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TECHNICAL REPORT

THE MEASUREMENT OF LUMINOUS FLUX

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TABLE OF CONTENTS

1	Scope	1
2	Terminology	1
2.1	Photometric quantities	1
2.1.1	Luminous flux	1
2.1.2	Luminous intensity	1
2.1.3	Illuminance	2
2.1.4	Luminance	2
2.2	Terms for measuring instruments	2
2.2.1	Photometer	2
2.2.2	Integrating	3
2.2.3	Integrating sphere; Ulbricht sphere	3
2.2.4	Box photometer	3
2.2.5	Photometer head	3
2.2.6	Acceptance area	3
2.2.7	Goniophotometer	3
3	Methods of measurement	4
4	Calculation of luminous flux from luminous intensity distribution	6
4.1	Measurement principle	6
4.2	Measurement of luminous intensity distribution	6
4.3	Method of calculation	6
4.4	Sources of error	7
5	Calculation of the luminous flux from the illuminance distribution	7
5.1	Measurement principle	7
5.2	Types of goniophotometers	8
5.2.1	Goniophotometer with light source in a fixed position	8
5.2.2	Goniophotometer with the light source rotated about a spatially fixed light centre	12

5.2.3	Goniophotometer with the light source rotated about a vertical axis with a moving light centre	12
5.3	Measurement of illuminance distribution	13
5.3.1	Movement of the photometer head	13
5.3.2	Angular step sizes	14
5.3.3	Speed of rotation	14
5.4	Angle encoding	15
5.5	Illuminance meter	15
5.6	Data acquisition and calculation of luminous flux	15
5.7	Stray light	17
5.8	Missed luminous flux	17
5.9	Summary of error sources	18
5.10	Characterization checklist	18
5.11	Calibrating and testing	19
5.11.1	Calibration	
5.11.2	Testing	19
5.11.2.1	Luminous flux standard lamp	20
5.11.2.2	Luminous intensity standard lamp	20
5.11.2.3	Calibrated illuminance meter	20
5.11.3	Intercomparison	21
6	Measurement with an integrating sphere	21
6.1	Measuring principle	21
6.2	Sphere theory	21
6.3	Spectral method	23
6.4	Box-photometer	24
6.5	Integrating sphere	24
6.5.1	Sphere diameter	24
6.5.2	Sphere paint	25
6.5.3	Arrangement of light source and screen	26
6.5.4	Influences of objects in the sphere and auxiliary lamp	28
6.6	Illuminance meter	29

6.7	Data acquisition	29
6.8	Luminous flux standard lamps	30
6.9	Execution of measurements	31
6.10	Testing and correction	32
6.10.1	Correction for the influence of the sphere paint	32
6.10.2	Corrections for incandescent lamp measurements	32
6.10.3	Corrections for measuring fluorescent lamps	33
6.10.4	Test for stability with time	34
6.11	Sources of error	34
6.12	Characterization of sphere photometers	35
7	Determination of luminous flux via illuminance, luminous intensity or luminance	35
7.1	Measurement principle	35
7.2	Measurement and calibration	36
7.3	Characterization	37
8	General measurement conditions	37
8.1	Operating conditions	37
8.2	Ageing	38
8.3	Burning position	38
8.4	Ambient temperature	38
8.5	Vibration and shock	39
8.6	Stabilization period	39
8.7	Electrical measurements	39
8.7.1	Measurement uncertainty	39
8.7.2	Power supply and operating mode	40
8.7.3	Wiring	40
8.7.4	Execution of the electrical measurements	41
8.7.5	Measuring circuit	41
8.8	Ballasts	41
8.9	Supply voltage	41
9	References	43
	Appendix	46

MEASUREMENT OF LUMINOUS FLUX

SUMMARY

This Technical Report defines the terminology required for luminous flux measurements. It then deals with the principles of luminous flux measurements and describes methods for the evaluation of the illuminance distribution, the measurement of luminous flux by means of an integrating sphere photometer and the determination of luminous flux via luminance, luminous intensity and illuminance measurements.

The report is based on and replaces CIE Publication No. 25, 1973 'Procedures for the measurement of luminous flux of discharge lamps and for their calibration as working standards' [1] and on the conclusions of the 'CIE-symposium on light and radiation measurement 81' [2]. The terminology follows that in the 'International Lighting Vocabulary' [3].

MESURES DE FLUX LUMINEUX

RESUME

Ce rapport technique contient d'abord la terminologie nécessaire pour les mesures de flux lumineux. Ensuite il traite des principes de mesure du flux lumineux et donne des détails sur l'évaluation de la distribution d'éclairement lumineux, la mesure du flux lumineux au moyen d'une sphère d'intégration photométrique, et la détermination du flux lumineux par l'intermédiaire de mesure de luminance, d'intensité lumineuse et d'éclairement.

Ce rapport remplace la publication CIE No. 25, 1973 'Procedures for the measurement of luminous flux of discharge lamps and for their calibration as working standards' [1] dont elle est issue et sur les conclusions du 'CIE-Symposium on Light and Radiation Measurement 81' [2]. La terminologie est empruntée au vocabulaire international de l'éclairage [3].

LICHTSTROM-MESSUNGEN

ZUSAMMENFASSUNG

Dieser Technische Bericht enthält zunächst die für Lichtstrommessungen wichtigen Begriffsbestimmungen. Danach werden die Prinzipien der Lichtstrommessung und Einzelheiten über die Auswertung der Lichtstärkeverteilung, die Auswertung der Beleuchtungsstärkeverteilung, die Lichtstrombestimmung über Leuchtdichte-, Lichtstärke- oder Beleuchtungsstärkemessungen behandelt. Die allgemeinen Meßbedingungen werden genannt.

Dieser Bericht ersetzt und stützt sich vor allem auf die Publikation CIE No. 25, 1973 'Procedures for the Measurement of Luminous Flux of Discharge Lamps and for their Calibration as Working Standards' [1] und auf die Ergebnisse des 'CIE-Symposium on light and radiation measurement 81' [2]. Bei den Begriffsbestimmungen sind die Angaben des Internationalen Wörterbuchs der Lichttechnik [3] weitgehend zugrunde gelegt.

1 Scope

The purpose of this report is to review the main methods in use for luminous flux measurements. One of these methods is used primarily by national standards laboratories (calculation from illuminance or luminance distribution), one is widely used in industry (measurement with an integrating sphere), while yet another form of measurement can be carried out in the limited number of industrial laboratories with access to a goniophotometer for measuring luminous intensity distributions. While each of the user groups will be primarily interested in the method in use in its field, it is necessary for a reference work on luminous flux measurements to cover all the main methods used for this purpose and to put them in perspective relative to each other.

2 Terminology <3>

2.1. Photometric quantities <3>

2.1.1 Luminous flux (Φ_v ; Φ)

Quantity derived from radiant flux Φ_e by evaluating the radiation according to its action upon the CIE standard photometric observer. For photopic vision

$$\Phi_v = K_m \int_0^{\infty} \frac{d\Phi_e(\lambda)}{d\lambda} \cdot V(\lambda) d\lambda, \quad (1)$$

where $d\Phi_e(\lambda)/d\lambda$ is the spectral distribution of the radiant flux and $V(\lambda)$ the spectral luminous efficiency.

Unit: lm

2.1.2 Luminous intensity (of a source, in a given direction) (I_v ; I)

Quotient of the luminous flux $d\Phi_v$ leaving the source and propagated in the element of solid angle $d\Omega$ containing the given direction, by the element of solid angle.

$$I = \frac{d\Phi_v}{d\Omega}. \quad (2)$$

Unit: cd = lm·sr⁻¹

2.1.3 Illuminance (at a point of a surface) (E_v ; E)

Quotient of the luminous flux $d\Phi_v$ incident on an element of the surface containing the point, by the area dA of that element.

$$E_v = \frac{d\Phi_v}{dA} . \quad (3)$$

Unit: $lx = lm \cdot m^{-2}$

2.1.4 Luminance (in a given direction, at a given point of a real or imaginary surface) (L_v ; L)

Quantity defined by the formula

$$L_v = \frac{d\Phi_v}{dA \cdot \cos \theta \cdot d\Omega} \quad (4)$$

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

Unit: $cd \cdot m^{-2} = lm \cdot m^{-2} \cdot sr^{-1}$

2.2 Terms for measuring instruments

2.2.1 Photometer <3>

Instrument for measuring photometric quantities.

2.2.2 Integrating photometer <3>

Photometer for measuring luminous flux, generally incorporating an integrating sphere.

2.2.3 Integrating sphere; Ulbricht sphere <3>

Hollow sphere whose internal surface is a diffuse reflector, as non-selective as possible.

2.2.4 Box photometer

A box photometer is an integrating photometer employing an arbitrarily shaped, hollow box or cavity instead of an integrating sphere.

2.2.5 Photometer head <4, 17>

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.

2.2.6 Acceptance area <17>

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

2.2.7 Goniophotometer <3>

Photometer for measuring the directional light distribution characteristics of sources, luminaires, media and surfaces.

3 Methods of measurement

The luminous flux of a light source can be calculated or measured by different methods:

- Calculation from the luminous intensity distribution (section 4)
- Calculation from the illuminance distribution (section 5)
- Measurement with a sphere photometer by photometric or spectral measurements (section 6)
- Measurement with a box photometer (section 6.4)
- Relative measurements via illuminance, luminous intensity or luminance (section 7)

Calculation of the luminous flux from the luminous intensity distribution is appropriate where measurements of the latter are already being made (e.g. for luminaires) <5>.

The derivation of the luminous flux from a measurement of the illuminance distribution of a lamp is the method used in many national standards laboratories to set up the basic standards of luminous flux. The unit of luminous flux, the lumen, is thus established in terms of the SI base unit of luminous intensity, the candela <6,7,12,13,14>. An accurate measurement of the spatial variation of the colorimetric properties of light sources <8> and of their spectral power distribution <9> can also be made using this method.

Luminous flux measurements using a sphere photometer are appropriate for:

- Measurements in industrial laboratories for production control
- Measurements by test houses and users
- The calibration of standard lamps (e.g. working standards) against higher order standard lamps, making extra corrections for errors due to

geometric, spectral and light distribution differences between the lamps to be compared.

- The measurement of light sources with luminous fluxes varying with time (e.g. adjustable lamps, flashlamps)
- The measurement of luminous flux as a function of time.

Measurements with a sphere of the light-output ratio of a luminaire which is calculated from the luminous flux of the lamp and the luminous flux of the luminaire, cannot be recommended if the luminous intensity distributions of lamp and luminaire differ considerably.

A luminous flux measurement with a box photometer only presents a direct relationship between the luminous flux of the light source and the indirect illuminance at an arbitrary point at an inside surface of the box, if the reference light source and the light source to be measured have the same spatial luminous intensity distribution, the same spectral distribution and same dimensions.

Measurements of spectral radiant flux can be made with an integrating sphere photometer, for light sources where the spectral power distribution varies with direction (e.g. metal halide lamps). This method gives all the information necessary for the calculation of:

- Spectral power distribution
- Luminous flux
- Radiant flux
- Colour
- Colour rendering indices

The determination of the luminous flux of light sources via a measurement of illuminance, luminous intensity or luminance is often carried out in practice to determine the influence of specific parameters (e.g. ageing, temperature, position). It usually takes the form of a relative measurement. The method can also be used for measuring the luminous flux of fluorescent lamps in lighting installations <10>.

The method used for the measurement of luminous flux depends on the available equipment. Equipment and method used are influenced by:

- The task of the photometric laboratory
- Economy
- Time consumption
- Acceptable measurement uncertainty.

4 Calculation of luminous flux from luminous intensity distribution

4.1 Measurement principle

According to the definition, the luminous flux Φ can be derived from the spatial distribution of the luminous intensity I by the relation

$$\Phi = \int_{(\Omega)} I \, d\Omega \quad (5)$$

where $\Omega = 4\pi$ sr Total solid angle

The luminous intensity distribution can be measured with a goniophotometer <11>.

4.2 Measurement of luminous intensity distribution

The measurement of luminous intensity distribution is described in a separate Technical Report of the CIE <11>. That report contains information about goniophotometers used for the measurement of luminous intensity distribution as well as data about the execution of the measurements.

4.3 Method of calculation

In order to evaluate the luminous flux, the luminous intensity should be integrated over the full solid angle as shown in equation (5). The element of solid angle $d\Omega$ can be expressed trigonometrically as

$$d\Omega = \sin \varepsilon \, d\varepsilon \, d\eta \quad (6)$$

with

$d\Omega$ Element of solid angle

ε, η Angles depending on the chosen coordinate system;

ε elevation angle with $\varepsilon = 0$ at zenith and η azimuth angle

The angles ε and η should be substituted to accord with the coordinate system used during the measurement of luminous intensity distribution.

In a practical evaluation the integrals are replaced by sums. In that case the luminous flux can for example be calculated according to the following formulae:

$$\text{A-planes: } \Phi = \Delta A \sum_{m=1}^M \sum_{n=-N+1}^N I(\alpha, A) \{ \sin(n\Delta\alpha) - \sin[(n-1)\Delta\alpha] \} \quad (7a)$$

$$\text{B-planes: } \Phi = \Delta B \sum_{m=1}^M \sum_{n=-N+1}^N I(\beta, B) \{ \sin(n\Delta\beta) - \sin[(n-1)\Delta\beta] \} \quad (7b)$$

$$\text{C-planes: } \Phi = \Delta C \sum_{m=1}^M \sum_{n=1}^N I(\gamma, C) \{ \cos[(n-1)\Delta\gamma] - \cos(n\Delta\gamma) \} \quad (7c)$$

$\Delta\alpha$ and $\Delta\beta$ represent angular step sizes of $\pi/2N$ and $\Delta\gamma$ corresponds to π/N , while ΔA , ΔB and ΔC are given by $2\pi/M$ (see appendix and reference <11>).

The smaller the angular steps that are chosen, the more accurate will be the resulting determination of luminous flux. Steep luminous intensity distributions require smaller angular steps.

4.4 Sources of error

Specific errors in the determination of the luminous flux through an evaluation of the luminous intensity distribution can be caused by:

- Errors in the measurement of luminous intensity <11>
- Too large step angles
- Shading of the light source by mechanical parts of the goniophotometer and the holder for the light source (see section 4.8)
- Instability of the light source during measurement
- Instability of the mechanical arrangement of the photometer.

5 Calculation of luminous flux from the illuminance distribution

5.1 Measurement principle

By definition, the luminous flux Φ can be derived from the distribution of illuminance E over a closed surface A around the light source using the re-

lation

$$\Phi = \int_{(A)} E \, dA \quad (8)$$

The illuminance distribution can be measured by means of a goniophotometer over a spherical surface around the light source. It is not necessary for the light source to be exactly at the centre of the imaginary sphere. It is, however, recommended that it should be positioned as close to the centre of the sphere as possible.

The minimum distance between the centre of the sphere and the photometer head depends on the largest dimension of the light source to be measured, for purely mechanical reasons. It may be smaller than the limiting photometric distance as long as the illuminance meter still evaluates illuminance correctly in terms of direction (cosine response), etc. <4>.

5.2 Types of goniophotometer

It is possible to distinguish between the different types of goniophotometer used for the measurement of illuminance distribution. In all of them the light source to be measured is operated in the prescribed burning position.

5.2.1 Goniophotometer with light source in a fixed position

In these goniophotometers the light source is operated in the prescribed burning position without being moved. The photometer head of the illuminance meter used for the measurement is rotated about two axes, which intersect one another at right angles, around the light source.

In the example depicted in Fig. 1a to 1c these two axes can be oriented arbitrarily in space by means of the outer frame, which remains stationary during a measurement.

In the terminology defined in the Appendix, the measurements are carried out in C-planes, with the innermost frame position characterised by the angle γ and the position of the middle frame by the angle C .

Fig. 1: Photograph of a model of a goniophotometer with a light source, which stays immobile in a fixed position

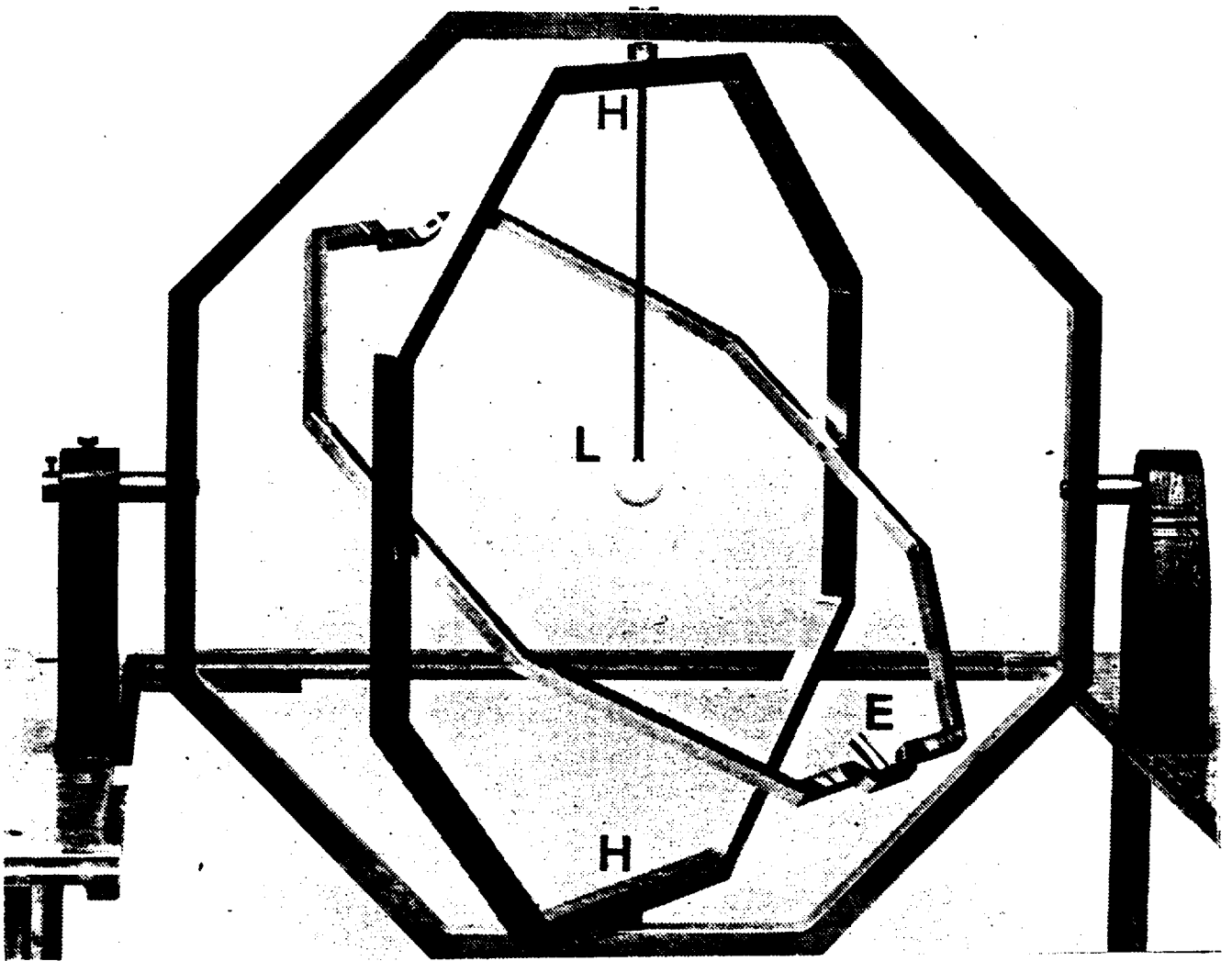


Fig. 1 a) For the luminous flux integration a compact light source L (e.g. an incandescent lamp) is supported on a holder H either from the top or the bottom of the frame. The holder is fixed rigidly to the external frame, which can be turned into any position, but is kept stationary during the measurement. The two inner frames move the photometer E over the surface of a sphere by rotating simultaneously.

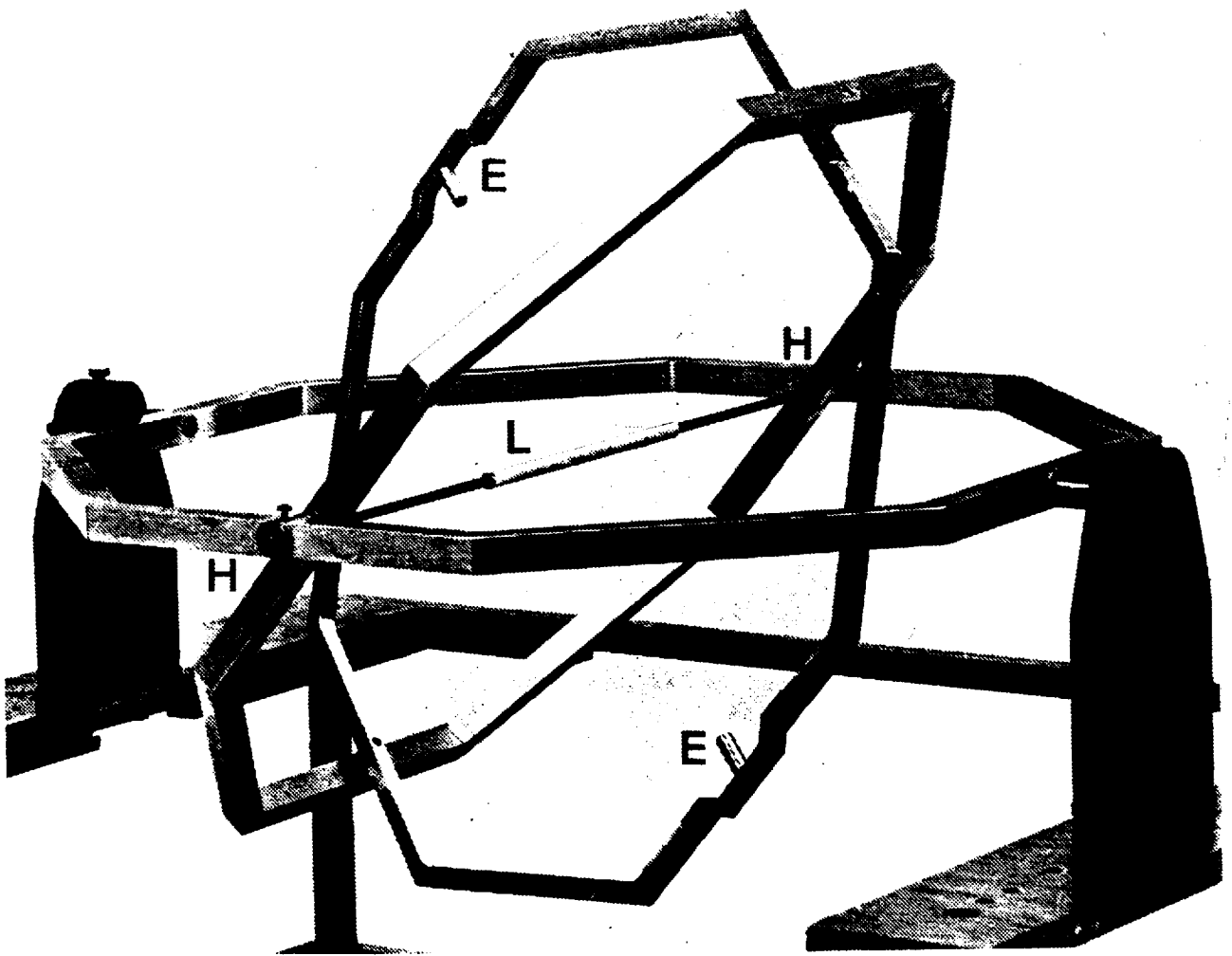


Fig. 1 b) With the external frame in a horizontal position the tubular lamp L is measured in a horizontal position. Mechanical support and electrical power are supplied via two lamp holders H. Two photometers E are moved over the surface of a sphere.

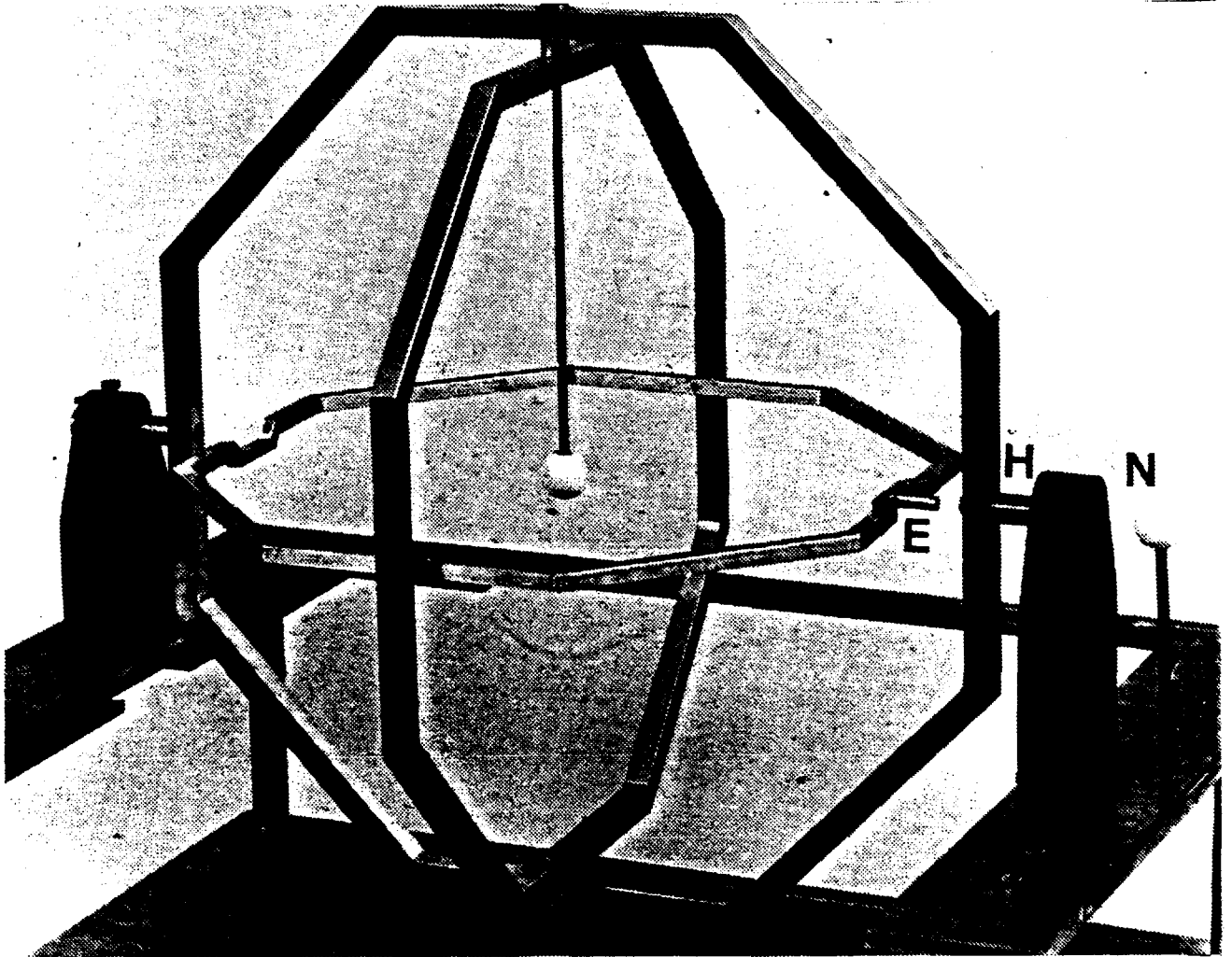


Fig. 1 c) To calibrate the photometer, the part of the inner frame carrying the photometer E is turned outwards by 180° . One of the bearings of the outer frame is hollow. Through it the luminous intensity standard lamp N, which is placed outside the system of rotating frames, illuminates the detector E with a known illuminance.