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THE MEASUREMENT OF ABSOLUTE LUMINOUS INTENSITY DISTRIBUTIONS

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CONTENTS

SUMMARY

This technical report contains the terminology required for measurements of luminous intensity distributions. It also summarizes the principles of luminous intensity measurements and the requirements for the photometer heads employed for such measurements. The coordinate systems used for the measurement and representation of luminous intensity distributions are described. The types of goniophotometers, possibilities for angle encoding, characteristics of the photo-electronic system and the acquisition and processing of the data in measurements of luminous intensity distributions are discussed in detail. Other subjects covered are the power supply, the measuring conditions and the execution, correction and representation of luminous intensity distribution measurements. The various sections contain sufficient data on the required characterization of goniophotometers.

The report is based mainly on the Technical Report of CIE Technical Committee TC-2.2 on "Methods of characterizing the performance of radiometers and photometers [1] as well as on CIE publications 24 [2], 27 [3] and 43 [4]. The terminology is largely based on the International Lighting Vocabulary [5].

RESUME

LA MESURE DES DISTRIBUTIONS D'INTENSITE LUMINEUSE ABSOLUE

Ce rapport technique contient la terminologie nécessaire pour la mesure des distributions d'intensité lumineuse. Il résume aussi les principes de mesure de l'intensité lumineuse et les qualités requises pour la tête photométrique utilisée pour de telles mesures. Les systémes de coordonnées utilisés pour la mesure et la représentation des distributions d'intensité lumineuse sont décrits. Les types de goniophotomètre, les possibilités de repérage angulaire, les caractéristiques du système électronique et celles de l'acquisition et du traitement des données dans les measures de distri bution de l'intensité lumineuse sont décrites en détail. Les autres sujets traités sont l'alimentation électrique, les conditions de mesures et leur éxécution, la correction et la représentation des mesures de distribution d'intensité lumineuse. Les différentes sections contienent des données suffisantes sur les caractéristiques requises pour les goniophotomètres.

Ce rapport s'appuye principalement sur le rapport technique du comité technique 2.2 de la CIE "Methods of characterizing the performance of radiometers and photometers" [1] ainsi que sur les publications CIE no 24 [2], 27 [3], et 43 [4]. La terminologie est largement empruntée au Vocabulaire International de l'Eclairage [5].

ZUSAMMENFASSUNG

DIE MESSUNG DER ABSOLUTEN LICHTSTÄRKEVERTEILUNG

Dieser Technische Bericht enthält zunächst die für Lichtstärkemessungen wichtigen Begriffsbestimmungen. Danach werden die Prinzipien der Lichtstärkemessung und Angaben über die dementsprechend zu verwendenden Photometerköpfe zusammengestellt. Die für die Messung und Darstellung der Lichtstärkeverteilung verwendeten Ebenensysteme werden angegeben. Besonders werden die Arten von Goniophotometern, die Möglichkeiten der Winkelerfassung, Aussagen über die Photoelektronik und die Registrierung und Datenverarbeitung bei der Messung der Lichtstärkeverteilung behandelt. Auch Aussagen zur Spannungsversorgung, zu den Meßbedingungen und zur Durchführung, Korrektur und Darstellung der Lichtstärkemessungen werden gemacht. Bei den einzelnen Kapiteln werden ausreichende Angaben über die notwendige Kennzeichnung von Goniophotometern aufgeführt.

Dieser Bericht stützt sich vor allem auf den Technischen Bericht des CIE Technischen Komitees TC-2.2 "Methods of characterizing the performance of radiometers and photometers" [1] sowie auf die CIE-Publicationen No. 24 [2], No. 27 [3], und No. 43 [4]. Bei den Begriffsbestimmungen sind die Angaben des Internationalen Wörterbuchs der Lichttechnik [5] weitgehend zugrunde gelegt.

1. TERMINOLOGY

1.1 QUANTITIES [5]

1.1.1 LUMINOUS INTENSITY

The luminous intensity I (of a source in a given direction) is the quotient of the luminous flux $d\phi$ leaving the source, propagated in an element of solid angle containing the given direction, by the element of solid angle $d\Omega$.

$$I = d\phi/d\Omega \qquad (1)$$

Symbol: I, I_v
Unit : Candela (symbol: cd)

1.1.2 ILLUMINANCE

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

$$E = d\phi/dA \qquad (2)$$

Symbol: E, E_v
Unit : Lux (symbol: lx)

1.1.3 LUMINANCE

The luminance L (in a given direction, at a point on the surface of a source or a receptor, or at a point in the path of a beam) is the quotient of the luminous flux, $d^2\phi$, leaving, arriving at, or passing through an element of surface dA at this point and propagated in directions defined by an elementary cone $d\Omega$ 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.

$$L = \frac{d^2\phi}{d\Omega \cdot dA \cdot \cos\varepsilon} \qquad (3)$$

ε Angle between the normal to the area and the direction considered
Symbol: L, L_v
Unit : Candela per square meter (symbol: $cd \cdot m^{-2}$)

1.2 SURFACE OF LUMINOUS INTENSITY DISTRIBUTION

The surface of luminous intensity distribution is the surface formed by the extremities of all the radius vectors drawn from a common origin, the length of each radius vector being proportional to the luminous intensity of the source in the corresponding direction.

1.3 LUMINOUS INTENSITY DISTRIBUTION CURVE

The luminous intensity distribution curve (for a lamp or light fitting) is the curve, generally polar, which represents the luminous intensity in a plane passing through the source, as a function of the angle measured from some given direction.

Note:

a) When the source has a symmetrical luminous intensity distribution, the plane is generally a meridian plane.
b) When the reference direction is vertical, angles are measured from the downward vertical.

1.4 ISOCANDELA DIAGRAM

The isocandela diagram is the array of isocandela curves. These are curves traced on an imaginary sphere with the source at its centre and joining all the points corresponding to those directions in which the luminous intensity is the same, or a plane projection of this curve.

1.5 MEASURING FIELD AND MEASURING-FIELD ANGLE IN LUMINANCE MEASUREMENTS[6]

The measuring field of a luminance meter is the totality of all points in the external space that radiate into the acceptance area and are sensed by the detector and evaluated by it with a direction-dependent responsivity of at least 10% of the maximum responsivity.

Note:

The measuring field is usually circular. Other fixed or variable shapes are also possible, however (e.g., trapezoidal, rectangular, quadratic).

The measuring-field angle α is the angle under which the measuring field appears when viewed from the measuring plane.

1.6 TERMS FOR MEASURING INSTRUMENTS

1.6.1 PHOTOMETER

A photometer is an instrument for the measurement of photometric quantities.

Note:

Photometric quantities are quantities that can be derived from radiometric quantities by means of certain conventions (law of additivity, V(λ) function, definition of the unit of luminous intensity) [7].

1.6.2 GONIOPHOTOMETER

A goniophotometer is a photometer for the measurement of the angular dependence of a photometric quantity.

Note:

A goniophotometer for the measurement of the spatial luminous intensity distribution is also called a luminous intensity distribution photometer.

A goniophotometer for the measurement of the spatial luminous intensity distribution usually consists of a mechanical device for the support and positioning of the light source and the photometer head and one (or more) - often moveable - photometer heads together with the necessary transducers and readouts as well as devices for acquiring and processing data.

1.6.3 PHOTOMETER HEAD

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

1.6.4 ACCEPTANCE AREA

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

1.7 PHOTOMETRIC CENTRE (OF A LAMP OR LUMINAIRE)

The photometric centre of a lamp or luminaire is the reference point from which the photometric distance law is applicable (see section 2.1). For lamps the photometric centre corresponds to the centre of gravity of the light-emitting area. For lamps with reflectors the photometric centre is situated at the centre of the exit aperture. For luminaires data about the photometric centre are contained in the Technical Report "Photometry of Luminaires" [8].

Note:

For the measurement of the luminous intensity distribution the photometric centre of the light source should lie on the crosspoint of the axes of the goniophotometer.

1.8 STRAY LIGHT

Stray light is the part of the luminous flux incident on and evaluated by the photometer head that does not reach the measuring area of the photometer head in a direct line from the light source.

1.9 LIMITING PHOTOMETRIC DISTANCE

The limiting photometric distance is the allowed minimum distance between light source and photometer head, for which the measuring error is smaller than the permitted error.

2. PRINCIPLES OF LUMINOUS INTENSITY MEASUREMENTS

Luminous intensities can be measured via a measurement of the illuminance and calculation via the photometric distance law, or by integration of the luminance. Both possibilities follow from the basic law of photometry.

2.1 PHOTOMETRIC DISTANCE LAW

The photometric distance law allows one to determine the luminous intensity according to

$$I = E \cdot r^2 / (\cos \varepsilon_2 \cdot \Omega_0) \qquad (4)$$

I	Luminous intensity in the direction to the acceptance area
E	Illuminance on the acceptance area
r	Distance between light source and acceptance area
ε_2	Angle of incidence, measured relative to the normal to the acceptance area
Ω_0	1sr (unit solid angle)

The quantity Ω_0 is used in accordance with the fourth edition of the CIE vocabulary (in preparation), which permits its optional use. There is no complete agreement on the need to use Ω_0, which may equally well be omitted or replaced by the number 1.

The Equation (4) only applies for distances r that exceed the limiting photometric distance.

measuring error depends on:

- the largest dimension of the light source
- the spatial and directional luminance distribution of the light source
- the spatial and directional responsivity of the acceptance area of the photometer head.

Note 1:

For a circular emitting area with constant luminance (lambertian radiator) and a circular receiving area the limiting photometric distance r is taken as 10 times (5 times) the diameter of the larger of the two areas. In this case the error of I in the direction of the axis of the disk in the calculation according to the photometric distance law is less than 0,5 % (1 %).

Note 2:

For narrow luminous intensity distributions the limiting photometric distance is greater than for a Lambertian radiator [9,10].

Note 3:

When calculating the luminous intensity according to equation (4) it should be ascertained, if necessary by means of measurements at different distances, whether the limiting photometric distance is exceeded. For goniophotometers with stationary photometer heads for which the measuring distance is smaller than the limiting photometric distance, the measuring distance can be extended by the use of a sufficiently large deflecting mirror. The polarization of the light by the deflecting mirror as well as the spectral reflectance of the deflecting mirror must be taken into account.

Note 4:

When the luminous intensity is derived according to equation (4) it is important to limit the incidence of stray light on the photometer head by means of baffles between the light source and the photometer head.

All parts of the background of the light source that are visible from the measuring area of the photometer head should be as black as possible [11]. As large a distance as possible should be kept between the light source and the background (Fig. 1).

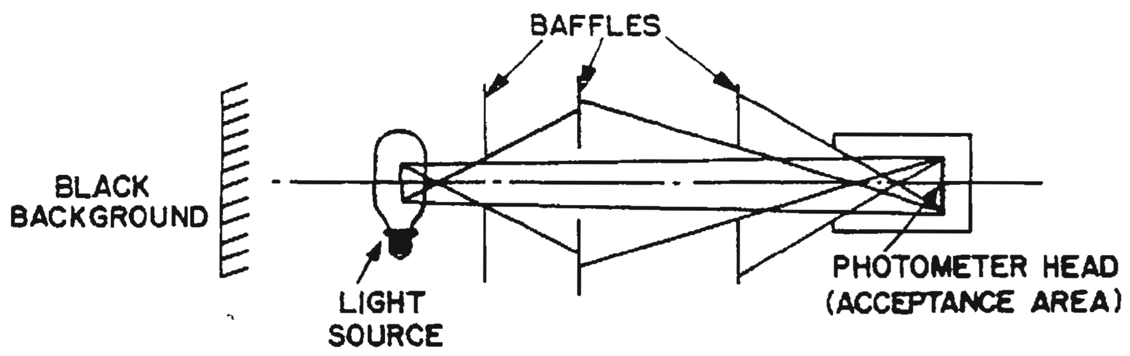

Fig. 1 Reduction of stray light in luminous intensity measurements

2.2 LUMINANCE INTEGRATION

Luminous intensity can be determined by means of luminance integration:

$$I = \int_{(A_1)} L(\varepsilon_1) \cdot dA_1 \cdot \cos\varepsilon_1 \qquad (5)$$

- A_1 emitting area
- dA_1 element of the emitting area
- $L(\varepsilon_1)$ luminance of the area element dA_1 in the direction in which the luminous intensity is to be determined
- ε_1 emitting angle of the area element dA_1 between its area normal and the direction for which the luminous intensity is to be determined.

3. TYPES OF PHOTOMETER HEADS

Depending on the theoretical relationship used for the determination of the luminous intensity (equation (4) or (5)), there are two types of photometer heads in use in goniophotometers.

3.1 PHOTOMETER HEAD FOR MEASURING ILLUMINANCE

For the determination of the luminous intensity according to equation (4) a photometer head for the measurement of illuminance must be employed. Such a photometer head must comply with the following requirements [1,6]:

- good fit of the relative spectral responsivity to the $V(\lambda)$ function (error f_1)
- linearity (error f_3)
- low fatigue (error f_5)
- independence from the ambient temperature (temperature coefficient α)
- as small a solid angle as possible for the acceptance area of the photometer head as seen from the photometric centre.

The terminology for the errors f_1 to f_5 and a classification of illuminance meters have been compiled by the CIE [6].

3.2 PHOTOMETER HEAD FOR LUMINANCE INTEGRATION

3.2.1 CONSTRUCTION

3.2.1.1 Photometer head with lens [12]

A photometer head for luminance integration by means of a lens consists of a lens with a diameter larger than the light source and a detector (including filter for $V(\lambda)$ correction) that is positioned behind a diaphragm at the focal point of the lens (also called the field stop) (Fig. 2). The measuring field angle α of such a photometer head is

$$\alpha = 2 \cdot \arctan (a/2f) \qquad (6)$$

f focal length of lens
a diameter of measuring-field stop

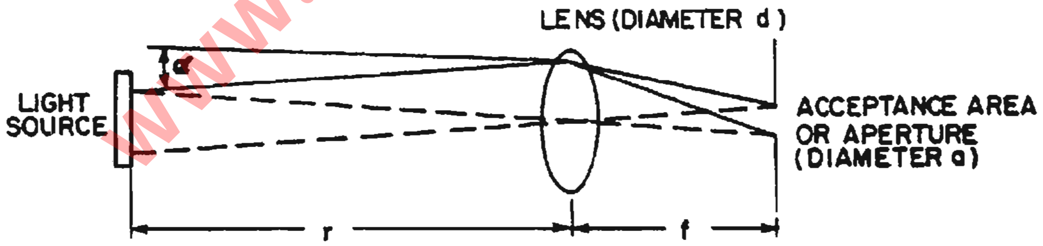

Fig. 2: Photometer head with lens for luminous intensity measurements by means of luminance integration

The largest diameter D of a light source that can be measured with a photometer head for luminance integration by means of a lens is given by

$$D = d - r \cdot a/f \qquad (7)$$

D largest permissible extent of the light source
d diameter of the lens
r distance between lens and light source

The measurements can be made at an arbitrary distance r between light source and lens as long as the condition according to equation (7) and conditions regarding the limiting photometric distance (limiting the ratio D/r to a maximum value) are satisfied (see also 3.2.3).

3.2.1.2 Photometer head with parallel oriented optics

Instead of a single lens it is also possible to use several lenses that are positioned immediately next to each other. By means of such an arrangement it is possible to measure light sources with larger emitting areas.

Note:

A photometer head with parallel oriented lenses can also be constructed in such a way that the lenses are merely positioned next to each other in a single line. This row of lenses can be moved or tilted in a plane normal to the measuring direction, and the luminance integration (summation) perpendicular to the row of lenses must be performed numerically [13].

3.2.1.3 Photometer head with tubes [14,15]

A photometer head for luminance integration can also be constructed by means of parallel tubes followed by a light collecting device and a photo-electric detector (with V(λ) response). Figure 3 shows such an arrangement, in which the light-collecting device is realized by means of a spherical device located behind the tubes and with an effect similar to an integrating sphere. The detector can be located at the side of the spherical device. A spatially constant evaluation of the luminance can be achieved by means of apertures in front of the detector.

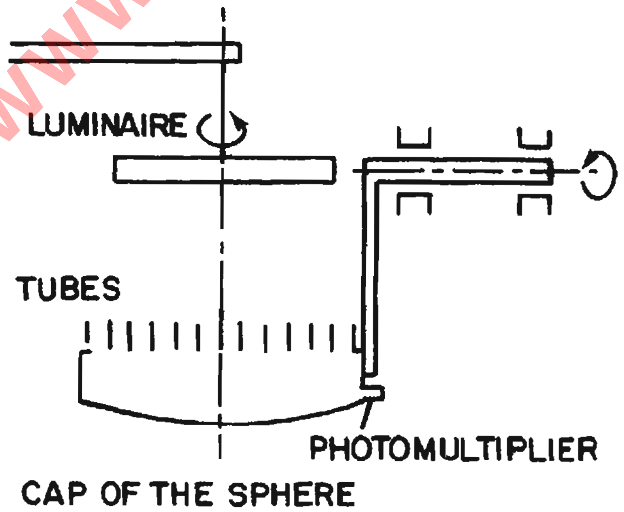

Fig. 3: Photometer head with tubes for luminance integration

The relative spectral responsivity of such a photometer head is determined decisively by the spectral reflectance of the interior paint of the spherical collecting device. Pollution of the paint - even if it is non-selective - can lead to a change in the relative spectral responsivity and in the absolute responsivity of the device as a whole.

Note:

A test of the relative spectral responsivity of the whole measuring head is not possible in practice.

Figure 4 shows another arrangement of the photometer head with parallel oriented tubes, for which a high uniformity of the spatial responsivity can be achieved and which has a stable and measurable spectral responsivity [16].

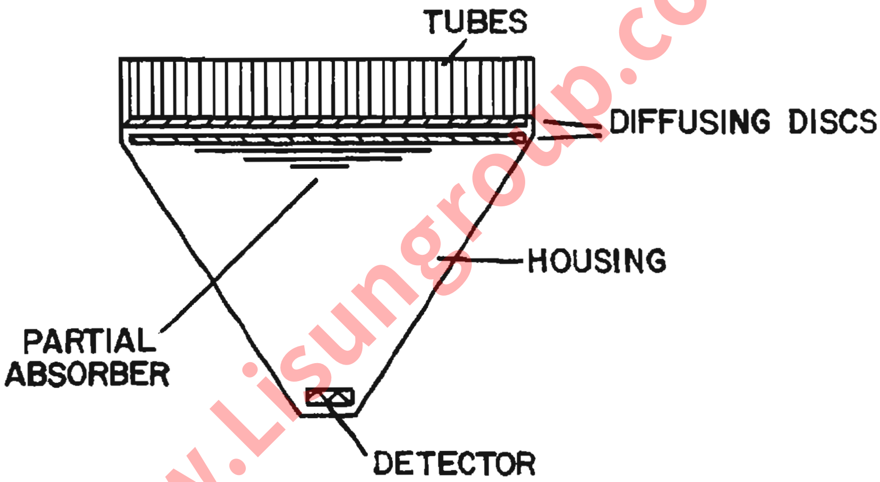

Fig 4: Photometer head for luminance integration

The distance between the light source and the acceptance area of the photometer head can influence the result of the measurement.

In order completely to cover the emitting area of a light source, the smallest distance r_{min} between the acceptance area and the light source should comply with (Fig. 5)

$$r_{min} = (\ell/\sqrt{2} - d/2) \cdot f/d \qquad (8)$$

where

ℓ	distance between adjacent tubes in tube plate
d	tube diameter
f	thickness of tube plate

For mechanical reasons, r_{min} must also exceed half of the largest extent (D) of the light source. Thus a conservative limit for the largest dimension (D_{max}) of the largest light source that may be measured with the instrument would be set by requiring the sum of r_{min} and $D_{max}/2$ to equal the fixed radius of rotation (r) of the goniophotometer. From this condition D_{max} can be specified as

$$D_{max} = 2(r - r_{min}) \quad (9)$$

D_{max}	largest extent of the largest permissible light source
r_{min}	according to equation (8)
r	given radius of rotation for a particular goniophotometer

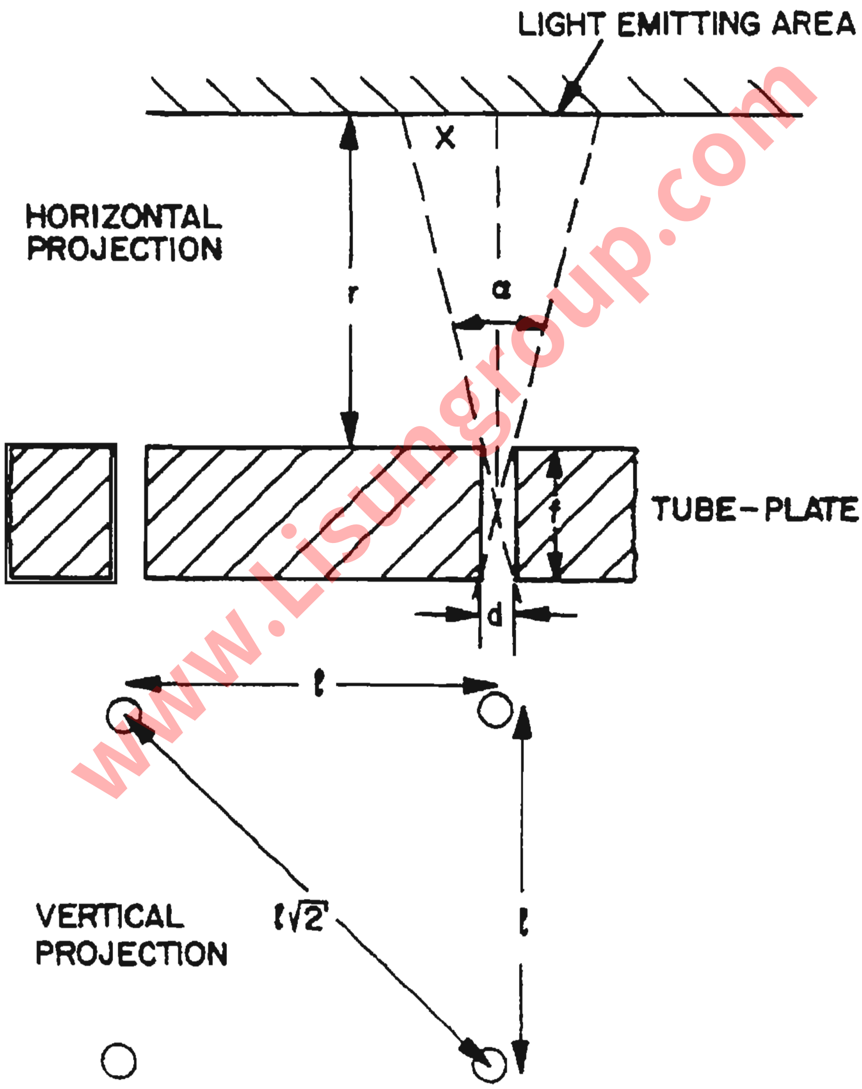

Fig. 5: Dimensions for photometer head for luminance integration with tube plate

The minimum diameter B of the acceptance area of the photometer head should be

$$B = D_{max} + 2 \cdot r \cdot d/f \qquad (10)$$

It should be ascertained whether the result is independent of the distance between light source and acceptance area.

3.2.2 INFLUENCE OF INHOMOGENEOUS ILLUMINATION [2,3,15]

A spatially inhomogeneous luminance of the light source can cause measuring errors, if the responsivity of the photometer head is not uniform over the acceptance area.

The measuring error will depend on the luminance distribution of the light source, the size of the source and the magnitude and distribution of responsivity differences over the acceptance area.

If a calibration is performed, the measuring error will depend on the relative properties of the calibration source and the source to be measured as well as on the position of the sources relative to the acceptance area.

If possible the calibration source and the source to be measured should be placed in the same position.

To provide a basis for the evaluation of possible measuring errors the responsivity distribution over the acceptance area should be determined.

This may be done by bringing the photometer head to a horizontal position with the normal to the acceptance area pointing upwards and moving a light source in a horizontal plane at a distance greater than the minimum distance r_{min} (see equation 8) in such a way that it covers successively the whole area above the photometer head.

The light source should have an approximately constant luminous intensity distribution in directions close to the normal and its emitting area should not exceed 1/10 of the acceptance area or 10 cm^2 (whichever is smaller). A 100 W frosted incandescent lamp may be used.

The readings of the photometer for the various positions of the lamp may be used to calculate the error f_9 by inhomegeneous illumination relevant to the intended use of the photometer.

A worst-case error is obtained if f_9 is determined as the largest percentage difference between readings.

$$f_9 = (1 - Y_{min} / Y_{max}) \cdot 100 \ \% \qquad (11)$$

Y_{min} minimum reading
Y_{max} maximum reading

If the photometer is to be used for the measurement of compact light sources, f_9 should be determined as the largest percentage difference of (a) the mean of the readings taken along the circumference of any circle contained within the acceptance area and centred on the midpoint of the area and (b) the midpoint reading

$$f_9 = \left[\left(\sum_{\alpha=0^\circ}^{360^\circ} Y_\alpha \right)_{max} - \left(\sum_{\alpha=0^\circ}^{360^\circ} Y_\alpha \right)_{min} \right] \cdot \frac{1}{Y_0} \cdot \frac{\Delta\alpha}{360} \cdot 100 \ \% \qquad (11a)$$

Y_0 midpoint reading
$\Delta\alpha$ angular step size of readings in degrees
$(\sum Y_\alpha)_{max}$ maximum of the mean reading along a circle
$(\sum Y_\alpha)_{min}$ minimum of the mean reading along a circle

If the photometer is to be used for the measurement of linear light sources, f_9 should be determined as the largest percentage difference of the mean reading along any diameters of the circles and the mean reading along the circle diameter parallel to the horizontal axis of the photometer.

If the photometer is to be used for both compact and linear light sources the larger of the above errors should be stated.

Readings should be taken at the smallest possible increments in circle diameters and angular distance between diameters. In the determination of f_9 percentage differences for increments of circle diameters of 20 cm and increments of angular distance of 5° should be calculated.

3.2.3 INFLUENCE OF THE MEASURING-FIELD ANGLE

When the luminous intensity is determined by an illuminance measurement the limiting photometric distance r determines a maximum value for the ratio D/r (D being the largest extent of the light source). This limiting ratio must also be taken into account if the luminous intensity is determined via a luminance measurement. For a photometer head with lens this means

$$\tan \alpha \leqslant D/r \qquad (12)$$

α Measuring-field angle according to equation (6)

For a photometer head with tubes it requires

$$d/f \leqslant 2\ D/r \qquad (13)$$

d,f see Fig. 5

4. MEASURING PLANE [2,3,4,17]

In general the luminous intensity distribution of light sources (lamps or luminaires) is measured in a number of planes. The number of luminous intensity distribution curves and the selection of measuring planes depend on the kind of light source and its use as well as on the type of goniophotometer. From the variety of possible measuring planes three systems of planes have proven specially useful.

4.1 A-PLANES (See Fig. 6)

The totality of A-planes is the group of planes for which the line of intersection goes through the photometric centre parallel to the emitting area and perpendicular to the assumed axis of the light source.

Note:

The system of A-planes is coupled rigidly to the light source and follows its tilt if the light source is tilted.

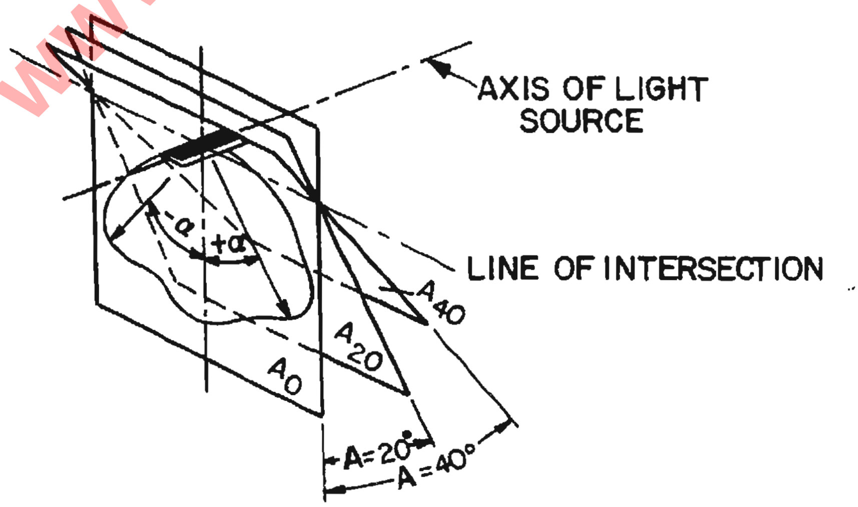

Fig. 6: A-planes

4.2 B-PLANES (See Fig. 7)

The totality of B-planes is the group of planes for which the line of intersection goes through the photometric centre and is parallel to the assumed axis of the light source and is perpendicular to the line of intersection of the A-planes.

Note:

The system of B-planes is coupled rigidly to the light source and follows its tilt if the light source is tilted.

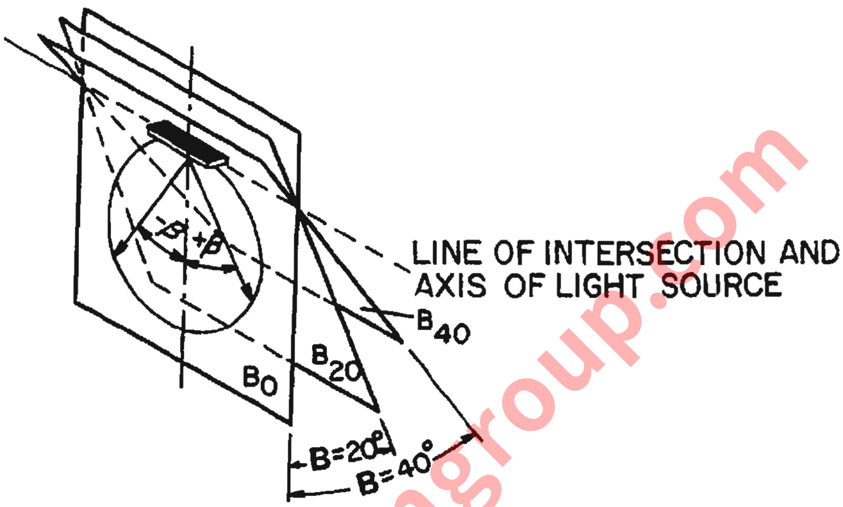

Fig. 7: B-planes

4.3 C-PLANES (See Fig. 8)

The totality of C-planes is the group of planes for which the line of intersection is the vertical line through the photometric centre.

Note:

The system of C-planes is generally oriented rigidly in space and does not follow a tilt in the light source. The line of intersection of C-planes is only perpendicular to the lines of intersection of the A- and B-planes for zero tilt ($\delta = 0$) of the light source.

In some cases the totality of C-planes is also referred to as the group of planes whose line of intersection is the line of intersection of A_0- and B_0-planes (see Fig. 9). In that case the system of C-planes is also rigidly coupled to the light source (as is the case for the A- and B-planes).

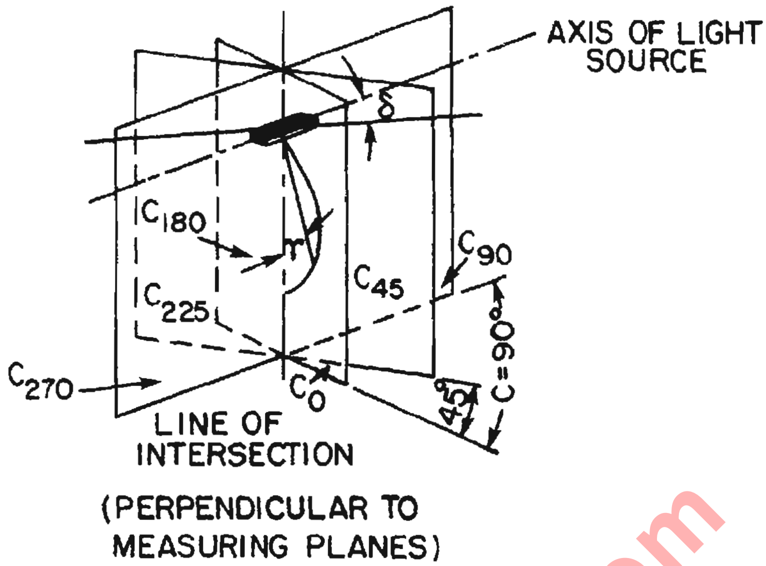

Fig. 8: C-planes (δ tilt angle of luminaire)

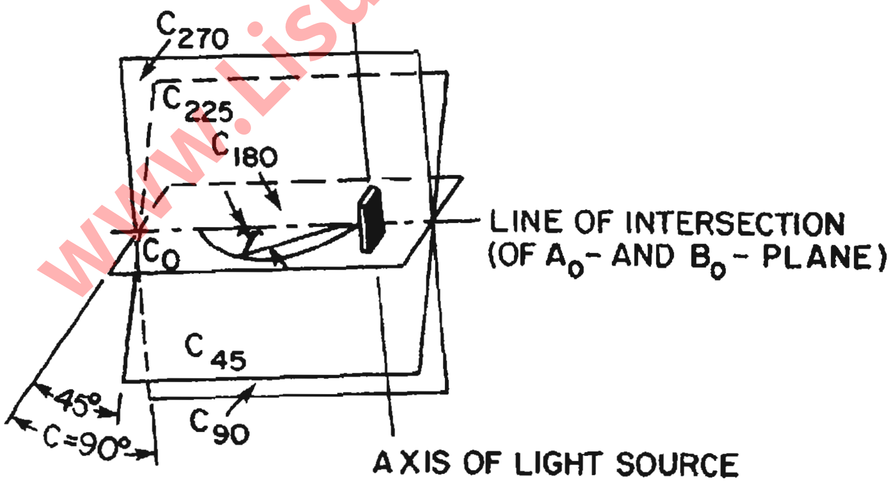

Fig. 9: C-planes with rigid coupling to the light source

4.4 CONICAL SURFACES (Fig. 10)

For some goniophotometers it is convenient to measure the luminous intensity distribution curves at constant polar angles and to describe the results as curves on conical surfaces. The axis of the cone corresponds to the line of intersection of the C-planes.

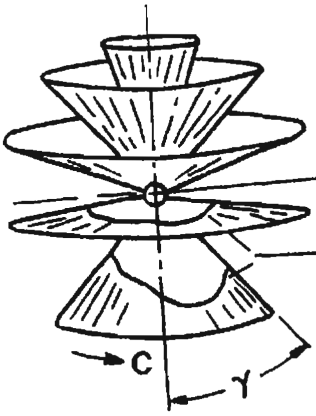

Fig. 10: Conical surfaces

4.5 SYMBOLS FOR PLANE ANGLES

The tilt angles of planes are designated by an index. The tilt angles of the A- and B-planes are taken from -180 ° through 0 ° to 180 °, those of the C-planes from 0 ° to 360 ° (semiplanes). The opening angle of the conical surfaces is measured relative to the line of intersection of the C-planes.

The following symbols are used (for angle symbols see Figs. 6-10):

- the angles in the A-plane have the symbol α and are measured from the line perpendicular to the line of intersection of the A- planes
- the angles in the B-planes have the symbol β and are measured from the line perpendicular to the line of intersection of the B-planes
- the angles in the C-plane have the symbol γ and are measured from the line of intersection of the C-planes in the downward direction
- the angles on the conical surfaces have the symbol C and are measured from the C_0-plane.

The tilt angles of the planes are added as indices to the relevant planes.

4.6 RELATIONSHIPS

A certain direction in each system of planes is characterized by two angles:

- an angle in one plane or conical surface
- and angle for the tilt of the plane or conical surface.

Table 1 shows the angle symbols commonly used in the various systems of planes.

TABLE 1

Angle symbols

System	Angle in the plane	Tilt angle of plane
A-planes	α	A
B-planes	β	B
C-planes	γ	C
Conical surfaces	C	γ

The conversion equations listed in Table 2 hold for the angles in Table 1.

TABLE 2

Conversion equations for systems of planes

Direction		Tilt angle of plane	Angle in the plane
Given	Wanted		
A,α	B,β	$\tan B = \tan \alpha / \cos A$	$\sin \beta = \sin A \,.\, \cos \alpha$
A,α	C,γ	$\tan C = \tan \alpha / \sin A$	$\cos \gamma = \cos A \,.\, \cos \alpha$
B,β	A,α	$\tan A = \tan \beta / \cos B$	$\sin \alpha = \sin B \,.\, \cos \beta$
B,β	C,γ	$\tan C = \sin B / \mathrm{tg}\, \beta$	$\cos \gamma = \cos B \,.\, \cos \beta$
C,γ	A,α	$\tan A = \cos C . \mathrm{tg}\, \gamma$	$\sin \alpha = \sin C \,.\, \sin \gamma$
C,γ	B,β	$\tan B = \sin C . \mathrm{tg}\, \gamma$	$\sin \beta = \cos C \,.\, \sin \gamma$

5. GONIOPHOTOMETER WITH FACILITY FOR TURNING THE LIGHT SOURCE [2,4,18]

5.1 PRINCIPLE

In these goniophotometers the light source is turned around a vertical as well as a horizontal axis. The photometer head is fixed. Accurate results for the luminous intensity distribution with this type of goniophotometer were only obtained for light sources in which the luminous intensity distribution is independent of orientation and temperature.

Note 1:

For measurements of the luminous intensity distribution of fluorescent lamps and luminaires with fluorescent lamps this type of goniophotometer can be used provided that for positions of the light source differing from the normal burning position the luminous intensity in each direction is held constant by means of an auxiliary detector or that the appropriate correction factors are applied (see section 5.4).

Note 2:

The optical distance between light source and photometer head can be increased by the use of a deflection mirror mounted at the far wall of the measuring room. Selective reflection and polarization by the mirror must be taken into account.

5.2 APPLICATION

Goniophotometers with a facility for turning the light source should only be used to measure incandescent lamps and fluorescent lamps or luminaires fitted with these lamps. These goniophotometers are the most advantageous type regarding construction and price. They are usually used for the determination of the luminous intensity according to the photometric distance law. The use of an auxiliary detector (section 5.4) is usually required.

5.3 CONSTRUCTION PRINCIPLES

There are three types of goniophotometers with facilities for turning the light source:

Type 1 Fixed horizontal axis and a moveable axis perpendicular to the fixed horizontal axis (Fig. 11) [19]. Measurements are made in the A- or B-planes, when the light source is turned around the horizontal axis and the second axis is in a fixed position.

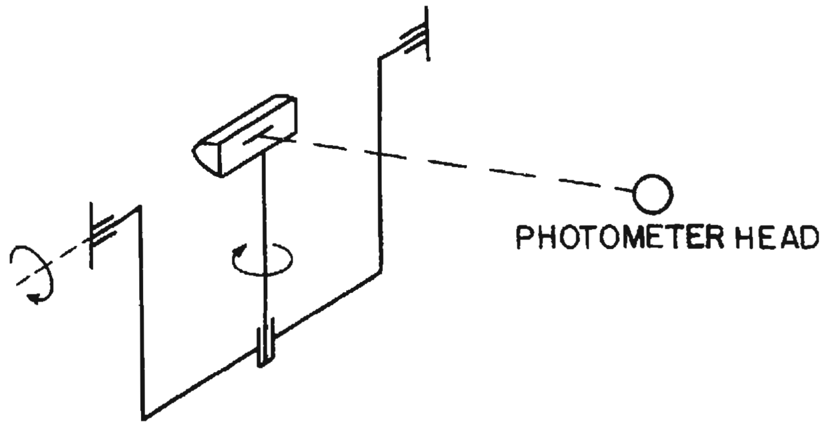

Fig. 11: Goniophotometer with facility for turning the light source, type 1.

Type 2 Fixed vertical axis, moveable horizontal axis (Fig. 12). Measurements are made in the A- or B-planes.

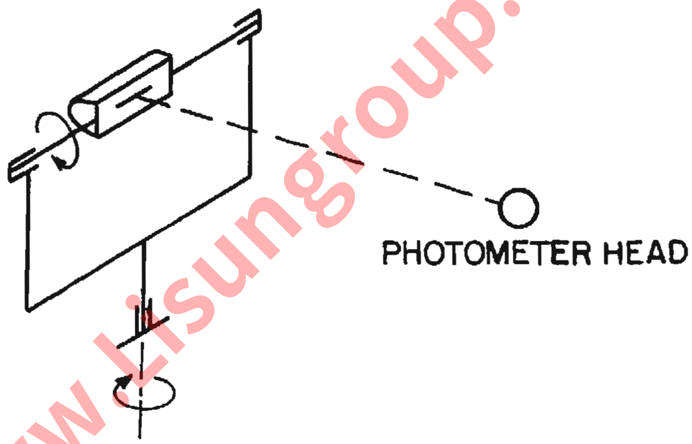

Fig. 12: Goniophotometer with facility for turning the light source, type 2.

5.4 AUXILIARY DETECTORS [2,3]

Light sources for which the (absolute) luminous intensity distribution changes with a change in burning position but not the relative luminous intensity distribution (e.g., fluorescent lamps or luminaires with fluorescent lamps) can be measured with a goniophotometer in which the light source is turned if the measurements are corrected by means of an auxiliary detector. For precision measurements this method is not recommended. An illuminance meter with a separate photometer head can be used as reference detector. The auxiliary detector must be fixed to the light source, so that it follows its movements. It should preferably be illu-

Type 3: Fixed vertical axis, moveable horizontal axis (Fig. 13). Measurements are made in the C-planes or conical surfaces. Type 3 is equivalent to type 2 if the light source is turned by 90 degrees.

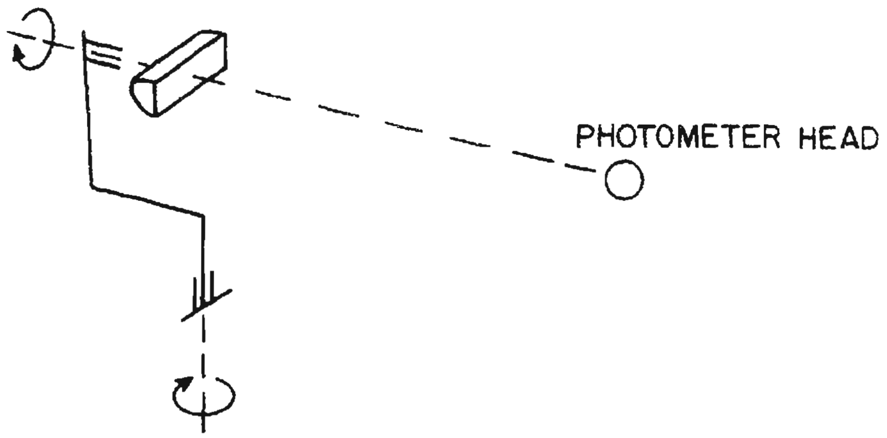

Fig. 13: Goniophotometer with facility for turning the light source, type 3.

minated by all parts of the emitting area and should not mask the illumination by the light source on the photometer head used for measuring the luminous intensity.

The only stringent requirements on the auxiliary detector are for small fatigue and drift parameters. The rest of the parameters characterizing the properties of illuminance meters are of less importance.

For the measurement of the luminous intensity distribution one has to obtain the reading on the auxiliary detector in the normal burning position of the light source. On turning the light source around a horizontal axis the reading on the auxiliary detector can be maintained at a constant level via a corresponding adjustment of the supply voltage.

A second possibility consists in keeping the supply voltage of the light source constant and correcting the measured luminous intensity in each direction by means of a correction factor.

$$I = K \cdot I_{meas} \qquad (14)$$

- I Luminous intensity of light source
- K Correction factor
- I_{meas} Measured (inaccurate) luminous intensity

The correction factor K follows from the measured readings on the auxiliary detector as

$$K = \frac{E_0}{E_\theta} \qquad (15)$$

E_0 Reading on the auxiliary detector for the light source in the prescribed burning position (after burn-in)

E_θ Reading on the auxiliary detector for the light source in the position characterized by the angle θ.

6. GONIOPHOTOMETER WITH MOVING PHOTOMETER HEAD [2,4,18]

6.1 PRINCIPLE

In these goniophotometers the light source is turned around a vertical axis and the photometer head moves around the light source in a vertical plane.
Instead of a moving photometer head one can also use a number of fixed photometer heads that are positioned in a vertical plane, corresponding to the movement of a photometer head. The possibility also exists to replace the process of turning the lamp by an arrangement of photometer heads in a number of vertical planes.

Note:

The use of fixed photometer heads in one or more vertical planes requires a number of photometer heads corresponding to the desired angular steps. All photometer heads have to be calibrated separately, which is in practice quite a disadvantage. In turn it is possible to use a simpler mechanical construction and the measuring time is significantly reduced.

6.2 APPLICATION

Since the light source is turned only about the vertical axis in these photometers and can therefore be measured in its normal burning position it is possible to measure all kinds of lamps and luminaires containing them. The prerequisite for an accurate measurement is a sufficiently large distance between the light source and the photometer head; this distance depends of course on the photometer head used. If a photometer head for illuminance measurements is used it is generally necessary to use a room of relatively great depth and height.

6.3 CONSTRUCTION PRINCIPLES

For goniophotometers with a moving photometer head there are basically three types

Type 1: The light source is turned at the point of intersection of the horizontal and vertical axes around a vertical axis. The photometer head is turned around a horizontal axis (Fig. 14). Alternatively the photometer head can be moved on a circle in the vertical plane around the light source without any mechanical coupling with the light source (Fig. 15).

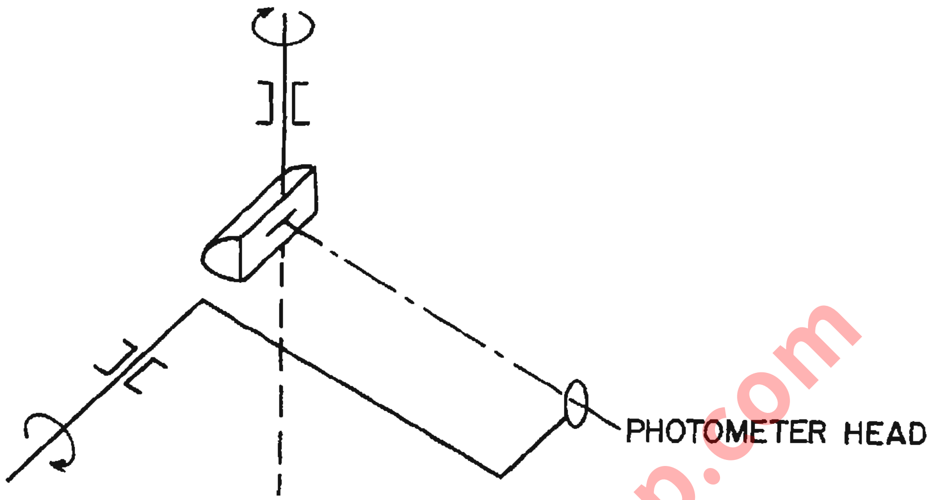

Fig. 14: Goniophotometer with moving photometer head, type 1. The photometer head is turned around a horizontal axis.

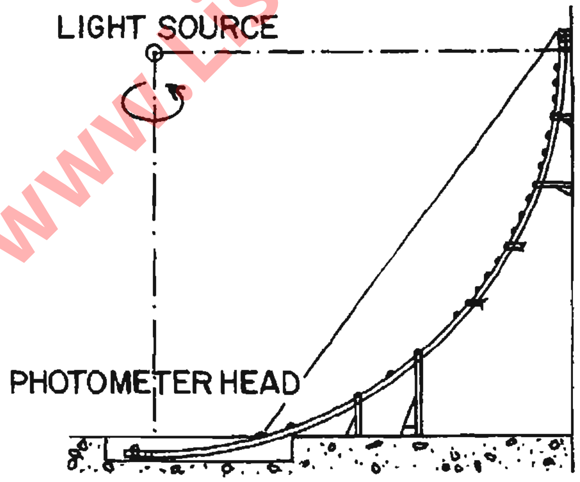

Fig. 15 Goniophotometer with moving photometer head, type 1. The photometer head moves on a circle around the measuring object without direct mechanical coupling.

Type 2: Light source and photometer head are at the opposite ends of a beam, which is turned around a horizontal axis through the centre of the beam [20]. The photometer head is rigidly fixed to the beam, while the horizontal spindle supporting the luminaire ensures that the luminaire hangs down like a plumb bob as the beam rotates. The light source is turned in the prescribed burning position around a vertical axis and the photometric centre of the light source is turned around a horizontal axis in a C-plane (Fig. 16). It must be mentioned that many types of lamps have a temperature-dependent light output. Therefore air velocity because of lamp movement must be kept low. Rotating the lamps can also give rise to changes because of centrifugal movement of, for instance, liquid metal. The required room depth is only half that of type 1. The use of this type is only meaningful in conjunction with a photometer head for illuminance measurements.

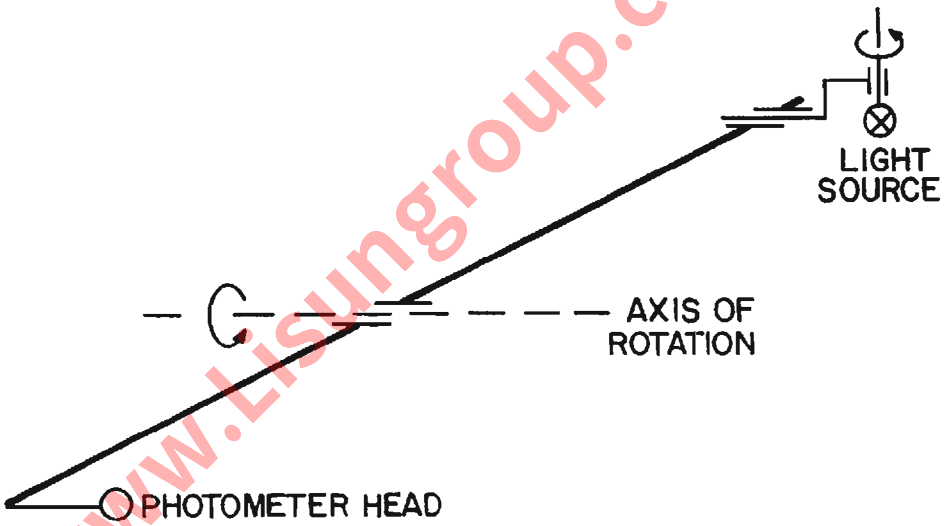

Fig. 16: Goniophotometer with moving photometer head, type 2. Movement of photometer head and light source on a circle in a vertical plane.

Type 3: The light source is turned around a vertical axis in a fixed position. The photometer head is moved along straight lines in C-planes (horizontally and vertically) without mechanical coupling to the light source (Fig. 17). The moving photometer head can be aligned with its optical axis on the photometric centre of the light source. If the responsivity of the photometer head as a function of the angle of incidence is taken into account numerically it can also stay in a fixed spatial orientation (optical axis of photometer head vertical or horizontal). The influence of the change in distance between light source and photometer head must be taken into account numerically.

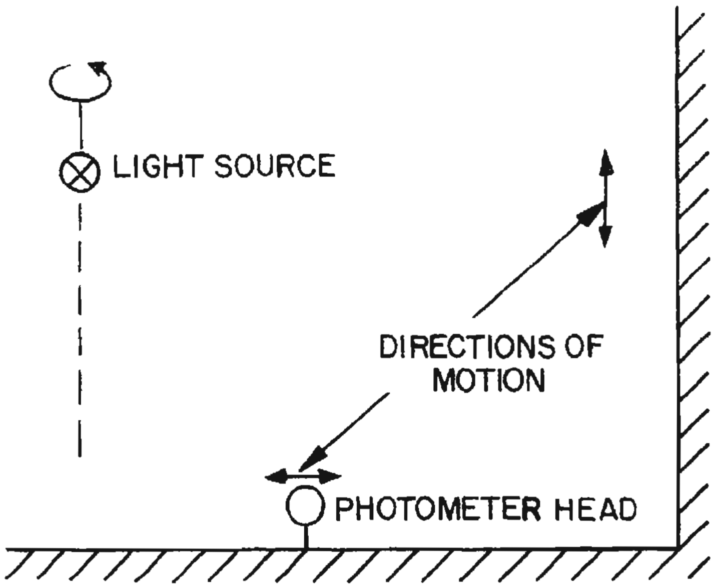

Fig. 17: Goniophotometer with moving photometer head, type 3. Movement of photometer head on a horizontal or vertical line.

For goniophotometers of types 1 and 3 it is possible to use a number of fixed photometer heads - each calibrated separately - instead of the moving one.

Their number depends on the required angular resolution and thus significantly on the kind of light source. The measuring time of such a goniophotometer can be very short. Calibration and ageing problems may be considerable with these multi-photometer head systems. Goniophotometers of the first type can be fitted with either a photometer head for the measurement of illuminance or with a photometer head for the measurement of luminance. Goniophotometers of the second and third type are used exclusively with photometer heads for the measurement of illuminance.

For goniophotometers with moving photometer head measurements are made in C-planes or on conical surfaces.

7. GONIOPHOTOMETERS WITH ROTATING MIRROR

7.1 PRINCIPLE

In these goniophotometers the light source is turned around a vertical axis and a mirror arrangement around a horizontal axis. The position of the photometer head is fixed.

Note:

The optical distance between light source and photometer head can be increased by the use of a deflecting mirror that is positioned at the far end of the measuring room. Selective reflection and polarization due to the mirror must be taken into account.

7.2 APPLICATION

Since the light source is turned only around a vertical axis in these goniophotometers and can therefore be measured in the prescribed burning position, all kinds of lamps and luminaires containing them can be measured.

The prerequisite for an accurate measurement is a sufficiently large distance between light source and photometer head, which depends on the kind of photometer head used.

7.3 CONSTRUCTION PRINCIPLES

Goniophotometers with rotating mirror are today usually built with a single mirror for easier alignment. Goniophotometers with several mirrors are, however, also known [21]. Figures 18 and 19 show the construction principle of a goniophotometer with rotating mirror. No direct light from the light source must reach the photometric head. The mirror must be sufficiently large so as not to cause vignetting in the beam path.

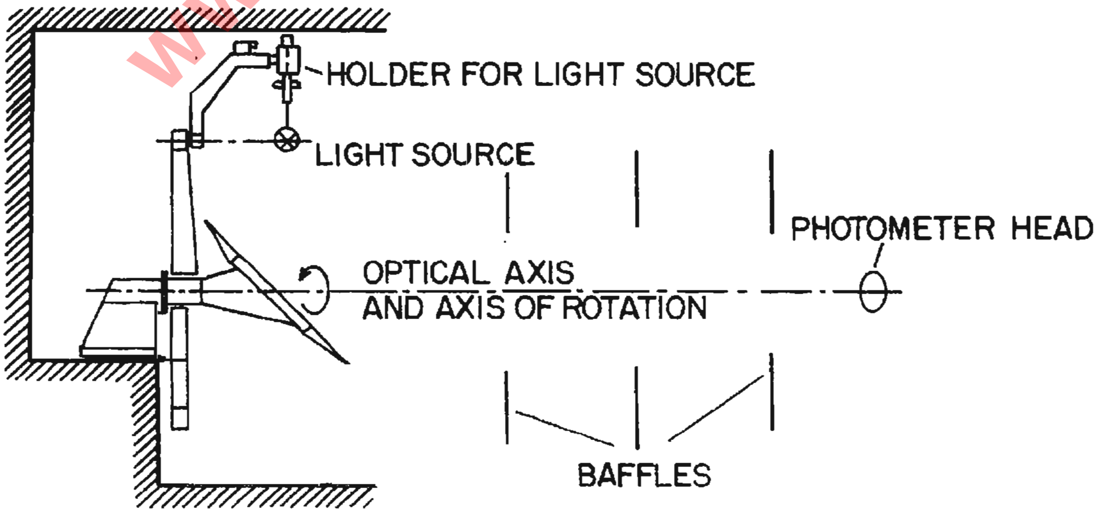

Fig. 18: Goniophotometer with rotating mirror (mirror on optical axis)

Baffles must be placed between mirror and photometer head so that no direct light from the light source and, preferably, also no light reflected from the floor, the ceiling or the walls can reach the photometer head. Measurements are made in C-planes or on conical surfaces.

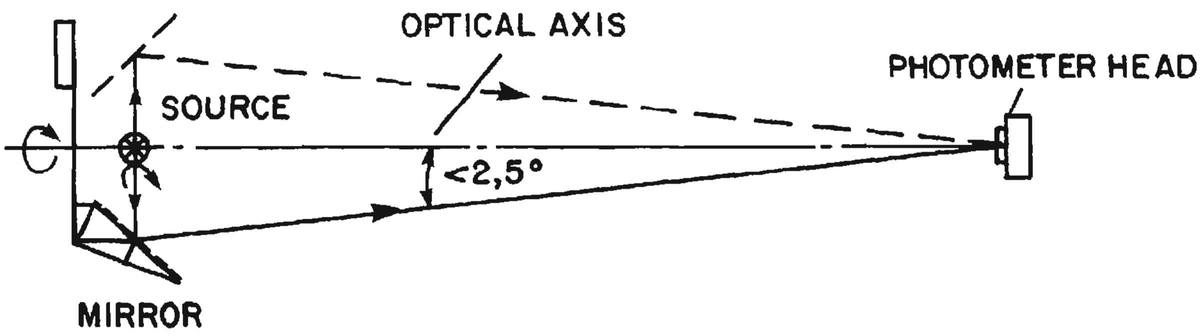

Fig 19: Goniophotometer with rotating mirror (lamp on optical axis).

The measurement of the error caused by the turning mirror should be performed according to section 3.2.2.

8. ANGLE MEASUREMENT

8.1 POSSIBILITIES

For the measurement of luminous intensity in a defined direction two angles must be determined according to the particular system of planes used. The positioning of the light source in the goniophotometer will usually be done by hand or by motor. If by motor, it can be controlled by hand or automatically. In the latter case an electric rotation measuring device is required. In all cases an angle measuring device can be used. Possible methods are:

- adjustment of the goniophotometer by hand, reading of the angles from angle scales
- adjustment of the goniophotometer by hand or by motor, angle encoding by means of a potentiometer, in which the voltage produced is a measure of the angular position
- use of stepping motors for which the number of pulses is a measure of the angular position

- use of angle encoders (pulse generators) in which the number of pulses is counted. An additional determination of the zero position has to be performed
- use of absolute angle encoders, which do not require a zero adjustment. A particular position remains encoded even if the power supply is switched off. Any particular reference angle can be defined as the zero position for specific measurements, with no loss of the absolute zero position, which is continually accessible.

The current position usually is indicated digitally.

8.2 REQUIREMENTS

A sufficiently accurate positioning of the light source must be possible. For measuring arrangements with variable angular steps it is recommended to choose an angular resolution of 0,1 °. A resolution of 0,01 ° is possible.

Measures should be taken to ensure that the indicated position is identical to the actual position of the light source and is not rendered inaccurate by the mechanical instability of the goniophotometer. This means that a heavy construction of the mechanical parts of the goniophotometer is necessary, which can influence the price of this equipment in an important manner.

9. PHOTOELECTRONICS AND DATA PROCESSING

With the photoelectronics one includes the electronics for the acquisition and processing of the signal from the photometer head (usually an operational amplifier with feedback) with additional circuits for the digital or analog display of the luminous intensity as well as suitable outputs, e.g., for connection to a computer or XY-recorder. Where applicable, the power supply for a thermostatted photometer head is also part of the photoelectronics. Circuits for auto-ranging are also a useful feature.

AC operated lamps, especially discharge lamps, will have a certain modulation of the light output at a frequency of 2 times the supply frequency. The measuring results should be unaffected by this modulation, by means of a sufficiently long time constant in the electronics or by time integration. However, this should not influence the measuring results as a function of the goniophotometer speed by measuring "on the fly."

For DC powered lamps the total measuring time can therefore usually be shorter than for AC powered ones.

The properties of the photometer head in conjunction with the photoelectronics have to conform to the same specifications as required for illuminance or luminance meters [6].

The acquisition of the measured values (sets of one luminous intensity reading, two angular positions and, where applicable, a reading from an auxiliary detector) can be performed:

- through manual registration of the desired quantities displayed in an analog or digital form

- by printing the set of measured values on a suitable printer

- by direct plotting of the luminous intensity distribution on an XY-recorder in polar or cartesian coordinates

- by storage in the memory of a suitable computer.

If a completely automatic measurement and acquisition of the luminous intensity distribution is required, the computer to be used for the necessary calculations and the printing of the measured values should be chosen on the basis of the information required for the light source. This includes printing of the luminous intensity distribution in the form of tables and graphs [3]. In addition: for lamps, the printing of the luminous flux value and of the luminous efficacy; for luminaires, the total luminous flux of the luminaire, the light output ratio of the luminaire, distribution of the mean luminance (for the evaluation of the glare limitation); for floodlights, the horizontal and vertical one-tenth-peak divergence (spread) of the utilized flux, the utilization factor, etc.

10. GENERAL MEASURING CONDITIONS

10.1 OPERATING CONDITIONS

All lamps should be operated and measured, unless otherwise agreed, according to the conditions specified in the applicable IEC recommendations and national standards. It is essential to state whether the measurements are made at nominal voltage, current or power. This ensures that the results can be compared with values measured at other laboratories within the unavoidable measuring uncertainty.

The values of the quantities to be fixed should be influenced as little as possible by the measuring and operating facilities. Unavoidable influences should be taken into account in the evaluation of the measurements.

Calibration should be performed with means (lamps, measuring equipment) calibrated directly or indirectly in comparison with internationally recognized standards.

10.2 AGEING

The operating parameters of lamps change over their lifetime to varying degrees. Changes are especially pronounced over the first part of their lifetime. In order to achieve a sufficient degree of repeatability of measurements it is therefore necessary to age the lamps.

The duration of ageing is specified for the different types of lamps in the applicable IEC recommendations and national standards.

10.3 BURNING POSITION

The operating position of light sources must comply with the applicable IEC recommendations and national standards or with the specifications of the manufacturer and the application. The burning position must be stated in the measuring report.

10.4 AMBIENT TEMPERATURE

The light sources should be operated during the measurement in a draught-free room in such a way that the convection flow of the surrounding air is not impaired. Photometric measurements are usually performed at an ambient temperature of 25 °C. For light sources with a strongly temperature dependent luminous flux the temperature tolerance should be ± 1 °C, for other light sources it should be ± 3 °C. If measurements are made at a different ambient temperature this temperature has to be stated.

The luminous flux of some special lamps is measured according to the specifications of the manufacturer if the lamp is operated within a defined and prescribed substitute luminaire.

The temperature should be measured with a thermometer with a resolution of at least 0,1 °C. The temperature measurements should be done at a representative spot and at about the same height as the light source.

The distance between the temperature sensor and the photometric centre of the light source to be measured should exceed half the largest horizontal extent of the light source by 0,5 m in the case of a goniophotometer. The temperature sensor must be shielded from direct irradiation by the light source to be measured.

10.5 VIBRATION AND SHOCK

When switched on, most lamps should not be subjected to accelerations exceeding 10 m/s^2 (4-3000 Hz) or positional changes exceeding 30 mm (up to 4 Hz). However, it is not possible to give a single set of limiting values for all types of lamps and luminaires.

10.6 STABILIZATION PERIOD

It is the purpose of the stabilization period to achieve a stable state of all parameters important for the measurement. During the stabilization the same operating conditions should apply as during the following measurement. Special attention should be paid to avoid changes in the burning position and the specified operating parameters (e.g., nominal voltage, power and current). The required stabilization period depends on the type of light source and the operating conditions. It should be checked by continuous monitoring of the readings. A light source can be considered as stabilized if the corresponding readings no longer show a trend in one direction.

Note: Some light sources remain stable for some time and then start changing again until a new stable situation is reached.

10.7 ELECTRICAL MEASUREMENTS

10.7.1 MEASUREMENT UNCERTAINTY

Differing results of photometric measurements are often caused by errors in the measurement or the adjustment of electrical parameters. For current and voltage (DC and AC) the uncertainty for incandescent lamp measurements should not exceed 0,1 %, while the corresponding figure for AC current and voltage in the case of discharge lamps is 0,2 %.

Note:

For incandescent lamps an error in the voltage of 1 % causes a deviation in the luminous flux of about 4 %. The same error in current causes an 8 % error in luminous flux.

There should be agreement as to which of the parameters to be measured (voltage, current, power) should be kept constant and what other conditions one should possibly meet.

10.7.2 POWER TYPE AND OPERATING MODE

With DC one can usually measure more accurately than with AC, since for AC the light source as well as the electrical measuring instruments are subject to a greater number of influencing quantities (e.g., frequency, wave form, phase lag). Because of the sometimes strong dependence of the photometric quantities on the electrical ones one should use supplies that are as stable as possible.

10.7.3 WIRING

Wires, ballasts and electrical measuring instruments should be positioned and, if necessary, screened in such a way that an influence of external fields is avoided. If it is required for some photometric measurements to determine the lamp voltage or power, the use of a measuring lamp holder is recommended.

Note:

A measuring lamp holder has four contacts, two for the current supply (I_L) and two separate ones for the measurement of the lamp voltage (U_L) directly at the lamp socket. A four electrode lamp holder reduces the voltage measuring error to zero, because no measurable current flows through the measuring contacts, when using a high impedance digital voltmeter.

10.7.4 EXECUTION OF THE ELECTRICAL MEASUREMENTS [22]

When measuring with current, volt or power meters, the voltmeter or the voltage path of the power meter should be connected between light source and current meter (or current path). The measuring current (power) of the instruments themselves must be taken into account (see also instructions in the applicable IEC recommendations). The capacity of the circuit may influence the results, especially if higher frequencies occur as for instance in low pressure sodium vapour lamps. Grounding errors can also substantially influence the measuring results.

For accurate AC measurements on discharge lamps, instruments should be of the "true rms" type to cope with harmonics. When measuring high frequency operated discharge lamps special methods and instruments are required [23].

10.7.5 MEASURING CIRCUIT

In the case of discharge lamps IEC recommendations specify the circuits for the light sources to be measured.

10.8 BALLASTS

Measurements on discharge lamps are usually made with reference ballasts. If other ballasts are used (e.g., for measurements on luminaires), the ballast used should be noted in the measuring protocol.

10.9 SUPPLY VOLTAGE

Measurements on incandescent lamps should preferably be performed with a DC supply because of the higher accuracy of the electrical measurements. Measurements on discharge lamps generally have to be performed with an AC supply.

The supply voltage during ageing should be stable to within 0,5 %, during the actual measurement to within 0,1 % and for calibrations with incandescent lamps as standards to within 0,02 %.

The frequency should differ at most by 0,1 % from the one for which the ballast is designed.

The total harmonic content of the AC supply voltage should not exceed 3 %. For the operation of high pressure lamps with a high proportion of reactive power the power supply should be chosen in such a way that the required reactive power can be met.

The total harmonic content is defined as the root-mean-square (r.m.s.) summation of the individual harmonic components, using the fundamental as 100 %.

Note: This implies that the source of supply should have a sufficiently low impedance compared with the ballast impedance and care should be taken that this applies under all conditions of measurement.

10.10 EXECUTION OF THE MEASUREMENTS

For the measurement the photometric centre of the light source should be positioned at the point of intersection of the axes of rotation.

The result of the measurement should not be influenced by the movement of the light source.

Note:

For measurements on fluorescent lamps the velocity of rotation should not exceed 3 revolutions per minute, to avoid influencing the result through the draught caused by the rotation.

Stray light on the photometer head should be reduced by the use of baffles, which should not cause vignetting in the beam path.

Before starting the measurements the light source should be burned in long enough to attain thermal equilibrium. All electrical and photometric instruments should be switched on long enough before the start of the measurements for their warm-up period to be exceeded at the start of the measurement [6].

11. CORRECTION OF MEASUREMENT RESULTS

If the light source is operated during the measurement with a voltage differing from the nominal voltage, if the ambient temperature differs from the specified one, or if the light source is measured in a position differing from the prescribed one, the results should be corrected if possible.

A correction of the results due to a voltage differing from the nominal one is possible if the relationship between the luminous flux of the lamp and the voltage is known. Results obtained with a different ambient temperature can be corrected to a certain extent. For lamps with a temperature dependent luminous flux, results can be corrected for a different ambient temperature if the relationship between luminous flux and ambient temperature is known. In the case of luminaires the temperature differential between luminaire and ambient must be known as well.

A correction due to a different burning position is possible for incandescent and fluorescent lamps by means of additional measurements with an auxiliary detector (see section 5.4).

12. PRESENTATION OF RESULTS

The results should be presented in a suitably chosen system of planes in cartesian or polar coordinates and in tabular form. It is also adviseable to convert the results to those for the nominal luminous flux (if known) of the lamp used in the measurement. The nominal luminous flux should be stated.

For measurements on luminaires which can be provided with different lamps of the same geometry (dimensions and position of the emitting area), it is recommended to refer the luminous intensity to a luminous flux of the lamps to be fitted in the luminaire of 1000 lm [2,3,4].

13. MECHANICAL ADJUSTMENT

13.1 GONIOPHOTOMETER WITH FACILITY FOR TURNING THE LIGHT SOURCE

For goniophotometers of this type the axes of rotation must be perpendicular and must have a point of intersection. It must be ensured that the horizontal and vertical axes really correspond to the directions in question. This requirement should be checked with a high precision level with an uncertainty of not more than 0,01 °.

At the point of intersection of the axes a mirror with a good optical surface finish and 5 mm diameter is put in the position of the light source in the plane through the light centre of the light source, which has a normal in the direction of the optical axis of the goniophotometer (line between the point of intersection of the axes and the centre of the measuring area of the photometer head).

The point of intersection of the axes and the centre of the measuring area are then adjusted to the same height by means of a hose level. A stable laser is positioned in such a way that the centre of its emitting area corresponds to the centre of the acceptance area of the (removed) photometer head. Its beam is directed at the centre of the optical mirror on the turning device for the light source.

The turning device for the light source is adjusted in such a way that the laser beam is reflected back exactly onto itself. This can be checked with a white, diffusely reflecting area around the laser emitting area and the visible position on it of the reflected laser beam. Then the procedure is as follows:

- Goniophotometer types 1 and 2

  If the mirror is turned around the vertical axis (it is now also vertical for type 2 goniophotometers) the reflected laser beam should hit the walls of the photometer room on a horizontal line. If the beam hits the wall to the side of the point of intersection of the axes of the turning device for the light source and at the height of the centre of the emitting area of the laser (to be checked with hose level) when the vertical axis is turned by about 45 ° in either direction, the vertical axis is set correctly.

  When rotating the device for turning the light source by 45 ° in either direction around the horizontal axis the reflected laser beam incident on the floor or the ceiling should coincide with the vertical line through the point of intersection of the axes.

- Goniophotometer type 3

For this type of goniophotometer the orientation of the vertical axis is checked in the same way as for types 1 and 2. The position of the horizontal axis is checked by turning the mirror around the horizontal axis. In that case the position of the reflected laser beam in the plane of the measuring area of the photometer head should not change.

13.2 GONIOPHOTOMETER WITH MOVING PHOTOMETER HEAD

In order to check the orientation of the vertical axis of the turning device for the light source, the photometer head is moved to the lowest position ($\gamma = 0$). A laser is mounted in place of the light source, with its beam directed at the centre of the (covered) acceptance area of the photometer head. If the laser is turned around the vertical axis the position of the beam in the plane of the acceptance area should not change.

For checking the position of the horizontal axis a thick white string with a weight at the bottom is fixed to the vertical axis. If a laser is put in the place of the photometer head and its beam hits the string, then the horizontal axis is located where the beam remains at the same spot on the string when the horizontal axis is turned.

13.3 GONIOPHOTOMETER WITH ROTATING MIRROR

In order to check the adjustment of the goniophotometer with a rotating mirror a measuring shaft is inserted in the receptacle for the light source, which contains the vertical axis and which has a diameter of a few millimeters at the point of intersection of the axes (location of the photometric centre). The position of the photometric centre is marked on it. The photometer head is replaced by a laser, with its beam after reflection from the mirror being directed at the photometric centre for any mirror position. By means of an aperture placed near the mirror the diameter of the laser beam should be restricted to less than 10 mm. When turning the mirror the laser beam should hit the photometric centre independent of the mirror position.

14. CALIBRATION

Goniophotometers can be calibrated by means of a luminous intensity standard lamp. Alternatively, the illuminance meter (luminance integrator) is calibrated and the distance between the point of intersection of the axes and the acceptance area is measured. For goniophotometers with rotating mirror the first method includes the properties of the mirror.

14.1 LUMINOUS INTENSITY STANDARD

The luminous intensity standard lamp is mounted with its photometric centre at the point of intersection of the axes in the prescribed burning position in such a way that the luminous intensity is measured in the direction for which the lamp is calibrated. From this follows the relationship between luminous intensity and reading.

14.2 CALIBRATED ILLUMINANCE METER

The illuminance meter is calibrated on a photometric bench and the distance between the point of intersection of the axes and the measuring area is measured. From these data it is possible to calculate the luminous intensity according to the photometric distance law. For a photometer head with luminance integration no distance measurement is required if it has been established that the reading is independent of the distance.

14.3 RELATIVE MEASUREMENTS

For the measurement of the relative luminous intensity distribution [2,3,4] no special calibration is required. The linearity of the photometer must be insured.

15. ERROR SOURCES AND MEASUREMENT ACCURACY

15.1 MECHANICAL ARRANGEMENT

The following mechanical defects can cause measuring errors:

- insufficient mechanical stability
- horizontal and vertical axis do not intersect
- the two axes are not perpendicular to each other
- with goniophotometers with rotating mirror, the optical axis of mirror and the rotating axis of turntable do not coincide
- vibration of moveable parts during rotation
- wrong positioning of the photometer head
- uneven rotation due to vibrations or lack of balancing.

15.2 ANGLE MEASUREMENTS AND ANGULAR STEP SIZE

The accuracy of luminous intensity measurements depends to a large extent on the measurement uncertainty for angle measurements and the angular step size. The measurement uncertainty depends essentially on the kind of angle encoder used. Information about this aspect should be obtained from the manufacturers. For a known luminous intensity distribution the measurement uncertainty in the luminous intensity caused by this aspect can be calculated.

If the goniophotometer is not stopped at each angular position (angles x,y) to perform a measurement, each measured value will be the mean over an angular interval that depends on the measuring time and the speed of rotation of the moveable parts. Factors influencing the resulting measurement uncertainty are:

- mechanical uncertainties with angle measurements
- angular uncertainties during the integration time, especially for AC powered light sources
- the time interval required for one sample
- the time interval between two successive angle steps.

15.3 INFLUENCE OF ROTATING MIRROR OR PHOTOMETER HEAD FOR LUMINANCE INTEGRATION

The mirror used in goniophotometers with rotating mirrors deviates in its properties from an ideal mirror. Measuring errors caused by the mirror can have the following causes:

- deviation of the mirror surface from a plane and the change of this deviation during rotation
- local changes of the reflectance of the mirror
- light scattering on the mirror surface due to diffuse reflection, damaged mirror surface or dust
- polarization of the light to be measured at the mirror surface
- wavelength dependence of the reflectance of the mirror surface
- insufficient plane parallelity of the substrate glass for rear coated mirrors (lens effects).

A polarization error caused by the mirror [24] can sometimes be eliminated by means of an analyser placed in front of the photometer head, which moves with the mirror. The error caused by the light scattered from a clean rotating mirror is difficult to eliminate. However, for a large measuring distance and a good mirror it is usually negligible.

The error due to the deviation of the mirror surface from a plane (surface roughness) cannot be eliminated. It can be made negligible by careful selection of the mirror.

It is possible to eliminate the error caused by the selective spectral reflection of the mirror surface by fitting the relative spectral response of the photometer head plus the mirror to the V(λ) function.

For photometer heads with luminance integration, errors can be caused by:

- non-constant spatial response
- insufficient size of the acceptance area
- insufficient distance between light source and acceptance area, causing some parts of the light source to be missed
- too large a measuring-field angle, causing the condition of the limiting photometric distance to be violated.

15.4 STRAY LIGHT

Stray light can invalidate the result of measurements of luminous intensity distributions. Therefore it is recommended to use baffles between the light source and the acceptance area of the photometer head that limit the incidence of stray light but do not cause vignetting in the beam path.

It is possible to determine the proportion of the stray light by placing a screen of the smallest possible dimension, that eliminates the direct incidence of light from the light source on the acceptance area, approximately halfway between the light source and the photometer head. The measurement of the luminous intensity distribution should be repeated with this screen in place. The measured signal is then due to the incidence of stray light and this amount should be subtracted from the measurement made without the screen. (See also [25]).

15.5 RELATIVE SPECTRAL RESPONSIVITY

The relative spectral responsivity of the photometer head used should be fitted very accurately to the spectral luminous efficiency $V(\lambda)$ of the human eye for photopic vision [1,6,7]. If the light source to be measured has the same spectral distribution as the calibration standard the quality of the $V(\lambda)$ fit is not important. This can be the case, for example, in relative measurements. For a goniophotometer with rotating mirror the $V(\lambda)$ fit of the photometer head should be made in conjunction with the mirror. For photometer heads for luminance integration one should pay attention to the fact that the relative spectral response may change due to dirt (even if it is non-selective) if a cavity is used for integration. The measurement of the relative spectral response for these photometer heads is always possible for the detector used but not generally for the complete photometer head.

15.6 ILLUMINANCE AND LUMINANCE METER

The photometer head with the attached photoelectronics determines the measurement accuracy to a large extent. Specifications and error limits for the measurement accuracy have been compiled in CIE publications [1,6].

15.7 DATA PROCESSING

For the acquisition and processing of the measurement data the errors with the digital signals will usually be negligible. If the data are acquired in an analog way errors due to the instruments used should be taken into account.

15.8 LIMITING PHOTOMETRIC DISTANCE

Errors depending on the luminous intensity distribution can be caused by too small a distance between the light source and the photometer head. Examples of error calculations are given in the literature [9,10].

15.9 OPERATING CONDITIONS

Errors can be caused by operating conditions deviating from prescribed conditions. They are:

- positioning of the photometric centre in a position deviating from the point of intersection of the two axes

- deviation of the orientation of the light source from the prescribed burning position. This influence can be corrected for only very inaccurately in the case of goniophotometers with a device for turning the light source

- start of the measurements before the end of the burn-in period or the warm-up period

- inaccurate adjustment and measurement of the operating voltage of the light source

- deviation of the mains frequency from the prescribed frequency

- varying contact resistance of the slip rings

- non-permissible harmonics content of the supply voltage

- deviation of the ambient temperature from the prescribed value

- temporal instability of the light source to be measured

- draught by means of ventilation equipment or too fast movement of the light source

- screening of parts of the light source by mechanical parts of the goniophotometer or by baffles in the light path.

15.10 PHOTOMETRIC STANDARD

The photometric data of the standard used in the calibration are subject to a measurement uncertainty. The value of the uncertainty of the standard should be taken from the calibration certificate and should be stated when giving error limits for the measurements. Additional errors are possible through the inaccurate setting of the electrical operating conditions for the photometric standard during calibration.

16. CHARACTERIZATION OF GONIOPHOTOMETERS

16.1 MECHANICAL ARRANGEMENTS

In order to characterize the mechanical details of a goniophotometer the following data should be supplied:

- type of goniophotometer

- geometrical dimensions
- permissible total weight of the light source
- permissible maximum dimensions of the light source
- angular interval over which the luminous intensity can be measured without screening by parts of the instrument
- measuring distance between light source and photometer head.

For goniophotometers with rotating mirrors:

- data on the quality of the mirror.

16.2 ANGLE ENCODING

In order to characterize the instruments used for angle encoding the following information is required:

- type of angle encoding
- resolution
- type of zero encoding
- possible deviations between the measured and the true angles.

16.3 PHOTOMETER HEAD

The properties of the photometer head should be stated in accordance with the relevant CIE recommendations [6]. For photometer heads with luminance integration the data according to section 3.2 should be added.

16.4 PHOTOELECTRONICS AND DATA PROCESSING

In order to characterize the photoelectronics and data processing the information in accordance with the relevant CIE publications [1,6] should be supplied. In addition the following should be stated:

- the integration interval for the illuminance integration.

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