement

For this measurement, a light source is arranged as described in 5.5.2 (illuminance meter) or 5.6.2 (luminance meter). A circular aperture, A, with 1/10 of the diameter of the acceptance aperture of the photometer, B, is placed in front of the acceptance aperture of the photometer. Stray light shall be prevented from falling on the acceptance aperture.

The circular aperture, A, is placed in each of five positions in front of the acceptance aperture of the photometer, B, as follows:

a) Position 1: centre of clear opening of aperture A in front of and centred on the photometer acceptance aperture B;

b) Positions 2 to 5: centre of clear opening of aperture A placed in front of and centred on a point which is 2/3 along the radius from the centre of the photometer acceptance aperture B. The four positions (2 to 5) are at 90° intervals around the centre of the entrance aperture.

5.14.3 Characterization

For characterizing the spatial responsivity on non-uniform illumination the index f_9 is used, defined as

$$f_9 = \frac{\sum_{i=2}^{5} |Y_i - Y_1|}{4\,Y_1} \tag{49}$$

where

Y_i is the output signal from the incident radiation X_i at each of the four points 2 to 5 in the plane of the acceptance aperture;

Y_1 is the output signal from the incident radiation X_1 at the centre of the acceptance aperture.

5.15 Range Change

5.15.1 General

The deviation arising from a change in the measurement range is the systematic deviation arising when the photometer is switched from one range to an adjacent range.

5.15.2 Measurement

For the measurement of the deviation arising from a range change, the illumination on the photometer head is adjusted to produce an initial reading of 90 % of full scale on the lower range A. The illumination is then increased by a factor k. This factor shall correspond to the factor for range change.

When changing the illumination, the range is changed from A to the next higher range B. The reading on the next higher range B is recorded.

NOTE 1 For photometers with digital displays, a range change is usually made in the ratio 1:10. Then $k = 10$.

NOTE 2 For photometers with a linear input-output relationship (the linearity of the photometer), the signal can be simulated by an accurate current source while the photometer head is switched off.

5.15.3 Characterization

For characterizing the deviation arising from changing range, the index f_{11} is used.

$$f_{11} = \left| \frac{Y_B}{k \cdot Y_A} - 1 \right| \tag{50}$$

where

Y_A is the reading on range A, for an input quantity X_A which corresponds to 90 % of full scale (the maximum reading in the case of digital meters);

Y_B is the reading on the next higher range (range B) for an input quantity X_B, which is a factor k greater than the input quantity X_A;

k is the factor defined in 5.15.2;

The index f_{11} is determined for each range change. The deviations caused by range changes shall be listed.

5.16 Focusing Distance (luminance meter only)

5.16.1 General

Even when focused on a local luminance that is spatially and temporally constant, luminance meters can have a change in output signal with a change of object distance.

5.16.2 Measurement

In order to measure the influence due to a change in focusing distance, a luminance standard is used whose luminous surface is sufficiently larger than the measurement field or the field of view of the photometer head that the surrounding field does not have any effect on the measurement. The luminance standard is positioned at a short distance in front of the entrance aperture. The luminance of the luminance standard is set to a level that results in an output signal approximately 90 % of the full-scale reading in an arbitrary range. The output signals are measured by focusing the photometer head for the longest and then for the shortest focusing distance specified by the manufacturer.

5.16.3 Characterization

The influence due to a change in focusing distance is characterized by the index f_{12}:

$$f_{12} = \left| \frac{Y_1}{Y_2} - 1 \right| \tag{51}$$

where

Y_1 is the output signal, focused at the shortest distance;

Y_2 is the output signal, focused at the longest distance.

6 Acronyms

SI	International System of Units
IEC	International Electrotechnical Commission
ILAC	International Laboratory Accreditation Cooperation
ISO	International Organization for Standardization
GUM	Guide to the expression of uncertainty in measurement (ISO/IEC Guide 98-3:2008)
VIM	International Vocabulary of Metrology — Basic and General Concepts and Associated Terms (ISO/IEC Guide 99:2007)
CMC	Calibration and Measurement Capabilities
BIPM	Bureau International des Poids et Mesures

Annex A
(normative)

Sources and Filters Used for the Determination of the UV and IR Response

Table A.1 — Nominal spectral transmittance $\tau_{UV}(\lambda)$ of UV band pass filter

Wavelength λ / nm	$\tau_{UV}(\lambda)$	Wavelength λ / nm	$\tau_{UV}(\lambda)$
< 250	0	680	0,000 50
250	0,000 67	685	0,002 13
255	0,008 11	690	0,006 37
260	0,036 0	695	0,013 4
265	0,092 8	700	0,020 9
270	0,176	705	0,028 7
275	0,285	710	0,036 7
280	0,385	715	0,040 4
285	0,476	720	0,038 3
290	0,556	725	0,032 5
295	0,612	730	0,025 4
300	0,654	735	0,018 8
305	0,684	740	0,013 2
310	0,705	745	0,009 07
315	0,723	750	0,006 14
320	0,731	755	0,004 04
325	0,739	760	0,002 64
330	0,743	765	0,001 68
335	0,741	770	0,001 05
340	0,733	775	0,000 67
345	0,721	780	0,000 43
350	0,703	785	0,000 27
355	0,674	790	0,000 18
360	0,628	795	0,000 12
365	0,556	> 795	0
370	0,447		
375	0,303		
380	0,145		
385	0,039 7		
390	0,004 4		
395	0,000 14		
400 - 675	0		

NOTE The nominal spectral transmittance values are based on a 2,5 mm thick glass filter of type UG11 (Schott, Germany), U-340 (Hoya, Japan), or ZWB1 (SCOG, China).

If a filter with different spectral transmittance is used the influence shall be evaluated, but the results shall be corrected and reported as specified by the nominal values.

Table A.2 — Nominal relative spectral power distribution of UV-A lamp

Wavelength λ / nm	$S_{UV}(\lambda)$	Wavelength λ / nm	$S_{UV}(\lambda)$
< 335	0	375	0,840
335	0,000 2	380	0,499
340	0,001 9	385	0,210
345	0,013 0	390	0,062 1
350	0,062 1	395	0,013 0
355	0,209	400	0,001 9
360	0,499	405	0,000 2
365	0,840	$S_{UV}(\lambda) = 0$ above 405 nm, except for an emission at 545 nm. The ratio of the visible part (545 nm) to the extended UV part (≤ 405 nm) shall be 35 lx·(W·m^{-2})$^{-1}$	
370	1		

NOTE The nominal relative spectral distribution values are based on a UV-A fluorescent lamp of type OSRAM colour 78.

If a different spectral distribution is used the influence shall be evaluated, but the results shall be corrected and reported as specified by the nominal values.

Table A.3 — Nominal spectral transmittance $\tau_{IR}(\lambda)$ of IR filter

Wavelength λ / nm	$\tau_{IR}(\lambda)$	Wavelength λ / nm	$\tau_{IR}(\lambda)$
< 760	0	810	0,676
760	0,001 2	815	0,729
765	0,005 7	820	0,769
770	0,019 8	825	0,796
775	0,053 4	830	0,814
780	0,114	835	0,826
785	0,203	840	0,842
790	0,310	845	0,847
795	0,421	850	0,852
800	0,524	855	0,857
805	0,609	860 – 1 100	0,860

NOTE The nominal spectral transmittance values are based on a 3 mm thick filter of type RG780 (Schott, Germany).

If a filter with different spectral transmittance is used the influence shall be evaluated, but the results shall be corrected and reported as specified by the nominal values.

Annex B
(informative)

General Comments

B.1 General

All the photometers covered by this Standard are designed to measure light evaluated in terms of the photopic function, $V(\lambda)$. It is important to note that there are situations where this function is not an appropriate measure for evaluation of the visual perception of a given lit environment, e.g. for measurements in the mesopic or scotopic regimes. The Standard defines quality indices characterizing the performance of photometers in general lighting measurement situations.

Examples of non-general lighting measurement situations are:

- photometry of spectrally narrow light sources (e.g. coloured LEDs, displays, lasers),
- photometry of sources radiating mainly outside the visible spectral range,
- special geometrical lighting conditions (e.g. highly non-uniform illuminance distributions, grazing incidences, high luminance contrasts),
- fast time varying effects (e.g. above upper frequency limit, ν_{u}, or small duty cycles),
- extreme environmental conditions.

In these cases special considerations shall be applied. Some guidelines are given in the following clause.

B.2 Quality Indices

B.2.1 $V(\lambda)$ Mismatch f_1'

This index describes how well the relative spectral responsivity of the photometer matches the $V(\lambda)$ function. As photometers are calibrated using CIE Source A, an incandescent tungsten filament lamp with a distribution (colour) temperature of $T_{\mathrm{A}} = 2\,856\ \mathrm{K}$, taking readings with light from all typical incandescent lamps (relative spectral distribution similar to CIE Source A) is likely to be reasonably accurate even if the $V(\lambda)$ match index has a large value. However, when measuring light from other sources this index is no longer appropriate. If the spectral distribution of the light and the spectral response of the photometer are known then it is possible to calculate a correction factor for the photometer readings.

B.2.2 UV Response f_{UV}

This index indicates the sensitivity of the instrument to UV radiation. While this may not be important when working in an environment where there is no UV radiation, it is critical when making measurements where UV is present: for example in daylight and under certain discharge lamps.

B.2.3 IR Response f_{IR}

This index indicates the sensitivity of the instrument to IR radiation. While this may not be important when working in an environment where there is no IR radiation, it is critical when making measurements where IR is present: for example under incandescent lamps.

B.2.4 Cosine Response f_2 (illuminance meter only)

It is the cosine response of the photometer that determines the accuracy of the measurement results for light that arrives at angles other than the normal to the photometer head. This index is particularly important when measuring real lighting installations such as office lighting and street lighting but is not important for meters used on optical benches in laboratories. It is important for photometers operated in integrating spheres.

B.2.5 Directional Response $f_{2,g}$ and Surround Field $f_{2,u}$ (luminance meter only)

These two indices characterize accuracy of the photometer when the luminance in the field of measurement is not constant and when the surrounding area is of different luminance. These indices are not important when the photometer is used for measuring small parts of uniform areas of luminance, but very important when measuring scenes with high contrast and arbitrary luminance of the surrounding field.

B.2.6 Linearity f_3

The linearity index is associated with errors in readings due to variations in the responsivity of the photometer to different light levels. Linearity is important for all light measurement applications.

B.2.7 Display-Unit f_4

This index is related to the possible error due to the reading resolution associated with the display-unit in the photometer. This index is important in all light measurement applications. However, if the photometer has an analogue output and that is connected to another electronic meter, then it is the quality of the other unit that is being used to log or display the reading that is important.

B.2.8 Fatigue f_5

This index characterizes the performance of a photometer after long exposure to light. This index is important if the meter is to be used to measure light continuously. However, if the meter is only used for a few seconds at a time then it is not so important to have a low value for this index.

NOTE Exposure of a photometer to a high illuminance may cause the photometer temperature to rise, see B.2.9 below.

B.2.9 Temperature Dependence $f_{6,T}$

Photometers are calibrated at 25 °C. If they are operated at other temperatures it is possible that the accuracy of the readings is reduced. The temperature dependence index indicates the magnitude of the potential measurement error due to change in the response of the photometer with changing temperature. If a photometer is to be used in a laboratory at a temperature close to 25 °C then this index is not particularly important. If it is known that a photometer is going to be used at a particular temperature it may be possible to re-calibrate the photometer at that temperature. Some photometers have built in temperature control that can maintain a fixed internal temperature for specified parts of the instrument for a range of ambient temperatures and thus reduce the temperature dependence.

B.2.10 Humidity Resistance $f_{6,H}$

The photometer shall resist humidity within a certain range. The humidity resistance test index evaluates the humidity resistance.

B.2.11 Modulated Light f_7

When photometers are measuring illuminance or luminance that is modulated, the reading given shall reflect the average value. This index reflects how well the meter averages out the varying light level. When measuring light that is not modulated such as daylight or light from DC lamps, this index is not important. However this parameter can be very important when measuring the light from pulsed or modulated light sources such as pulsed LEDs and some discharge lamps.

B.2.12 Polarization f_8

Specular reflections and certain luminaries may cause light to be polarized. When polarized light is present it is important for photometers to have a low value for this index.

B.2.13 Spatial Non-Uniformity Response f_9

In a general lighting situation it is presumed that the illumination is uniform over the sensitive area of the photometer. In some cases (for example illuminance measurement of a LED at short distance) the illuminance distribution may vary significantly and the photometer will measure an averaged illuminance distribution. In addition, depending on the construction of the photometer, the spectral responsivity may change significantly over the sensitive area of the photometer and deviate from the measured spectral irradiance or radiance responsivity function. When making measurements where the distribution of light is not uniform over the sensitive area of the photometer it is important to have a low value for this index.

B.2.14 Range Change f_{11}

This parameter relates to the errors that may be introduced when the range is changed on the instrument. This is important in all cases where different ranges are used, or if the calibration has been performed on a range that it different from that used during measurements.

B.2.15 Focusing Distance f_{12} (luminance meter only)

This parameter relates to the errors that may be introduced when the focus of a luminance meter is changed and thus it is important in all cases.

NOTE It is always necessary to focus a luminance meter before measurements are made, even if the value for f_{12} is low, as other errors may be introduced. A low value for f_{12} is particularly important when measuring scenes where a large depth of field is required, for example measuring luminance at grazing incidence at short range.

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