Product Categories

- Goniophotometer
- Spectroradiometer
- Integrating Sphere
- LED Test Instruments
- CFL Testing Instruments
- Photometer and Colorimeter
- EMI and EMC Test Systems
- Electronic Ballast Tester
- Electrical Safety Tester
- Environmental Test Chamber
- Plug and Switch Testing
- AC and DC Power Supply
- Object Color and Glossiness Test
- Mask Produce and Test Machine
- Electronic Components Test

High Precision Spectroradiometer Integrating Sphere System

Product No: LPCE-2(LMS-9000)

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Company*
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Message*
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61

1

Related Applications

LM-79 and LM-80 Test Solutions

LEDs and Luminaire Test Solutions

Description Video Download

LPCE-2 Integrating Sphere Spectroradiometer LED Testing System is for single LEDs and LED lighting products light measurement. LED's quality should be tested by checking its photometric, colorimetric and electrical parameters. According to CIE 177, CIE84, CIE-13.3, IES LM-79-19, Optical-Engineering-49-3-033602, COMMISSION DELEGATED REGULATION (EU) 2019/2015, IESNA LM-63-2, IES-LM-80 and ANSI-C78.377, it recommends to using an array spectroradiometer with an integrating sphere to test SSL products. The LPCE-2 system is applied with LMS-9000C High Precision CCD Spectroradiometer or LMS-9500C Scientific Grade CCD Spectroradiometer, and A molding integrating sphere with holder base. This sphere is more round and the test result is more accruacy than the traditional integrating sphere.


Fluorescent Lamp Test Solutions


Automotive Electronics Test Solutions

Related Standards

IEC International Electrotechnical Commission

CIE International Commission on Illumination

SASO Saudi Arabian Standards Organization

BIS Bureau of Indian Standards

NOM Norma Oficial Mexicana

• Electrical: Voltage, Current, Power, Power Factor, Displacement Factor, Harmonic
• LED Light Decay Test according to LM-80: Flux VS time, CCT VS time, CRI VS time, Power VS time, Power Factor VS time, Current VS time and Flux Efficiency VS time.

Option: The LPCE-2(LMS-9000C) or LPCE-2(LMS-9500C) work with a IS-1.5MT Constant Temperature Integrating Sphere and TMP-8 Multiplex Temperature Tester can fully meet IES LM-82

High Precision LPCE-2(LMS-9000C) System Configuration (It is suitable for the Middle & Small Manufactory or General Test Lab):
High Precision CCD Spectroradiometer (LMS-9000C), Optical Fiber (CFO-1.5M), Digital Power Meter (LS2050B/LS2050C/LS2012), DC Power Source (DC Series), AC Power Source (LSP-500VARC or LSP-500VARC-Pst), Integrating Sphere (IS-1.5MA and IS-0.3M), Standard Light Source (SLS-50W and SLS-10W), 19 Inch Cabinet (CASE-19IN). You can download the detail PDF here: LPCE-2 (LMS-9000C) High Precision CCD Spectroradiometer Integrating Sphere System Brochure

Specification:
• Spectral Wavelength Accuracy: ±0.3nm, Wavelength Reproducibility: ±0.1nm
• Sample Scanning Steps: ±0.1nm
• Accuracy of Chromaticity Coordinate (Δx, Δy): ±0.002 (under Standard A Lamp)
• Correlated Color Temperature CCT: 1,500K~100,000K, CCT Accuracy: ±0.3%
• Color Rendering Index Range: 0~100.0, Accuracy: ±(0.3%rd±0.3)
• Luminous Flux Range: 0.01-200,000lm; Photometric linear Accuracy: ±0.5%
• Stray light: <0.015%(600nm) and <0.03%(435nm)
• Integration Time: 0.1~10,000ms
• It can measure the temperatures inside and outside of integrating sphere
• Flux testing method: spectrum, photometric and spectrum with photometric revision
• The system includes the auxiliary lamp device and the software includes self-absorption function
• It can measure the temperatures inside and outside of integrating sphere
• Connect with PC via USB cable. The English version software can be run in Win7, Win8, Win10 and Win11 (The driver was Certificated by Microsoft)
• The LM-79 Photometric, Colorimetric and Electricity report can be exported PDF and LED Optical Maintenance test report can be exported Excel or PDF

LISUN Model	LMS-9000C	LMS-9000CUV-VIS	LMS-9000CVIS-NIR
Wavelength	350-800nm	200-800nm	350-1050nm

Agriculture lighting PAR, PPF and PPFD introduce and relevant test instruments
Color and spectrum measurement difference between goniospectraodiometer and integrating sphere system
Led test instruments supplier in China
Integrating sphere setup for the LED light measurement
What is the Integrating sphere, and how does it work
Integrating sphere: Sphere with light source
Based on the LM-79 standard, how to use the integrating spheres and spectrophotometers to test the LED luminaire
Agricultural plant growth market development
How you can use light source in an integrating sphere to get product reliability results

Related Successful Case

French-LISUN engineer repair LSG-1700B probe for customers free of charge
Germany-Customers independently installed LPCE-2 (LMS-9000) High Precision Spectroradiometer Integrating Sphere System by watching the video
France-Successfully installed LSG-1700B high-precision goniophotometer by watching the video

Spectroradiometer Integrating Sphere System Brochure

Specification:
• CCD detector: Hamamatsu TE-cooled (Temp: -10°C ±0.05°C) high sensitivity back-thinned detector
• Spectral wavelength accuracy: ±0.2nm, Resolution: ±0.1nm, Sample scanning steps: ±0.1nm
• Accuracy of chromaticity coordinate (Δx, Δy): ±0.0015 (under Standard A Lamp)
• Correlated color temperature CCT: 1, 500K~100, 000K, CCT accuracy: ±0.2%
• Color rendering index range: 0~100.0, Accuracy: ±(0.3%rd±0.3)
• Photometric linear Accuracy: ±0.2%
• Stray light: <0.015%(600nm) and <0.03% (435nm)
• Integration time: 0.1ms-60s
• It can measure the temperatures inside and outside of integrating sphere
• Flux testing method: spectrum, photometric and spectrum with photometric revision
• The system includes the auxiliary lamp device and the software includes self-absorption function
• It can measure the temperatures inside and outside of integrating sphere
• Connect with PC via USB cable. The English version software can be run in Win7, Win8, Win10 and Win11 (The driver was Certificated by Microsoft)
• The LM-79 Photometric, Colorimetric and Electricity report can be exported PDF and LED Optical Maintenance test report can be exported Excel or PDF

LISUN Model	LMS-9500C	LMS-9500CUV-VIS	LMS-9500CVIS-NIR
Wavelength	350-800nm	200-800nm	350-1050nm

Taejin Choi

2020-01-12

It was an essential product for manufacturing and research. I purchased it after confirming that it is a CIE/IEC certified product. The quality of the product is excellent and the satisfaction with the price is high. Employees are also satisfied with their response to repairs and after-sales services.

Tags : Integrating Sphere , LPCE-2 , LPCE-2 (LMS-9000A) , LPCE-2 (LMS-9000B) , LPCE-2 (LMS-9000C) , LPCE-2(LMS-9000) , Spectroradiometer

Precision Rotation Luminaire Goniophotometer by watching the vedio

Turkey–Install LSG-1700B Goniophotometer by watching the video

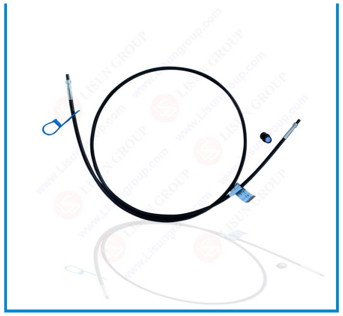
Iran-Free installation and training for LPCE-2(LMS-9000A)High precision spectrometer integrating sphere system

India-Installation and training for LSG-1700B Goniophotometer and Maintenance of LPCE-2 Integrating Sphere Testing System

India-LISUN engineer visit India to do installation and training for LPCE-2 High Precision Spectroradiometer Integrating Sphere System

Egypt – Installation of LSG-1800B Goniophotometer and LPCE-2 (LMS-9000B) Integrating Sphere System

IS-*MA Integrating Sphere With Holder Base



CFO-1.5M Optical Fiber

SLS-50W Standard Light Source

DC3005 Digital CC and CV DC Power Supply

Illuminating
ENGINEERING SOCIETY

IES LM-79-08

Approved Method: Electrical and Photometric Measurements of Solid-State Lighting Products

IES LM-79-08

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Contents

IES Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting Products

Foreword

This approved method is a guide developed for the measurement of solid state lighting (SSL) products. While many other standards for photometric measurements of light sources and luminaires are available, these standards are separated for measurement of lamps or luminaires. Since the current SSL products are in the forms of luminaires or lamps, and LED light sources in the luminaires are not easily separated as replaceable lamps, these existing standards cannot be applied directly to SSL products. This necessitates the use of absolute photometry. See the annex in this document for a description of how absolute photometry varies from relative photometry, which has historically been the lighting industry standard. Thus, this standard provides test methods addressing the requirements for measurement of SSL products. Since SSL technologies are still at their early stages, requirements for measurement conditions and appropriate measurement techniques may be subject to change at any time as the SSL technologies advance.

1.0 INTRODUCTION

1.1 Scope

This approved method describes the procedures to be followed and precautions to be observed in performing reproducible measurements of total luminous flux, electrical power, luminous intensity distribution, and chromaticity, of solid-state lighting (SSL) products for illumination purposes, under standard conditions. This approved method covers LED-based SSL products with control electronics and heat sinks incorporated, that is, those devices that require only AC mains power or a DC voltage power supply to operate. This document does not cover SSL products that require external operating circuits or external heat sinks (e.g., LED chips, LED packages, and LED modules). This document covers SSL products in a form of luminaires (fixtures incorporating light sources) as well as integrated LED lamps (see **section 1.3 f**). This document does not cover fixtures designed for SSL products sold without a light source. This document describes test methods for individual SSL products, and does not cover the determination of the performance rating of products, in which individual variations among the products should be considered.

1.2 General

SSL products as defined in this document utilize LEDs (including inorganic and organic LEDs) as the optical radiation sources to generate light for illumination purposes. An LED is a *p-n* junction semiconductor device that emits incoherent optical radiation when biased in the forward direction. White light is produced by LEDs using two methods: visible spectra of two or more colors produced by LEDs are mixed, or the emission (in the blue or ultraviolet region) from LEDs is used to excite one or more phosphors to produce broadband emission in the visible region (Stokes emission). A general description of LEDs and lighting is available in Ref. 1. Although constant current control is typical for stand alone LEDs, this document deals with integrated SSL products incorporating the semiconductor device level current control, thus the electrical parameters of interest are the SSL product's input electrical parameters.

For special purposes, it may be useful to determine the characteristics of SSL products when they are operated at other than the standard conditions described in this approved method. Where this is done, such results are meaningful only for the particular conditions under which they were obtained and these conditions shall be stated in the test report.

The photometric information typically required for SSL products is total luminous flux (lumens), luminous efficacy (lm/W), luminous intensity (candelas) in one or more directions, chromaticity coordinates, correlated color temperature, and color rendering index. For the purpose of this approved method, the determination of these data will be considered photometric measurements.

The electrical characteristics measured for AC-powered SSL products are input RMS AC voltage, input RMS AC current, input AC power, input voltage frequency and power factor. For DC-powered SSL products, measured electrical characteristics are input DC voltage, input DC current, and input power. For the purpose of this approved method, the determination of these data will be considered electrical measurements.

1.3 Nomenclature and Definitions

a) Units of electrical measurement are the volt, the ampere and the watt.
b) Units of photometric measurement are the lumen and the candela[2]. Chromaticity coordinates are specified in terms of the CIE recommended systems[3], the (x, y) or (u', v') chromaticity coordinates. To specify tolerance of chromaticity independent

from correlated color temperature (CCT), the (u', v') coordinates should be used. The chromaticity can also be expressed by CCT and Duv (signed distance from the Planckian locus on the CIE (u', $2/3\ u'$) diagram; defined in Ref. 4).

c) Regulation refers to the constancy of the voltage applied to the SSL product under test.

d) Seasoning time refers to the advance operation of the test SSL product for a given number of hours from the brand-new condition. Photometric data obtained immediately after this seasoning time is referred to as “initial” data.

e) Stabilization refers to the operation of test SSL products for a sufficient period of time such that the electrical and the photometric values become stable. This is sometimes called warm-up time.

f) Integrated LED lamp refers to an LED device with an integrated driver and a standardized base that is designed to connect to the branch circuit via a standardized lampholder/socket, (e.g., replacement of incandescent lamps with screw base).

g) LED luminaire refers to a complete LED lighting unit consisting of a light source and driver together with parts to distribute light, to position and protect the light source, and to connect the light source to a branch circuit. The light source itself may be an LED array, an LED module, or an LED lamp.

h) Preburning refers to operation of a light source prior to mounting on a measurement instrument, to shorten the required stabilization time on the instrument.

i) Photometer head refers to a unit containing a detector, a $V(\lambda)$-correction filter, and any additional components (aperture, diffuser, amplifier, etc.) within the unit.

2.0 AMBIENT CONDITIONS

2.1 General

Photometric values and electrical characteristics of SSL products are sensitive to changes in ambient temperature or air movement due to thermal characteristics of LEDs.

2.2 Air Temperature

The ambient temperature in which measurements are being taken shall be maintained at 25°C ± 1°C, measured at a point not more than 1 m from the SSL product and at the same height as the SSL product. The temperature sensor shall be shielded from direct optical radiation from the SSL product and optical radiation from any other source. If measurements are performed at other than this recommended temperature, this is a non-standard condition and shall be noted in the test report.

2.3 Thermal Conditions for Mounting SSL Products

The method of mounting can be the primary path for heat flow away from the device and can affect measurement results significantly. The SSL product under test shall be mounted to the measuring instrument (e.g., integrating sphere) so that heat conduction through supporting objects causes negligible cooling effects. For example, when a ceiling-mounted product is measured by mounting at a sphere wall, the product may be suspended in open air rather than directly mounted in close thermal contact with the sphere wall. Or, the product may be held by support materials that has low heat conductivity (e.g., Teflon). Any deviation from this requirement shall be evaluated for impact in measurement results. Also, care should be taken so that supporting objects do not disturb air flow around the product. If the SSL product under test is provided with a support structure that is designated to be used as a component of the luminaire thermal management system, the product shall be tested with the support structure attached. Any such support structure included in the measurement shall be reported.

2.4 Air Movement

The incidence of air movements on the surface of a SSL product under test may substantially alter electrical and photometric values. Air flow around the SSL product being tested should be such that normal convective air flow induced by device under test is not affected.

3.0 POWER SUPPLY CHARACTERISTICS

3.1 Waveshape of AC power supply

The AC power supply, while operating the SSL product, shall have a sinusoidal voltage waveshape at the prescribed frequency (typically 60 Hz or 50 Hz) such that the RMS summation of the harmonic components does not exceed 3 percent of the fundamental during operation of the test item.

3.2 Voltage Regulation

The voltage of an AC power supply (RMS voltage) or DC power supply (instantaneous voltage) applied to the device under test shall be regulated to within ±0.2 percent under load.

4.0 SEASONING OF SSL PRODUCT

For the purpose of rating new SSL products, SSL products shall be tested with no seasoning.

Note: Some LED sources are known to increase their light output slightly during the first 1000 h of operation; many other LED sources do not follow such behavior. The no seasoning requirement is adopted because the increase of light output of LED products from *0 h to 1000 h, if it occurs, is less than* several percent, which does not result in significant changes in initial luminous flux ratings or life ratings of the products.

5.0 STABILIZATION OF SSL PRODUCT

Before measurements are taken, the SSL product under test shall be operated long enough to reach stabilization and temperature equilibrium. The time required for stabilization depends on the type of SSL products under test. The stabilization time typically ranges from 30 min (small integrated LED lamps) to 2 or more hours for large SSL luminaires). The SSL product during stabilization shall be operated in the ambient temperature as specified in **section 2.2** and in the operating orientation as specified in 6. It can be judged that stability is reached when the variation (maximum – minimum) of at least 3 readings of the light output and electrical power over a period of 30 min, taken 15 minutes apart, is less than 0.5 %. The stabilization time used for each SSL product shall be reported.

For measurement of a number of products of the same model, stabilization methods other than described above (e.g., preburning of the product– see **section 1.3 h**) may be used if it has been demonstrated that the method produces the same stabilized condition (measured total luminous flux within 0.5 % agreement) as when using the standard method described above.

6.0 OPERATING ORIENTATION

The SSL product under test shall be evaluated in the operating orientation recommended by the manufacturer for an intended use of the SSL product. Stabilization and photometric measurements of SSL products shall be done in such operating orientation.

Note: The light emission process of an LED is not affected by orientation. However, the orientation of an SSL product can cause changes in thermal conditions for the LEDs used in the product, and thus the light output may be affected by orientation of the SSL product. The orientation of the SSL product as mounted for measurement shall be reported with the results.

7.0 ELECTRICAL SETTINGS

The SSL product under test shall be operated at the rated voltage (AC or DC) according to the specification of the SSL product for its normal use. Pulsed input electrical power and measurements synchronized with reduced duty cycle input power intended to reduce p-n junction temperatures below those reached with continuous input electrical power shall not be used for SSL product testing.

If the product has dimming capability, measurements shall be performed at the maximum input power condition. If the product has multiple modes of operation including variable CCT, measurement may be made at different modes of operation (and CCTs) if necessary, and such setting conditions shall be clearly reported.

8.0 ELECTRICAL INSTRUMENTATION

8.1 Circuits

For DC-input SSL products, a DC voltmeter and a DC ammeter are connected between the DC power supply and the SSL product under test. The voltmeter shall be connected across the electrical power inputs of the SSL product. The product of the measured voltage and the current gives the input electrical power (wattage) of the DC powered SSL products.

For AC-input SSL products, an AC power meter shall be connected between the AC power supply and the SSL product under test, and AC power as well as input voltage and current shall be measured.

8.2 Uncertainties

The calibration uncertainties (see note below) of the instruments for AC voltage and current shall be ≤ 0.2 percent. The calibration uncertainty of the AC power meter shall be ≤ 0.5 percent and that for DC voltage and current shall be ≤ 0.1 percent.

Note: Uncertainty here refers to relative expanded uncertainty with a 95 % confidence interval, normally with a coverage factor k=2, as prescribed in Refs. 5 and 6. If manufacturer's specification does not specify uncertainty this way, then manufacturers should be contacted for proper conversion.

9.0 TEST METHODS FOR TOTAL LUMINOUS FLUX MEASUREMENT

The total luminous flux (lumen) of SSL products shall be measured with an integrating sphere system or a goniophotometer. The method may be chosen depending on what other measurement quantities (color, intensity distribution) need to be measured, the size of SSL products, and other requirements. Some guidance on the use of each method is given below.

<Integrating sphere system>
The integrating sphere system is suited for total luminous flux and color measurement of integrated LED lamps and relatively small-size LED luminaires (see **section 9.1.2** for the guidance on the size of SSL products that can be measured in an integrating sphere of a given size). The integrating sphere system has the advantage of fast measurement and does not require a dark room. Air movement is minimized and temperature within the sphere is not subject to the fluctuations potentially present in a temperature-controlled room. It should be noted that the heat from the SSL product mounted in or on the integrating sphere may accumulate to increase the ambient temperature of the product under test (see **section 9.1.1** for further details).

Two types of integrating sphere systems are used, one employing a V(λ)-corrected photometer head (sphere-photometer, see **section 9.2**), and another employing a spectroradiometer as the detector (sphere-spectroradiometer, see **section 9.1**). Spectral mismatch errors (see **section 9.2.6**) occur with the first method due to the deviation of the relative spectral responsivity of the integrating sphere photometer from the V(λ), while there are theoretically no spectral mismatch errors with the second method. The spectroradiometer method is preferred for measurement of SSL products because spectral mismatch errors with the photometer head (see **section 1.3 i**) tend to be significant for LED emissions and correction is not trivial, requiring knowledge of the system spectral responsivity as well as the spectrum of the device under test. In addition, with the spectroradiometer method, color quantities can be measured at the same time as total luminous flux. See **sections 9.1** and **9.2** for further descriptions on both methods. General recommendations for measurement with integrating sphere photometers are available in Refs. 7 and 8.

<Goniophotometer>
Goniophotometers provide measurement of luminous intensity distribution as well as total luminous flux. Goniophotometers can measure total luminous flux of SSL products of relatively large size (corresponding to dimensions of traditional fluorescent lamp luminaires) while they can measure small SSL products as well. A goniophotometer is installed in a dark room, normally temperature-controlled, and is not subject to heat accumulation from a source being measured. Care must be taken, however, for drafts from ventilation that might affect measurement of SSL products that are sensitive to temperature. The ambient temperature must be measured and maintained as specified in **section 2.2**. Measurements with a goniophotometer are time-consuming compared to a sphere photometer. Goniophotometers using broadband photopic detectors are susceptible to the spectral mismatch errors noted above. In fact, correction for spectral mismatch can be more difficult if there is significant variation in color with angle. See **section 9.3** for the use of goniophotometers for measurement of SSL products. General recommendations on goniophotometry are available in Refs. 8 and 9.

9.1 Integrating sphere with a spectroradiometer (Sphere-spectroradiometer system)

This type of instrument measures total spectral radiant flux (unit: W/nm), from which total luminous flux and color quantities are calculated. By using an array spectroradiometer, the measurement speed can be of the same magnitude as for a photometer head.

9.1.1 Integrating sphere The size of the integrating sphere should be large enough to ensure that the measurement errors due to effects of baffle and self-absorption (see **section 9.1.5**) by the test SSL product are not significant. See **section 9.1.2** for the guidance on the size of the sphere required relative to the size of the SSL products to be measured. In general, sphere size of 1 m or larger is typically used for compact lamps (size of typical incandescent and compact fluorescent lamps), and 1.5 m or larger for larger lamps (e.g., size of 4-foot linear fluorescent lamps and HID lamps). The sphere should also be large enough to avoid excessive temperature increase due to heat from the light source being measured. 2 m or larger spheres are typically used for measurement of light sources of 500 W or larger.

The integrating sphere shall be equipped with an auxiliary lamp for self-absorption measurement (see **section 9.1.5**). The auxiliary lamp for a sphere-spectroradiometer system must emit broadband radiation over the entire spectral range of the spectroradiometer. Thus, a quartz halogen lamp is typically used for this purpose. The auxiliary lamp light output needs to be stable throughout all of the self-absorption measurements.

An interior coating reflectance of 90 % to 98 % is recommended for the sphere wall, depending on the sphere size and usage of the sphere. A higher reflectance is advantageous for higher signal obtained, and smaller errors associated with spatial nonuniformity of sphere response and intensity distribution variations of the SSL products measured. Higher reflectance is preferred particularly for a sphere-spectroradiometer system to ensure sufficient signal-to-noise ratios in the entire visible region. It should be noted, however, that, with higher reflectance, the sphere responsivity becomes more sensitive to self-absorption effects and long-term drift, and also, there will be more variation in spectral throughput. If there is an opening in the sphere, the average reflectance should be considered, and higher coating reflectance will be advantageous to compensate for the decrease of average reflectance.

9.1.2 Sphere geometry **Figure 1** shows recommended sphere geometries of a sphere-spectroradiometer system for total luminous flux measurement of SSL products. The reference standards are for total spectral radiant flux. The 4π geometry (a) is recommended for all types of SSL products including those emitting light in all directions (4π sr) or only in a forward direction (regardless of orientation). The 2π geometry (b) is acceptable for SSL products emitting light only in forward directions (regardless of orientation), and may be used for SSL products having a large housing or fixture that are too large to use the 4π geometry. In either geometry, the size of the SSL product under test should be limited for a given size of the sphere to ensure sufficient spatial uniformity of light integration and accurate correction for self-absorption. For measurement of integrated LED lamps, the sphere may be equipped with a lamp holder with a screw-base socket.

In the 4π geometry, as a guideline, the total surface area of the SSL product should be less than 2 % of the total area of the sphere wall. This corresponds to, for example, a spherical object of less than 30 cm diameter in a 2 m integrating sphere. The longest physical dimension of a linear product should be less than 2/3 of the diameter of the sphere.

In the 2π geometry, the opening diameter to mount a SSL product should be less than 1/3 of the diameter of the sphere. The SSL product shall be mounted within the circular opening and in such a way that its front edges are flush with the edges of the opening (or it can be slightly inside the sphere to ensure that all emitted light is caught in the sphere). In this case, the gaps between the edges of the opening and the SSL product (or reference standard) can be covered with a surface (inner side is white) in order that the measurement can be made in a room with normal ambient lighting as the sphere is completely shielded from outside (See **Figure 2** (a)). If this is not convenient and the gaps are to be kept open, a dark room arrangement (around the opening, at least) may be necessary so that no external light or reflected light enters the sphere (See **Figure 2** (b)). In either case, the SSL product under test should be mounted to the sphere so that support material or structure does not conduct the heat from the SSL product to the sphere wall. See also **section 2.3**.

In either geometry, the size of the baffle should be as small as possible to shield the detector port from direct illumination from the largest test SSL product to be measured or the standard lamp. It is recommended that the baffle is located at 1/3 to 1/2 of

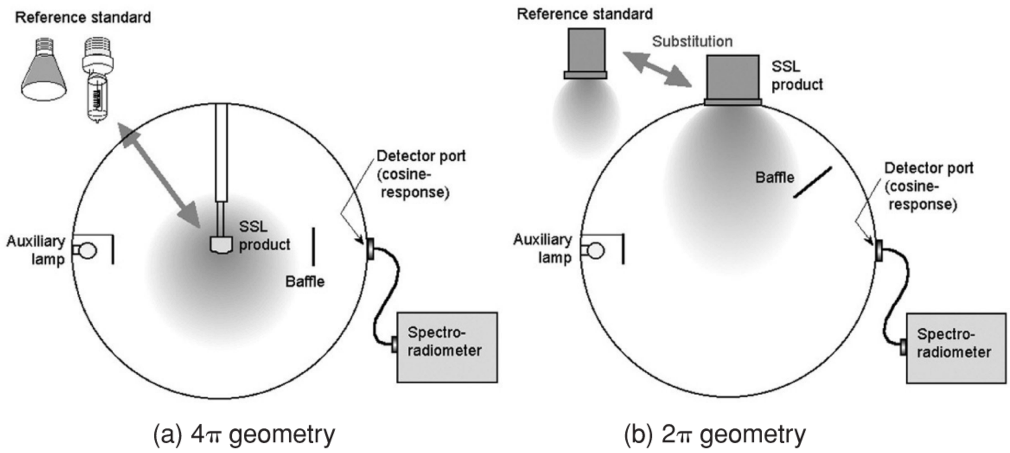


Figure 1. Recommended sphere geometries for total luminous flux measurement using a spectroradiometer. (a): for all types of SSL products, (b): for SSL products having only forward emission.

the radius of the sphere from the detector port. The auxiliary lamp should have a shield so that its direct light does not hit any parts of the SSL product under test or the detector port.

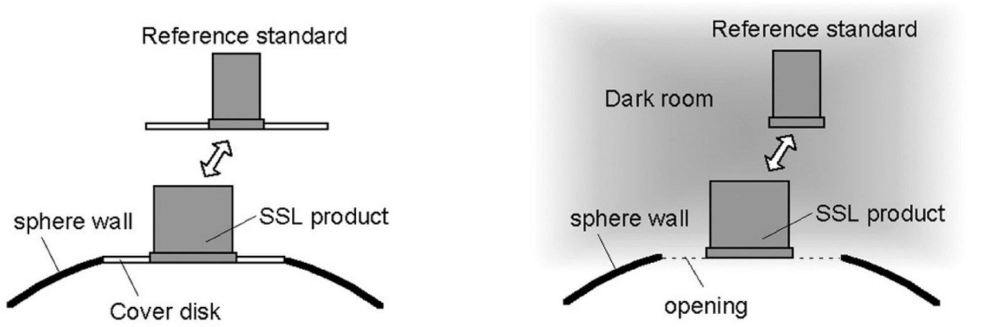
Standard lamps for total spectral radiant flux are normally quartz-halogen incandescent lamps that have broadband spectrum to calibrate the spectroradiometer for the entire visible region. For the 2π geometry, standard lamps having only forward distributions are required. For example, a quartz-halogen lamp with a reflector providing appropriate intensity distributions may be used as a reference standard source. For the 4π geometry, standard lamps having omni-directional intensity distributions are commonly used but standard lamps having forward intensity distributions may also be needed. Note that the light output of incandescent standard lamps changes if their burning position is changed.

It should be noted that integrating spheres do not have perfectly uniform responsivity over their internal sphere surfaces. The sphere responsivity tends to be slightly lower for the lower half of the sphere due to contamination by falling dust, and also around the sphere seams where small gaps exist. Therefore, if a sphere (4π geometry) is calibrated with an omni-directional standard lamp and measures an SSL product having downward intensity distributions, the luminous flux tends to be measured slightly lower than it is. This error tends to be more prominent for light sources having narrow beam distributions. The magnitude of errors depends on how well the sphere is designed and maintained, and will be cancelled if the angular intensity distributions of the standard lamp and the test SSL products are the same. To ensure that this error is not significant, standard lamps having different intensity distributions (omni-direction, downward/broad, downward/narrow) may be prepared and chosen for the type of SSL products to be measured. Or, if only omni-directional standard lamps are used, correction factors should be established and applied when SSL products having different intensity distributions are measured. Such correction factors may be established by measuring lamps or SSL products having different intensity distributions calibrated for total luminous flux using other accurate means (e.g., calibration traceable to national measurement institute (NMI), or using well-designed goniophotometer).

The ambient temperature in a sphere shall be monitored according to **section 2.2**. A temperature probe is often mounted behind the baffle that shields the detector port from the light source if the baffle is mounted at the same height as the center of the sphere (case of **Figure 1** (a)). When a SSL product is mounted on the sphere wall (e.g., case of **Figure 1** (b)), the ambient temperature shall be measured behind the baffle (side of spectroradiometer) in the sphere, in addition to the ambient air outside the sphere near the product (follow **section 2.2**). Both readings must meet the 25±1°C requirement.

If the ambient temperature in the closed sphere exceeds 25±1°C due to the heat generated by the SSL product under test, the SSL product may be stabilized with the sphere partially open to achieve the required ambient temperature within 25±1°C until measurement is made with the sphere closed. When measurement is taken, the sphere should be closed gently to avoid air movement inside the sphere. Note that, if the stability of the flux output of the product is monitored with the sphere photometer when the sphere is open, the room lights should be turned off and the position of open hemispheres should not be moved.

9.1.3 Principle of measurement The instrument (integrating sphere plus spectroradiometer) must be calibrated against a reference standard calibrated for total spectral radiant flux. Since the integrating sphere is included in this calibration, the spectral throughput of the sphere need not be known. The total spectral radiant flux $\Phi_{TEST}(\lambda)$ of a SSL product under test is obtained by comparison to that of a reference standard $\Phi_{REF}(\lambda)$:



(a) SSL product mounted with a cover disk.

(b) SSL product mounted without a cover disk.

Figure 2. Mounting conditions of the SSL product under test.

$$\Phi_{\mathrm{TEST}}(\lambda) = \Phi_{\mathrm{REF}}(\lambda) \cdot \frac{y_{\mathrm{TEST}}(\lambda)}{y_{\mathrm{REF}}(\lambda)} \cdot \frac{1}{\alpha(\lambda)} \quad (1)$$

where $y_{\mathrm{TEST}}(\lambda)$ and $y_{\mathrm{REF}}(\lambda)$ are the spectroradiometer readings for SSL product under test and for reference standard, respectively, and $\alpha(\lambda)$ is the self-absorption factor (see **section 9.1.5**).

From the measured total spectral radiant flux $\Phi_{\mathrm{TEST}}(\lambda)$ [W/nm], the total luminous flux Φ_{TEST} [lm] is obtained by

$$\Phi_{\mathrm{TEST}} = K_{\mathrm{m}} \int_{\lambda} \Phi_{\mathrm{TEST}}(\lambda) V(\lambda) \mathrm{d}\lambda \quad (2)$$

$$(K_{\mathrm{m}} = 683 \text{ lm/W})$$

9.1.4 Spectroradiometer Either mechanical scanning type or array type spectroradiometers may be used. The array spectroradiometer has the advantage of shorter measurement time due to the multiplex nature of arrays. The spectroradiometer shall have a minimum spectral range from 380 nm to 780 nm. The defined visible spectral region is 360 nm to 830nm[2].

The detector port of the integrating sphere shall be a flat diffuser or a satellite sphere (a very small integrating sphere-detector system with an opening) mounted flush to the sphere coating surface, so that the input of the spectroradiometer at the detector port has an approximate cosine response with the directional response index f_2 (CIE Pub. 69)[10] being less than 15%. It should be noted that an optical fiber input (with no additional optics), often provided with array spectrometers, has a narrow acceptance angle and should not be used without additional optics for cosine correction.

Calibrated spectroradiometers measure photometric quantities without spectral mismatch errors; however, there remain many other sources of error associated with spectroradiometers. Note that errors in some poor quality array spectroradiometers can be larger than high quality photometer heads. Errors can be significant when the spectral distribution of a test SSL product is dissimilar to the standard source (tungsten source). Major sources of error include bandwidth, scanning interval, wavelength accuracy, spectral stray light, detector nonlinearity, and input geometry. For accurate colorimetry, a bandwidth and scanning interval of 5 nm or smaller are required for spectroradiometric methods. Follow other recommendations given in Ref. 3,22 to minimize the errors and evaluate measurement uncertainties.

9.1.5 Self-absorption correction Self-absorption is the effect, in which the responsivity of the sphere system changes due to absorption of light by the lamp itself in the sphere. Errors can occur if the size and shape of the test light source is different from those of the standard light source. The self-absorption correction is critical, since the physical size and shape of the SSL products under test are typically very different from the reference standard size and shape. The self-absorption is wavelength dependent because the spectral reflectance of the sphere coating is not spectrally flat. The self-absorption factor is given by,

$$\alpha(\lambda) = \frac{y_{\mathrm{aux,TEST}}(\lambda)}{y_{\mathrm{aux,REF}}(\lambda)} \quad (3)$$

where $y_{\mathrm{aux,\,TEST}}(\lambda)$ and $y_{\mathrm{aux,\,REF}}(\lambda)$ are the spectroradiometer readings for the auxiliary lamp when the SSL product under test or the reference total spectral radiant standard, respectively, are mounted in or on the sphere (4π or 2π geometry). In this case, the SSL product and the reference standard are not operated. Only the auxiliary lamp is operated.

9.1.6 Calibration The instrument (integrating sphere plus spectroradiometer) shall be calibrated against total spectral radiant flux standards traceable to an NMI.

9.2 Integrating sphere with a photometer head (Sphere-photometer system)

This method is a traditional approach of integrating sphere photometry, using a photometer head as the detector for an integrating sphere. This method is acceptable but less preferred due to the potential for large spectral mismatch errors in the measurement of luminous flux of SSL products (if the mismatch corrections are not applied) and also due to a need for separate measurement instruments for color quantities.

9.2.1 Integrating sphere See descriptions given in 9.1.1, which also apply to this method, except for a difference in the requirement of auxiliary lamp. For a sphere-photometer system, the auxiliary lamp does not have to be limited to incandescent lamps. Rather, it is advantageous to use an auxiliary lamp that has a spectral distribution similar to those of the SSL products typically measured, so that self-absorption is measured accurately especially when the self-absorption is very large (α<0.8) or when the housing of SSL product under test is large and strongly colored. The auxiliary lamp needs to be stable throughout the self-absorption measurement of all SSL products under test. A stable white LED source, for example, may be used.

9.2.2 Sphere geometry The recommended integrating sphere geometries for this method are shown in **Figure 3**. The difference from **Figure 1** is that a photometer head is used as the detector. See **section**

9.1.2 for recommendations and requirements using these 4π and 2π geometries. All the descriptions in **section 9.1.2** apply for this method except differences in the requirements of reference standard lamp.

The reference standard lamps are assigned total luminous flux, and the same requirements as given in **section 9.1.2** on the different intensity distributions apply. For example, for a narrow beam SSL product, standard lamps having similar narrow beam intensity distribution should be used. If only omni-directional standard lamps are used, correction factors should be established for different types of intensity distribution.

While reference standards are traditionally incandescent lamps, they do not have to be limited to incandescent lamps for a sphere-photometer system. Stable and reproducible SSL products (e.g, using temperature-controlled white LED sources) may be used as a reference standard of total luminous flux. It is advantageous, in reducing spectral mismatch errors, to have the spectral distribution of the reference standard to be similar to that of typical SSL products measured. Using SSL products as a reference standard may also be advantageous in achieving angular intensity distributions similar to those of the SSL products to be measured.

9.2.3 Principle of measurement The total luminous flux of the test device is obtained by comparison to that of a reference standard:

$$\Phi_{TEST} = \Phi_{REF} \bullet \frac{y_{TEST}}{y_{REF}} \bullet \frac{F}{\alpha} \qquad (4)$$

where Φ_{REF} is the total luminous flux (lumen) of the reference standard, y_{TEST} and y_{REF} are the photometer signals for SSL product under test and for reference standard, respectively. F is the spectral mismatch correction factor (see **section 9.2.6**), and α is the self-absorption factor (see **section 9.2.5**). If factor F is not determined, F=1 should be used and the resulting uncertainty should be considered.

9.2.4 Photometer head The photometer head (see **section 1.3 i**) shall have relative spectral responsivity well matched to the V(λ) function, while the spectral throughput of the sphere also affects the total spectral responsivity. The f_1' value (defined in CIE Pub. 69)[10] of the total sphere system (photometer head plus integrating sphere) shall be less than 3 %. To further reduce uncertainty of measurements, a spectral mismatch correction may be applied. See **section 9.2.6** for the procedures for determining f_1' value and spectral mismatch correction factor.

The photometer head shall have an approximate cosine response with the f_2 value[10] (directional response index) of less than 15 %, and the diffuser surface shall be mounted flush to the sphere coating surface. If a satellite sphere is used for cosine response, its opening shall not be recessed; the opening edges of the satellite sphere shall be flush to the integrating sphere coating surface.

9.2.5 Self-absorption correction A self-absorption correction shall be applied unless test SSL product and luminous flux reference standard are of the same model and same size (strict substitution). The self-absorption factor can be measured by

$$\alpha = \frac{y_{aux,TEST}}{y_{aux,REF}} \qquad (5)$$

where $y_{aux,TEST}$ and $y_{aux,REF}$ are the photometer signals for the auxiliary lamp when the SSL product under test or the total luminous flux reference standard, respectively, is mounted in or on the sphere (4π or 2π

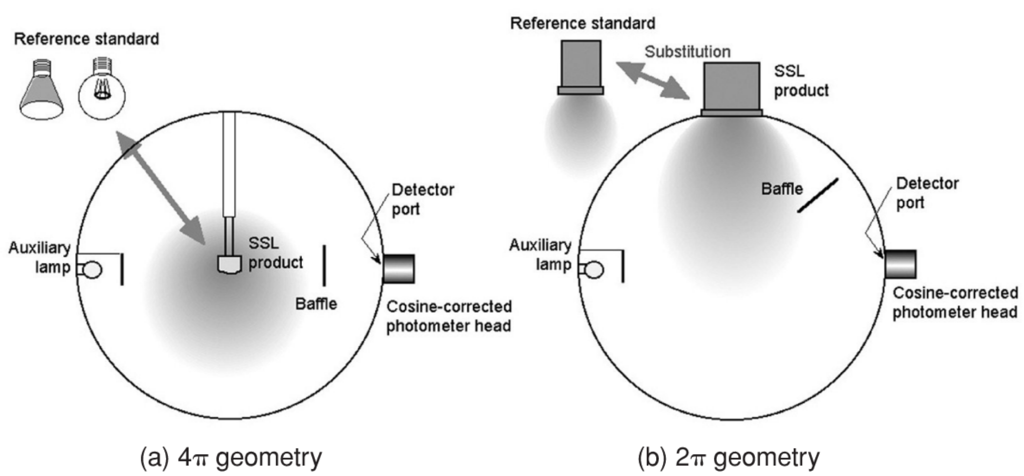


Figure 3. Recommended sphere geometries for total luminous flux measurement using a photometer head. (a): for all types of SSL products, (b): for SSL products having only forward emission.

geometry). They are not operated; only the auxiliary lamp is operated. The auxiliary lamp can be a halogen or incandescent lamp or a white LED source.

9.2.6 Determination of f_1' and Spectral Mismatch Correction Factor The spectral responsivity of the integrating sphere photometer cannot be perfectly matched to the V(λ) function. An error (called *spectral mismatch error*) occurs when a test SSL product has a different spectral power distribution from that of the standard source. The f_1' value[10] is an index that indicates the degree of mismatch in spectral responsivity, and the value (in %) gives a rough indication of the magnitude of errors that can occur for general white light sources, but errors can be larger than the f_1' value for SSL products consisting of only a few narrowband emissions.

To determine f_1' value, the relative spectral responsivity of the total sphere system $s_{rel}(\lambda)$ must be obtained. $s_{rel}(\lambda)$ is given as a product of relative spectral responsivity of the photometer head $s_{ph,rel}(\lambda)$ and the relative spectral throughput of the sphere $T_{rel}(\lambda)$:

$$s_{rel}(\lambda) = s_{ph,rel}(\lambda)\, T_{rel}(\lambda) \tag{6}$$

The $s_{ph,rel}(\lambda)$ should be measured in hemispherical illumination geometry. If it is measured only in normal direction, uncertainty should be determined. $T_{rel}(\lambda)$ is theoretically given by

$$T_{rel}(\lambda) = k \bullet \frac{\rho_a(\lambda)}{1-\rho_a(\lambda)} \tag{7}$$

where $\rho_a(\lambda)$ is the average reflectance of the entire inner sphere surfaces (including ρ=0 for an opening, if there is one) and k is a normalization factor. If $\rho_a(\lambda)$ of the integrating sphere in use is measured accurately, $T_{rel}(\lambda)$ may be obtained using this equation. However, integrating spheres in use are more or less contaminated and the data of coating samples tend to deviate from the reflectance of the real sphere surface. Therefore, it is recommended that $T_{rel}(\lambda)$ be directly measured on the integrating sphere using the procedures given in the Annex B of Ref. 7.

Once $s_{rel}(\lambda)$ is determined, f_1' is calculated by

$$f_1' = \frac{\int_\lambda \left| s^*_{rel}(\lambda) - V(\lambda) \right| d\lambda}{\int_\lambda V(\lambda)\, d\lambda} \times 100\% \quad \text{with} \tag{8}$$

$$s^*_{rel}(\lambda) = \frac{\int_\lambda S_A(\lambda) V(\lambda)\, d\lambda}{\int_\lambda S_A(\lambda)\, s_{rel}(\lambda)\, d\lambda} \bullet s_{rel}(\lambda)$$

where $S_A(\lambda)$ is spectral distribution of CIE Illuminant A and $V(\lambda)$ is the spectral luminous efficiency function.

With knowledge of $s_{rel}(\lambda)$ and the relative spectral power distribution $S_{TEST}(\lambda)$ of the SSL product under test, the spectral mismatch correction factor F is given by:

$$F = \frac{\int_\lambda S_{REF}(\lambda) s_{rel}(\lambda) d\lambda \int_\lambda S_{TEST}(\lambda) V(\lambda) d\lambda}{\int_\lambda S_{REF}(\lambda) V(\lambda) d\lambda \int_\lambda S_{TEST}(\lambda) s_{rel}(\lambda) d\lambda} \tag{9}$$

where, $S_{REF}(\lambda)$ is the spectral distribution of the reference standard source. Spectral mismatch errors can be corrected by multiplying the factor F to the measured lumen value of the SSL product. The accuracy of $S_{TEST}(\lambda)$ is generally not very critical, and thus, the nominal spectral distribution of a product may be used.

For further details on f_1' and spectral mismatch correction, see Refs. 10 and 7.

9.2.7 Calibration The integrating sphere photometer shall be calibrated against total luminous flux standards traceable to an NMI.

9.3 Goniophotometer

Goniophotometers are normally used for measurement of luminous intensity distribution, from which total luminous flux can be obtained.

9.3.1 Type of Goniometer Goniophotometers shall be the type that maintains the burning position unchanged with respect to gravity; therefore, only Type C goniophotometers[9] are allowable. Type C goniophotometers include moving detector goniometers and moving mirror goniophotometers. Care should be exercised to prevent light reflected from the mechanical structure of the goniophotometer or any other surface including secondary reflections from surfaces of the SSL product itself from reaching the photodetector. The speed of rotation of the positioning equipment should be such as to minimize the disturbance of the thermal equilibrium of the SSL product.

9.3.2 Principle of Total Luminous Flux Measurement By measuring the luminous intensity distribution $I(\theta,\phi)$ of the source, the total luminous flux is obtained by

$$\Phi = \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} I(\theta,\phi) \sin\theta\, d\theta\, d\phi \tag{10}$$

If the photometer head is calibrated for measuring illuminance $E(\theta,\phi)$,

$$\Phi = r^2 \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} E(\theta,\phi) \sin\theta\, d\theta\, d\phi \tag{11}$$

where r is the rotation radius of the reference plane of the photometer head. A sufficiently long photometric distance, *r*, is required for measurement of luminous intensity distribution (See **section 9.3.1**).

The distance requirement is not critical if only total luminous flux is to be measured. As indicated by Eq. (11), as long as the illuminance is measured accurately, the total luminous flux can be measured accurately even with a relatively short photometric distance (radius r), thus less space for the goniophotometer is required for a given size of light source to be measured. In this case, the detector must have cosine corrected angular responsivity within its field of view for the test SSL product. By definition given in Eq. (11), the location of the light source relative to the rotation center is theoretically not relevant, and therefore, the alignment of light source is not critical for measurement of total luminous flux.

9.3.3 Scanning resolution Scanning resolution fine enough to accurately define the test sample shall be used. For typical wide-angle, smooth intensity distributions, a 22.5° lateral (horizontal) and 5° longitudinal (vertical) grid may be acceptable. Finer angle resolution (smaller test increments) shall be used where the luminous intensity from the SSL product is changing rapidly or is erratic, such as in beam forming sources. Further guidance on selecting the correct scanning resolution, based on experience gained over the years testing other luminaire and lamp types, are in Refs. 9, 11-17.

9.3.4 Angle coverage The range of the angular scan must cover the entire solid angle to which the SSL product emits light. A disadvantage of a goniophotometer, when measuring total luminous flux, is that a goniophotometer in general has some angular region where emission from a light source under test is blocked by its mechanism (e.g., an arm for SSL product holder) so that measurement in that direction cannot be made (such angle is called dead angle). This is not a problem for SSL products that emit light only in the forward direction similar to many existing fixtures. However, this can be a problem for SSL products that emit light in all directions (e.g., integrated LED lamps similar to compact fluorescent lamps). Goniophotometers with a large dead angle are not suited for total flux measurement of such SSL products. If the dead angle is small (e.g., ±10° or less), it is possible to interpolate the missing data points with an additional uncertainty.

9.3.5 Polarization It should be noted that mirror type goniophotometers have a detection system that is polarization sensitive due to the slightly polarizing characteristics of mirrors themselves. Sensitivity to polarized light can cause significant errors when measuring the total luminous flux of SSL products that emit polarized light. For measurement of such SSL products, goniophotometers that do not use a mirror are recommended. Some mirror type goniophotometers have an option to mount a photometer head directly on the rotating arm for such purposes.

9.3.6 Photometer head The photometer head of the goniophotometer should have relative spectral responsivity matched to the V(λ) function. The f'_1 value[10] of the spectral responsivity shall be less than 3 %. It is further desirable to apply spectral mismatch corrections for the photometer reading. For determination of f'_1 and spectral mismatch correction factor, see eqs. (8) and (9) in **section 9.2.6**, with $s_{rel}(\lambda)$ being the relative spectral responsivity of the photometer head, measured in normal direction.

For the total luminous flux measurement described in **section 9.3.2**, the photometer head shall have good cosine response within the angle range where light is incident, with the $f_2(\varepsilon,\phi)$ value (relative deviation from the cosine function)[10] of less than 2 % within the acceptance angle range. The field-of-view of the photometer head should be limited (e.g., using aperture screens) in order to shield stray light reflected from the angles other than from the light source being measured. To minimize stray light errors within the field-of-view of the photometer, it is recommended to use a light trap on the other side of the detector arm and/or use low reflectance materials (such as black velvet) for the wall and floor surfaces.

9.3.7 Calibration The goniophotometers for measuring luminous intensity distribution shall be calibrated against the illuminance or luminous intensity standards traceable to national standards. In addition, goniophotometers for measuring total luminous flux shall be validated by measurement of total luminous flux standard lamps traceable to national standards. Such validation measurements should use standard lamps having similar angular intensity distributions (directional / omni-directional) as the types of SSL products to be tested with the goniophotometer.

10.0 LUMINOUS INTENSITY DISTRIBUTION

The recommendations given in **section 9.3** pertain to goniophotometers used to measure luminous intensity distribution as well as total luminous flux. For measurement of luminous intensity distribution, a sufficient photometric distance should be used – generally, more than five times of the largest dimension of the test SSL product having broad angular distributions. A longer distance may be needed for narrow beam sources (e.g., see Ref. 13).

The coordinate system and geometry for mounting SSL products should follow the practice used in traditional luminaire testing in specific applications[9,11-17]. The absolute luminous intensity distribution (referred to as *absolute photometry method* in traditional luminaire testing; e.g., see Ref. 16) of measured SSL products shall be reported. Note that presentation of normalized luminous intensity data using the *relative photometry method, commonly used in traditional luminaire testing,* cannot be used for SSL products. If calculation of zonal flux is needed, guidance is available in Annex A of Ref. 16.

Electronic data of measured luminous intensity distributions, if necessary, shall be prepared in the "IES file" format for absolute photometry specified in IES LM-63.[18] IES file is an electronic data format that can be used by specifiers and designers to reliably predict illuminance levels in design applications. The data, however, should be used with the understanding that the photometric file describes the performance of a single luminare and does not necessarily represent the average performance of a group of the same SSL Luminaires.

11.0 LUMINOUS EFFICACY

The luminous efficacy (lm/W) of the SSL product, η_v, is given as the quotient of measured total luminous flux Φ_{TEST} (lumen) and the measured electrical input power P_{TEST} (watt) of the SSL product under test as

$$\eta_v = \frac{\Phi_{TEST}}{P_{TEST}} \text{ [lm/W]} \qquad (12)$$

Note that the luminous efficacy described above is *luminous efficacy of a source* as defined in Ref. 19. It should not be confused with *luminous efficacy of radiation*, which is the ratio of luminous flux (lumen) to radiant flux (watt) of the source.

12.0 TEST METHODS FOR COLOR CHARACTERISTICS OF SSL PRODUCTS

The color characteristics of SSL products include chromaticity coordinates, correlated color temperature, and color rendering index. These characteristics of SSL products may be spatially non-uniform, and thus, in order that they can be specified accurately, the color quantities shall be measured as values that are spatially averaged, weighted to intensity, over the angular range where light is intentionally emitted from the SSL product.

12.1 Method using a sphere-spectroradiometer system

The first recommended method to achieve this is to measure total spectral radiant flux using a sphere-spectroradiometer system as described in **section 9.1**. The measured total spectral radiant flux is a spatially integrated quantity, thus color characteristics calculated from this are already spatially averaged. Follow the recommendations given in **section 9.1** to perform measurements with this method.

General recommendations on the use of spectroradiometers for color measurements are available in Refs. 20 and 21. Various error analyses and correction methods in spectral color measurement are available in Ref. 22.

12.2 Method using a spectroradiometer or colorimeter spatially scanned

This method may be used when a sphere-spectroradiometer system is not available, or when the test sample is too large to be measured with a sphere-spectroradiometer system. This method uses a spectroradiometer and/or a colorimeter that measures the chromaticity of the SSL product under test in different directions. This can be achieved most efficiently by mounting the color-measuring instrument on a goniometer (called *gonio-spectroradiometer*, or *gonio-colorimeter*). The luminous intensity distribution and chromaticity coordinates can be measured at the same time, taking readings at appropriate angle intervals (see **section 9.3.3**) over the entire angle range where the light is intentionally emitted from the product. Then, the spatially averaged chromaticity is obtained from all measured points using Eq. (13) below, or based on spatially integrated tristimulus values.

If a gonio-spectroradiometer or *gonio-colorimeter* is not available, this can also be achieved by manually positioning the instrument for given directions at a constant distance, as the angle accuracy is not very critical in this measurement. The chromaticity coordinates and luminous intensity (or illuminance) shall be measured at 10° or less intervals for vertical angle θ over the angle range where light is intentionally emitted from the source and at minimum two horizontal angles ϕ=0° and 90° (see **Figure 4**). The chromaticity measurements need to be made only for the θ angles where the average luminous intensity is more than 10 % of the peak intensity. The average chromaticity coordinates (x, y) or (u', v') shall be obtained as a weighted mean of all measured points, weighted by the illuminance and the solid angle factor at each point as below.

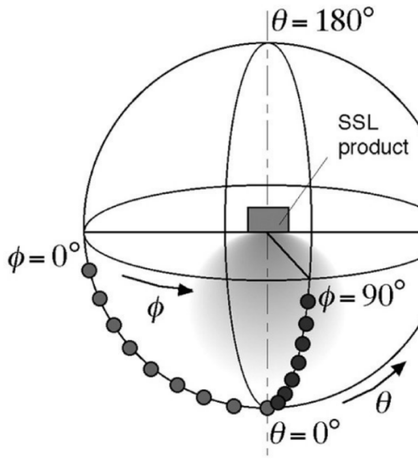


Figure 4. Geometry for the chromaticity measurement using a goniometer (the figure shows the case for a SSL product emitting light in downward directions only).

The chromaticity coordinates and luminous intensity for ϕ=0° and ϕ=90° (or more ϕ angles) are first averaged at each θ angle and expressed as $x(\theta_i)$, $y(\theta_i)$ and $I(\theta_i)$ where θ_i =0°, 10°, 20°,…., 180°. Then the average chromaticity coordinate x_a is calculated as a weighted mean:

$$x_a = \sum_{i=1}^{19} x(\theta_i) \cdot w_i(\theta_i) \quad \text{with} \quad w_i(\theta_i) = \frac{I(\theta_i) \cdot \Omega(\theta_i)}{\sum_{i=1}^{19} I(\theta_i) \cdot \Omega(\theta_i)} \tag{13}$$

and

$$\Omega(\theta_i) = \begin{cases} 2\pi\left[\cos(\theta_i) - \cos\left(\theta_i + \frac{\Delta\theta}{2}\right)\right]; \text{ for } \theta_i = 0° \\ 2\pi\left[\cos\left(\theta_i - \frac{\Delta\theta}{2}\right) - \cos\left(\theta_i + \frac{\Delta\theta}{2}\right)\right]; \text{for } \theta_i = 10°, 20°, \ldots 170° \\ 2\pi\left[\cos\left(\theta_i - \frac{\Delta\theta}{2}\right) - \cos(\theta_i)\right]; \text{for } \theta_i = 180° \end{cases}$$

$$\Delta\theta = 10°$$

Chromaticity coordinate y_a and other average color quantities are calculated similarly. This formula is an approximation but provides sufficient accuracy for practical applications. Rigorously, the spatially integrated color quantities are calculated from the geometrically-total flux of the tristimulus values, X, Y, Z.

If a tristimulus colorimeter is used, it should be calibrated against the test SSL product by comparison with a spectroradiometer, or it should measure only color differences from a reference point (e.g, perpendicular direction), and the chromaticity of the reference point should be measured with a spectroradiometer so that absolute chromaticities at all the points are obtained based on the spectroradiometer reading. The photometric output (illuminance) also needs to be recorded to calculate the weighted average described above. For this color uniformity measurement, the measurement distance shall be more than 5 times the largest dimension of the light-emitting area of the product under test.

If the spatial nonuniformity of color of a given product has been determined to be negligibly small ($\Delta u'v' \leq 0.001$, see **section 12.5**), the average chromaticity of the product of the same model can be measured in one direction near the peak of its intensity distribution.

The spectroradiometer used in this measurement (described in **section 12.2**) shall be calibrated against spectral irradiance or spectral radiance standards traceable to a national metrology institute.

12.3 Spectroradiometer parameters impacting measured color characteristics

The spectroradiometer shall have a minimum spectral range of 380 nm to 780 nm. The spectroradiometer used in either methods (**sections 12.1** or **12.2**) should be selected and set up so that the relative spectral distribution is measured accurately even for SSL products having narrowband spectral distributions. The bandwidth and scanning intervals are among important parameters for measurement of spectral distributions of light sources in general. The bandwidth and wavelength scanning intervals shall be 5 nm or smaller (unless appropriate correction methods are applied) and should be matched unless wavelength intervals are very small (e.g., 1 nm or less). Further details are available in Refs. 3, 20, 21. Various error analyses and correction methods (bandpass, stray light, etc.) in spectral color measurements for various light sources including LEDs are available in Ref. 22.

12.4 Colorimetric calculations

The chromaticity coordinates (x, y) and/or (u', v'), and correlated color temperature (CCT, unit: Kelvin) are calculated from the relative spectral distribution of the SSL product according to the CIE definitions (Ref. 3). CCT is defined as the temperature of a Planckian radiator having the chromaticity nearest the chromaticity of the light source on the $(u', 2/3\ v')$ chromaticity diagram (known as CIE 1960 (u, v) diagram, now obsolete). The Color Rendering Index (CRI) is calculated according to the formulae defined in Ref. 23.

12.5 Spatial non-uniformity of chromaticity

SSL products may have variation of color with angle of emission. Spatial non-uniformity of chromaticity shall be evaluated using the measurement conditions described in **section 12.2**. The spatial distribution of chromaticity coordinates of the SSL product are measured at two vertical planes (ϕ=0°, ϕ=90°), and the spatially averaged chromaticity coordinate is calculated from these points according to eq. (13). The spatial non-uniformity of chromaticity, $\Delta u'v'$, is determined as the maximum deviation (distance on the CIE (u', v') diagram) among all measured points from the spatially averaged chromaticity coordinate. For this evaluation, accuracy only in chromaticity differences is critical, and thus, all measurements may be made with a tristimulus colorimeter if a spectroradiometer is not available.

13.0 UNCERTAINTY STATEMENT

If statement of uncertainty is required, follow the recommendations given in Refs. 5 and 6. For all photometric measurements, use expanded uncertainty with a confidence interval of 95 %, thus, in most cases, using the coverage factor k=2.

14.0 TEST REPORT

The test report shall list all significant data for each SSL product tested together with performance data. The report shall also list all pertinent data concerning conditions of testing, type of equipment, SSL products and reference standards. Typical items reported are:

a) Date and testing agency
b) Manufacturer's name and designation of SSL product under test
c) Measurement quantities measured (total luminous flux, luminous efficacy, etc.)
d) Rated electrical values (clarify AC (frequency) or DC) and nominal CCT of the SSL product tested
e) Number of hours operated prior to measurement (0 h for rating new products)
f) Total operating time of the product for measurements including stabilization
g) Ambient temperature
h) Orientation (burning position) of SSL product during test
i) Stabilization time
j) Photometric method or instrument used (sphere-photometer, sphere-spectroradiometer, or goniophotometer)
k) Designation and type of reference standard used (wattage, lamp type, intensity distribution type - omni-directional/directional) and its traceability
l) Correction factors applied (e.g., spectral mismatch, self-absorption, intensity distribution, etc.)
m) Photometric measurement conditions (for sphere measurement, diameter of the sphere, coating reflectance, 4π or 2π geometry. For goniophotometer, photometric distance.)
n) Measured total luminous flux (lm) and input voltage (V), current (A), and power (W) of each SSL product
o) Luminous intensity distribution (if applicable).
p) Color quantities (chromaticity coordinates, CCT and/or CRI for white light products)
q) Spectral power distribution (if applicable)
r) Bandwidth of spectroradiometer, if spectral distribution and/or color quantities are reported
s) Equipment used
t) Statement of uncertainties (if required)
u) Deviation from standard operating procedures, if any

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Annex (Informative)

This annex provides background information regarding the development of this standard. This annex explains how the measurement of solid-state lighting (SSL) products differ from measurement of traditional lamps and luminaires, why this standard is needed, and why sampling is not addressed.

Why Solid-State Lighting is Different

In photometric measurements of traditional lamps and luminaires, the operating conditions are different depending on the type of lamp. These operating conditions include the reference ballast, electrical measurement, stabilization time, handling of lamp, and more. Thus different standards were developed for different lamp types and even luminaires that use multiple lamp types. Standards for measurement of SSL products are needed because LED sources have different requirements for operation and temperature conditions than traditional light sources.

SSL products can be in the form of lamps such as integrated LED lamps, or luminaires, which range in scale from small lamps to the size of large fluorescent luminaires. Depending on the size and quantities needed, these products may be measured in an integrating sphere or a goniophotometer. Thus SSL products are measured by lamp photometry engineers as well as by luminaire photometry engineers, having different practices and culture. This standard brings a common basis and uniform measurement methods for both groups of engineers.

Traditionally, photometric measurements have been made for lamps and for luminaires separately using different test methods. Lamps are typically measured with integrating spheres, and total luminous flux and chromaticity are the main quantities of interest. Luminaires are normally measured with goniophotometers, and luminous intensity distribution and luminaire efficiency are the main quantities of interest. Standards have been developed separately for measurement of lamps (such as LM-9 linear fluorescent lamps, LM-45 incandescent lamps, and LM-66 for compact fluorescent lamps) and for measurement of luminaires (such as LM-41 for indoor fluorescent luminaires). However, for most current SSL products, LED lamps cannot be separated from luminaires, and the nature of SSL products resembles both light sources and luminaires. Thus, none of the existing standards for lamps or luminaires are directly applicable to SSL products.

Relative and Absolute Photometry

Traditional luminaire photometry methods do not work for SSL products because traditionally, luminaires are normally tested with a goniophotometer using a procedure called *relative photometry*. In this method, a luminaire under test and the bare lamp(s) used in the luminaire are measured separately. Then the luminous intensity distribution data of the luminaire measured with the goniophotometer are normalized by the measured total luminous flux of lamps used in the tested luminaire. Therefore, the luminous intensity distribution is normally presented in relative scale (e.g., candela per 1000 lumens). Such test methods cannot be used for SSL products because, in most SSL products, LED lamp sources are not designed to be separated from the luminaire. Even if the LED source can be separated and measured separately, the relative photometry method will not work accurately because the light output of the LED source will change significantly if operated outside the luminaire due to differences in thermal conditions. Therefore, existing standards for measurement of luminaires cannot be used for SSL products.

Some IES standards (e.g., LM-35-02) describe the *absolute photometry* method, in which the absolute luminous intensity distribution of a luminaire is measured without separate measurement of the lamps. SSL products should be measured using such absolute photometry method. However, absolute photometry is rarely used for traditional luminaires and is not described in sufficient detail in these standards. **Section 9.3** of this standard describes detailed requirements for such absolute photometry for total luminous flux measurement of SSL products.

Sampling

With the *relative photometry* method commonly used for luminaires, the results are independent from individual variations of lamp lumen output because of the normalization using the measured total luminous flux of lamps. As a result, the individual variation of lamp light output due to lamp variation and variation in the ballast factor of the control gear is removed.

Inconsistencies in luminous flux measurements as a result of variations in luminaire geometry are normally insignificant when the inconsistencies due to variations in the luminous flux produced by the lamp(s) are removed. It should be noted that the variation in luminous flux provided by the lamp is a function of both the lamp(s) and their ballast/control gear. As a result, it has been historically sufficient to measure only one sample for rating a luminaire product. This is the practice often used in performance rating of luminaires. On the other hand, the results of measurement of SSL products are directly affected by the output of the sources, and are always subject to individual variations of LED sources, which tend to be significantly larger than even those of fluorescent lamps. Therefore, measurement of one sample is insufficient for rating SSL products and appropriate sampling and averaging of results is required for SSL products. The tolerance requirements for individual product variations may be different for different applications. LM-79 describes test methods for individual SSL products and does not cover such sampling methods for rating products, which should be covered by a regulatory requirement, customer requirement or agency requirement.

Next Steps

This standard will continue to evolve as the SSL industry evolves. In particular, measurement of luminaire characteristics using goniophotometry will need to be further detailed. Requirements of luminaires differ for different lighting applications, and it will require substantial efforts to cover this area. The IES Testing Procedures Committee will continue work to improve this standard as well as develop additional standards and methods needed for measurement of SSL products.

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