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**METHODS OF CHARACTERIZING
ILLUMINANCE METERS
AND LUMINANCE METERS**

Performance, characteristics and specifications

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Chairmen:	Nielsen, O.	Denmark
	Dezsi, G.	Hungary
Members:	Krochmann, J.	Germany, Fed. Rep.
	Rattunde, R.	Germany, Fed. Rep.
	Betts, D.B.	Great Britain
	Garforth, F.A.	Great Britain
	Hengstberger, F.	South Africa
	Ottoson, A.	Sweden
	Rennilson, J.J.	USA

Editorial Committee:

Chairman:	Hengstberger, F.	South Africa
	Key, P.J.	Great Britain
	Billmeyer, F.	USA
	Zalewski, E.F.	USA

CONTENTS

0	INTRODUCTION	1
1	DEFINITIONS	1
1.1	MEASUREMENT TERMS	1
1.1.1	E Illuminance E	1
1.1.2	E Spherical illuminance E_0	1
1.1.3	E Cylindrical illuminance E_z	2
1.1.4	E Semi-cylindrical illuminance E_{zh}	2
1.1.5	L Luminance	4
1.1.6	L Equivalent veiling luminance	4
1.2	INSTRUMENT TERMS	4
1.2.1	Photometer	4
1.2.1.1	E Definition	4
1.2.1.2	L Definition	5
1.2.2	Photometer head	5
1.2.3	Acceptance area	5
1.2.4	L Measurement field, measurement field angle	6
1.2.5	L Field of view, angular field of view	6
1.2.6	L Fifty percent, ten percent and one percent measurement angles	6
1.2.7	Measurement range and display range	6
2	CALIBRATION	
2.1	L UTILIZATION OF LUMINANCE STANDARD	7
2.1.1	L Use of white standards	7
2.1.2	L Use of highly diffuse, transmitting materials	8
2.1.3	L Use of other sources for calibration	8
2.1.4	L Built-in reference source	8
2.2	PHOTOMETRIC STANDARDS	8
2.3	LABORATORY ERRORS	9
2.4	CALIBRATION CONDITIONS	9
3	PROPERTIES OF PHOTOMETER HEADS FOR WHICH A NUMERICAL ASSESSMENT IS RECOMMENDED	9
3.1	DEVIATION OF RELATIVE SPECTRAL RESPONSIVITY FROM THE $V(\lambda)$ FUNCTION	9
3.2	UV RESPONSE	10
3.2.1	Definition	10
3.2.2	Measurement	10
3.2.3	Characterization	11

3.3	IR RESPONSE	11
3.3.1	Definition	11
3.3.2	Measurement	11
3.3.3	Characterization	12
3.4	DIRECTIONAL RESPONSE	12
3.4.1 E	Directional response for the measurement of illuminance	12
3.4.1.1 E	Description	12
3.4.1.2 E	Measurement	12
3.4.1.3 E	Illuminance E	12
3.4.1.4 E	Spherical illuminance E_0	13
3.4.1.5 E	Cylindrical illuminance E_z	13
3.4.1.6 E	Semi-cylindrical illuminance E_{zh}	14
3.4.2 L	Directional response for the measurement of luminance	14
3.4.2.1 L	Description	14
3.4.2.2 L	Measurement of directional response	14
3.4.2.3 L	Characterization	15
3.4.2.4 L	Measurement of the effect of the surrounding field	16
3.5	POLARIZATION DEPENDENCE	17
3.5.1	Description	17
3.5.2	Measurement	17
3.5.3	Characterization	18
3.6	EFFECT OF NONUNIFORM ILLUMINATION OF THE ACCEPTANCE AREA OF A PHOTOMETER HEAD	18
3.6.1	Description	18
3.6.2	Measurement	18
3.6.3	Characterization	18
3.7 L	ERRORS DUE TO A CHANGE IN FOCUSING DISTANCE	19
3.7.1 L	Description	19
3.7.2 L	Measurement	19
3.7.3 L	Characterization	19
3.8	FURTHER PROPERTIES	19
3.8.1	Dark signal	19
3.8.2	Linearity	20
3.8.3	Fatigue	20
3.8.4	Temperature dependence	20
4	PROPERTIES OF PHOTOMETERS FOR WHICH A NUMERICAL ASSESSMENT IS RECOMMENDED	20
4.1	LINEARITY OF THE DETECTOR	20
4.1.1	Definition	20
4.1.2	Measurement	20
4.1.3	Characterization	20
4.2	CHARACTERIZATION PARAMETER OF THE DISPLAY UNIT	21

4.3	FATIGUE	21
4.3.1	Definition	21
4.3.2	Measurement	22
4.3.3	Characterization	22
4.4	TEMPERATURE DEPENDENCE	22
4.4.1	Description	22
4.4.2	Measurement	22
4.4.3	Characterization	23
4.5	EVALUATION OF MODULATED LIGHT	23
4.5.1	Description	23
4.5.2	Lower and upper frequency limits	23
4.5.2.1	Definition	23
4.5.2.2	Measurement	24
4.5.2.3	Characterization	24
4.5.3	Peak overload capability	24
4.5.3.1	Definition	24
4.5.3.2	Measurement	24
4.5.3.3	Characterization	26
4.5.4	Settling time	26
4.5.4.1	Definition	26
4.5.4.2	Characterization	26
4.6	ERRORS ARISING FROM RANGE CHANGE	27
4.6.1	Definition	27
4.6.2	Measurement	27
4.6.3	Characterization	27
4.7	WARMUP PERIOD	28
4.8	INFLUENCE OF THE SUPPLY VOLTAGE	28
5	PROPERTIES OF PHOTOMETERS FOR WHICH A NUMERICAL ASSESSMENT CANNOT YET BE RECOMMENDED	28
5.1	AGEING	28
5.2	ZERO-SETTING DRIFT	28
5.3	MECHANICAL DURABILITY	28
5.4	CLIMATIC DURABILITY	28
5.5	INFLUENCE OF EXTERNAL MAGNETIC FIELDS	29
5.6	CALIBRATION ADJUSTMENT	29
6	FURTHER CONSIDERATIONS FOR ASSESSING PHOTOMETERS	29

7	FEASIBILITY OF CORRECTING THE MEASUREMENT RESULTS	29
7.1	ERRORS CAUSED BY IMPERFECT $V(\lambda)$ MATCHING	29
7.2	LINEARITY ERROR AND ERROR OF THE OUTPUT APPARATUS	30
7.3	ERROR DUE TO AMBIENT TEMPERATURE	30
7.4	FATIGUE ERROR	31
7.5	ERROR CAUSED BY RANGE CHANGE	31
8	INFORMATION ON DATA SHEETS FOR PHOTOMETERS	31
9	ASSESSMENT OF PHOTOMETERS	32
Table 1	Summary of parameters for individual characteristics and representative values (1983) for best available commercial illuminance meters	33
Table 2	Summary of parameters for individual characteristics and representative values (1983) for best available commercial luminance meters	33
10	STANDARDS FOR CALIBRATION	34
10.1	STANDARD SOURCES OF ILLUMINANCE	34
10.2	STANDARD SOURCES OF LUMINANCE	34
11	REFERENCES	35
11.1	REFERENCES CITED	35
11.2	OTHER REFERENCES	36

Summary

This technical report defines the properties of photometers and photometer heads for the measurement of illuminance and luminance. Methods of calibration are given and several sources of errors are described. Several properties determining the performance of photometers can be characterized by numerical values. There are some properties, however, which it has not been found possible to quantify.

The report is intended to serve as a guide for anyone wishing to do light measurements and for those who want to judge the quality of instruments. It is not intended for the casual buyer and user of such instruments.

**Méthodes de caractérisation des luxmètres et luminancemètres
Exécution, caractéristiques et attributs**

Résumé

Le present rapport définit les propriétés des photomètres et des têtes de mesure photométriques pour la mesure d'éclairement et de luminance lumineuse. Quelques méthodes d'étalonnage sont données et les sources d'erreur sont indiquées. Les propriétés déterminant les performances des photomètres peuvent être représentées par des valeurs numériques. Pour les autres propriétés, une valeur numérique ne peut être déterminée.

Ce rapport a pour but de servir de guide à ceux qui désirent faire des mesures de lumière ainsi qu'à ceux qui désirent apprécier la qualité des instruments. Il n'est pas destiné à l'usage de l'acheteur ou utilisateur occasionnel de telles instruments.

Methoden zur Charakterisierung von Beleuchtungsstärkemessern und Leuchtdichtemessern - Ausführung, Eigenschaften und Merkmale

Zusammenfassung

Dieser technische Bericht definiert die Eigenschaften von Photometern und Photometerköpfen für die Messung von Beleuchtungsstärke und Leuchtdichte. Einige Kalibriermethoden werden gegeben und Fehlerquellen werden genannt. Einige Eigenschaften, die die Güte eines Photometers bestimmen, lassen sich durch Masszahlen charakterisieren, während andere sich noch nicht mittels Masszahlen beschreiben lassen.

Der Bericht soll als Hilfe für alle dienen, die Lichtmessungen durchführen und für diejenigen, die die Qualität von Messgeräten beurteilen möchten. Er ist nicht geeignet für gelegentliche Käufer oder Benutzer solcher Geräte.

0 INTRODUCTION

The purpose of this report is to give an objective means for evaluating the properties of illuminance and luminance meters that are under consideration for a given application.

The factors that constitute the evaluation may also serve as a guide to manufacturers in developing improved photometric instruments.

The report is therefore divided into sections dealing with the optical properties of photometer heads and other sections dealing with signal processing in the associated measuring apparatus. Some practical methods for calibration are given and possible calibration errors are mentioned.

Methods for assessing individual errors are presented and a list of estimated state-of-the-art performance parameters is appended. The terminology presented is taken mainly from CIE publication No. 53 (1982)¹ "Methods of characterizing the performance of radiometers and photometers." In some cases, definitions are taken from existing literature.

Where the photometer head is used separately for one type of quantity, a letter, E or L, designates the specific section for illuminance and luminance measurements respectively.

1 DEFINITIONS

1.1 MEASUREMENT TERMS

1.1.1 E Illuminance E^2

The illuminance E at a point of an area is the quotient of the luminous flux $d\phi$ received by an area element dA containing that point and the area of that element.

$$E = \frac{d\phi}{dA} \quad (1)$$

Note: The illuminance E follows from the luminance distribution in the lit hemisphere as

$$E = \int_{(2\pi \text{ sr})} L \, d\Omega \cos \epsilon \quad (2)$$

L Luminance in the direction of $d\Omega$

ϵ Angle of incidence (see fig. 1)

1.1.2 E Spherical illuminance E_0^3

The spherical illuminance E_0 is the integral of the luminance over the full solid angle $4\pi \text{ sr}$.

$$E_0 = \int_{(4\pi \text{ sr})} L \, d\Omega \quad (3)$$

L Luminance in the direction of $d\Omega$

$d\Omega$ Element of solid angle

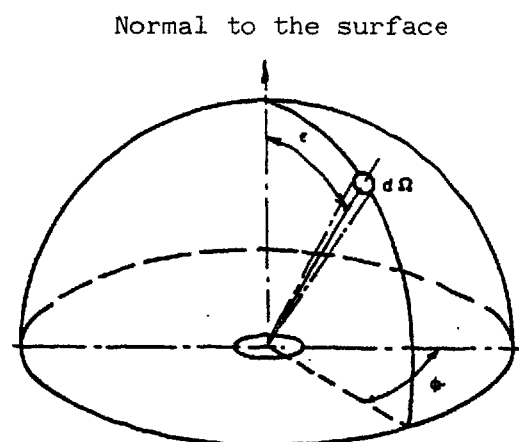


Fig. 1: Coordinates for defining illuminance and spherical illuminance. The direction for $\phi=0$ should be specified if necessary.

Note: The spherical illuminance E_0 is four times the quotient of the luminous flux Φ on the outside of a small imaginary sphere around the point and the surface area A_K of the sphere.

$$E_0 = \frac{4 \Phi}{A_K} \quad (4)$$

1.1.3 E Cylindrical illuminance E_z ^{3,4}

The cylindrical illuminance E_z is the arithmetic mean of the vertical illuminance E_v at a point

$$E_z = \frac{1}{\pi} \int_{(4\pi \text{sr})} L d\Omega \sin \epsilon = \frac{1}{2\pi} \int_0^{2\pi} E_v d\phi \quad (5)$$

L Luminance in the direction of $d\Omega$

$d\Omega$ Element of solid angle

ϵ Angle of incidence, measured with respect to the optical axis (see fig. 2)

E_v Vertical illuminance for an area element with its normal in the direction $d\phi$

ϕ Angle in the plane perpendicular to the optical axis (see fig. 2)

1.1.4 E Semi-cylindrical illuminance E_{zh} ^{4,5}

The semi-cylindrical illuminance E_{zh} is the arithmetic mean E_v of the vertical illuminance at a point in the range of azimuth angles $-\pi/2 \leq \phi \leq \pi/2$ (see fig. 3)

$$E_{zh} = \frac{1}{\pi} \int_{-\pi/2}^{\pi/2} E_v d\phi \quad (6)$$

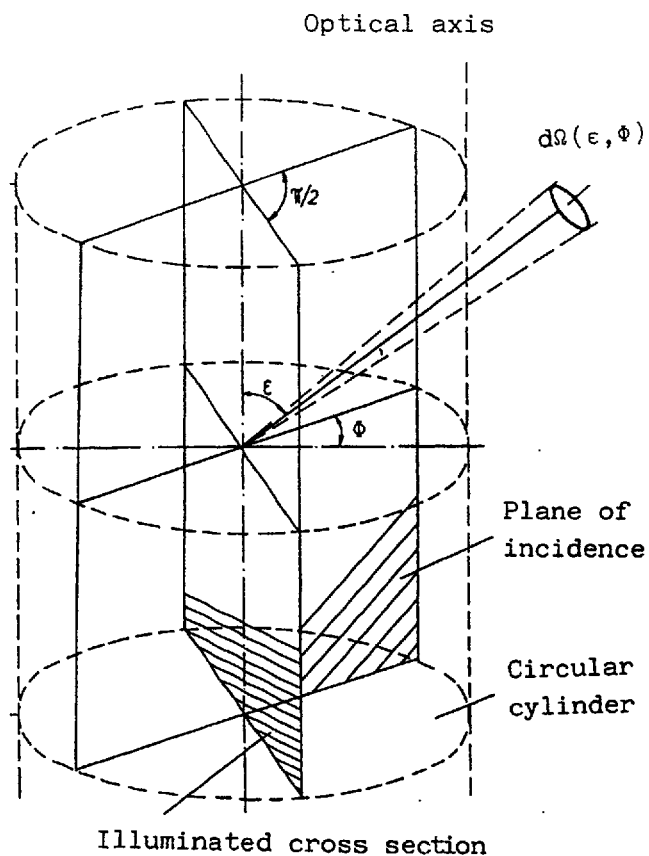


Fig. 2: Co-ordinates for the definition of cylindrical illuminance.
The direction for $\phi = 0$ should be stated if necessary.

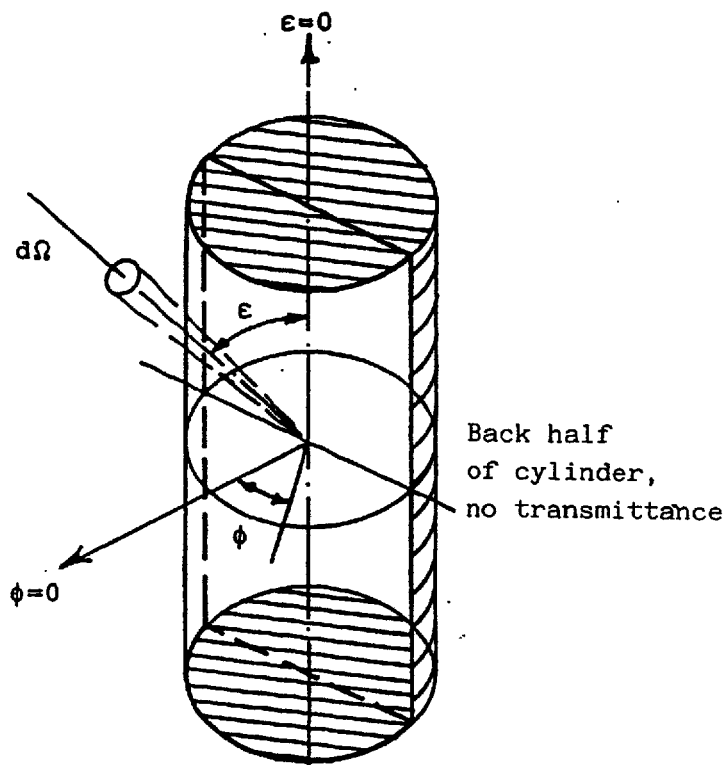


Fig. 3: Coordinates for defining semi-cylindrical illuminance.

1.1.5 L Luminance²

(in a given direction, at a point on the surface of a source or a detector, or at a point in the path of a beam)

Quotient of the luminous flux leaving, arriving at, or passing through an element of surface at this point and propagated in directions defined by an elementary cone containing the given direction, by the product of the solid angle of the cone and the area of the orthogonal projection of the element of surface on a plane perpendicular to the given direction.

$$L = \frac{d^2\phi}{d\Omega dA \cos \epsilon}, \text{ unit: cd m}^{-2} \quad (7)$$

ϵ Angle of radiation, measured with respect to the surface normal

1.1.6 L Equivalent veiling luminance⁶

The equivalent veiling luminance is the luminance, which, when added to the luminance of the surroundings, renders the same observed contrast-reduction as that made by stray light in the eye. For a point light source and $\theta > 2^\circ$, the equivalent veiling luminance [cd m^{-2}] is calculated by:

$$L_s = K E_{gl} \theta^{-2} \quad (8)$$

E_{gl} Illuminance (lx) at the eye perpendicular to line of sight caused by the source of glare.

θ Glare angle (in degrees) measured with respect to the line of sight.

K Factor, increasing with age. For young people the value is 10. Dimension: $\text{degree}^2 \text{ sr}^{-1}$.

Note: For a hemisphere with a luminance distribution $L(\theta, \beta)$ the equivalent veiling luminance L_s is:

$$L_s = \frac{K}{2} \int \int L(\theta, \beta) \theta^{-2} \sin 2\theta d\theta d\beta \quad (9)$$

θ Glare angle, measured with respect to the direction of sight (optical axis)

β Angle in the plane perpendicular to $\theta=0$.

1.2 INSTRUMENT TERMS**1.2.1 Photometer¹**

A photometer is an instrument for the measurement of photometric quantities. Photometric quantities can be derived from radiometric quantities by means of certain conventions (law of additivity, $V(\lambda)$ function, definition of the unit of luminous intensity). The measuring instrument displays the measured value. The reading can be either digital or analog.

1.2.1.1 E Definition

Illuminance meters usually consist of a built-in or detachable photometer head (with cable link), a transducer and the display unit. Power supplies can be part of an illuminance meter even if they are separate. Illuminance meters that are suitable for the measurement of the relevant quantities by means of attachable or built-in accessories are referred to as

- Instrument for the measurement of illuminance (E meter)
- Instrument for the measurement of spherical illuminance (E_o meter)
- Instrument for the measurement of cylindrical illuminance (E_z meter)
- Instrument for the measurement of semi-cylindrical illuminance (E_{zh} meter)

1.2.1.2 L Definition

A luminance meter is a photometer for the measurement of luminance.

Luminance meters usually consist of a built-in or detachable photometer head (with cable link), a converter and display unit. Power supplies can be part of a luminance meter or separate.

1.2.2 Photometer head¹

A photometer head consists of a light-sensitive detector and facilities for the spectral weighting (e.g., colour filters) or for the spectral dispersion (e.g., gratings) of the light. It may also contain facilities for directional evaluation of the light, e.g., diffusing windows, lenses, apertures. The light-sensitive detector converts the incident light into an electrical quantity.

The photometer head of a luminance meter has either a variable-focus or a fixed-focus optical system in front of the detector. Whereas simple instruments have only a tube in front of the detector, photometer heads with variable focus normally have an optical viewing arrangement for visual orientation of the measurement field. By the use of additional lenses the range of focus can be increased or the spatial evaluation function changed (to facilitate the measurement of equivalent veiling luminance, for example).

1.2.3 Acceptance area⁷

The acceptance area is the area of the photometer head which is receiving and directionally evaluating the incident light (fig.4).

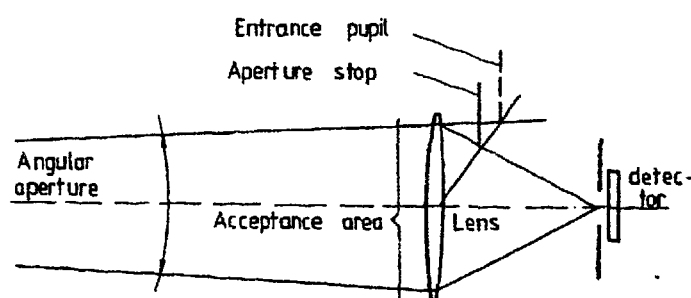


Fig. 4: Diagram illustrating the definition of the acceptance area.

Note: The acceptance area of a luminance meter is the area of the lens which contributes to the response of the instrument. Strictly speaking, the acceptance area is the image of the limiting aperture stop called the entrance pupil that limits the cone of rays entering the system.

1.2.4 L Measurement field, measurement field angle⁷

The measurement field is the sum total of all points in object space, radiating toward the acceptance area, collected by the detector, and evaluated with a directionally dependent responsivity of at least 10% of the maximum responsivity (fig.5).

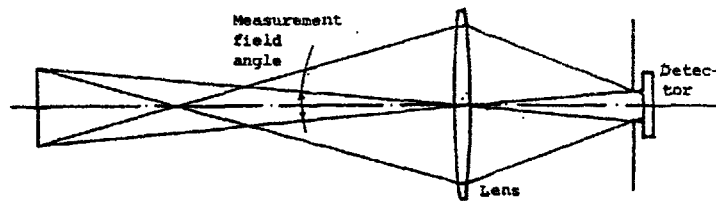


Fig. 5: Diagram showing characteristic ray tracing in a luminance meter.

Note 1: The measurement field is generally circular. It can, however, have other shapes (i.e., trapezoidal, square or quadrilateral) or be completely variable. The measurement field angle is the angle subtended by the infinitely distant measurement field at the entrance pupil.

Note 2: The measurement field of circularly limited fields is defined only by the measurement field angle. Differently shaped measurement fields can have the field angle expressed in various ways comprising various planes on the optical axis of the photometer head.

Note 3: The measurement field angle corresponds to the ten percent measurement angle. (See section 1.2.6).

1.2.5 L Field of view, angular field of view⁷

The field of view is the sum total of all points in object space visible through the eyepiece of the photometer head. The angular field of view is the angle subtended by the field of view at the entrance pupil.

1.2.6 L Fifty percent, ten percent and one percent measurement angles

The fifty percent, ten percent or one percent measurement angle ($\epsilon_{1/2}$, $\epsilon_{1/10}$ and $\epsilon_{1/100}$ respectively) of a photometer head (luminance meter), measured in a plane through the optical axis, is the angle within which the response of the photometer is equal to or greater than one-half, one-tenth or one-hundredth of the response to incident light in the direction of the optical axis.

Note: Use of the fifty percent measurement angle can lead to errors in resolution of the luminance of two closely spaced objects.

1.2.7 Measurement range and display range

The display range is the range of all values of the measured quantity that can be read on a measuring instrument.

The measurement range is that range of values of the measured quantity in which defined, agreed or guaranteed error limits are not exceeded. For measuring instruments with a number of display ranges, different error