



Approved Method **Total Flux Measurement of Lamps Using an Integrating Sphere**



IES Approved Method for Total Flux Measurement of Lamps Using an Integrating Sphere

Publication of this Lighting Measurement
has been approved by the IES.
Suggestions for revisions
should be directed to the IES.

Copyright 2017 by the Illuminating Engineering Society.

Approved by the IES Standards Committee, January 9, 2017, as a Transaction of the Illuminating Engineering Society.

All rights reserved. No part of this publication may be reproduced in any form, in any electronic retrieval system or otherwise, without prior written permission of the IES.

Published by the Illuminating Engineering Society, 120 Wall Street, New York, New York 10005.

IES Standards and Guides are developed through committee consensus and produced by the IES Office in New York. Careful attention is given to style and accuracy. If any errors are noted in this document, please forward them to Brian Liebel, IES Director of Standards and Research, at the above address for verification and correction. The IES welcomes and urges feedback and comments.

ISBN # 978-0-87995-357-7

Printed in the United States of America.

DISCLAIMER

IES publications are developed through the consensus standards development process approved by the American National Standards Institute. This process brings together volunteers representing varied viewpoints and interests to achieve consensus on lighting recommendations. While the IES administers the process and establishes policies and procedures to promote fairness in the development of consensus, it makes no guaranty or warranty as to the accuracy or completeness of any information published herein.

The IES disclaims liability for any injury to persons or property or other damages of any nature whatsoever, whether special, indirect, consequential or compensatory, directly or indirectly resulting from the publication, use of, or reliance on this document

In issuing and making this document available, the IES is not undertaking to render professional or other services for or on behalf of any person or entity. Nor is the IES undertaking to perform any duty owed by any person or entity to someone else. Anyone using this document should rely on his or her own independent judgment or, as appropriate, seek the advice of a competent professional in determining the exercise of reasonable care in any given circumstances.

The IES has no power, nor does it undertake, to police or enforce compliance with the contents of this document. Nor does the IES list, certify, test or inspect products, designs, or installations for compliance with this document. Any certification or statement of compliance with the requirements of this document shall not be attributable to the IES and is solely the responsibility of the certifier or maker of the statement.



Documents

Document Sharing Hub

Prepared by
The IES Testing Procedures Sub-Committee on Photometry of Light Sources

Steven Long, *Chair*

L. Ayers*	S. Ellersick*	R. Low*	D. Rogers*
R. Bergman	D. Ellis	J. Marella	M. Sapcoe
E. Bretschneider*	B. Feagin*	G. McKee	K. Tracy*
E. Carter*	A. Gelder*	D. Miletich*	V. Wu*
D. Chan*	P.-C. Hung*	C. Miller	R. Young*
G. Connelly*	A. Jackson	M. Nadal*	G. Yu*
R. Daubach*	D. Karambelas*	Y. Ohno*	Y. Zong
J. Demirjian*	T. Kawabata*	M. Piscitelli*	
M. Duffy*	M. Kotrebai	B. Rao*	* Advisory
P. Elizondo*	J. Leland*	S. Rao*	**Honorary

IES Testing Procedures Committee

C. Cameron Miller, *Chair*
Rebecca Kuebler, *Vice Chair*
David Ellis, *Secretary*
Jianzhong Jiao, *Treasurer*

C. Andersen	K. Hemmi*	M.-H. Lu*	L. Stafford*
L. Ayers	Y. Hiebert*	J. Marella	G. Steinberg
A. Baker	R. Higley*	J. Marsh*	W. Sun*
R. Berger	R. Horan*	P. McCarthy	L. Swainston*
R. Bergin*	J. Hospodarsky	G. McKee	R. Taylor*
R. Bergman	S. Hua*	D. Miletich*	K. Tracy*
C. Bloomfield*	J. Hulett	M. Minarczyk*	R. Tuttle*
E. Bretschneider	P.-C. Hung	Z. Mooney*	T. Uchida*
K. Broughton*	D. Husby**	M. Nadal*	J. Vollers*
E. Carter*	A. Jackson	D. Nava*	K. Wagner*
D. Chan*	D. Jenkins*	D. O'Hare*	J. Walker*
P.-T. Chou*	J. Jiao	Y. Ohno*	Y. Wang*
G. Connelly*	D. Karambelas*	J. Pan*	H. Waugh*
J. Creveling*	H. Kashani*	D. Park*	D. Weiss*
J. Dakin*	T. Kawabata*	N. Peimanovic*	J. Welch*
R. Daubach*	R. Kelley*	E. Perkins*	K. Wilcox*
L. Davis*	M. Kotrebai	M. Piscitelli*	V. Wu*
J. Demirjian*	J. Lawton*	G. Plank*	J. Yon
M. Duffy*	L. Leetzow*	E. Radkov	R. Young*
P. Elizondo	J. Leland*	D. Randolph*	J. Zhang*
P. Franck*	K. Lerbs*	C. Richards*	Y. Zong*
J. Fye*	R. Levin*	E. Richman*	
A. Gelder*	R. Li*	D. Rogers*	* Advisory
M. Grather	M. Liang*	M. Sapcoe	**Honorary
Y. Guan*	K. Liepmann*	A. Serres*	
K. Haraguchi*	S. Longo	A. Smith	
R. Heinisch*	R. Low*	R. Speck*	

Contents

FOREWORD	1
INTRODUCTION	1
1.0 SCOPE	1
2.0 NORMATIVE REFERENCES	1
3.0 NOMENCLATURE AND DEFINITIONS	1
3.1 Total Luminous Flux	1
3.2 Sphere Efficacy	1
3.3 Sphere Responsivity	2
4.0 PHYSICAL AND ENVIRONMENTAL TEST CONDITIONS	2
5.0 INTEGRATING SPHERE EQUIPMENT	2
5.1 Integrating Sphere Geometry: 4π	2
5.2 Integrating Sphere Geometry: 2π	3
5.3 Sphere Coating	3
5.4 Baffle	5
5.5 Auxiliary Lamp	5
5.6 Photometer Detection	6
5.7 Spectroradiometer Detection	7
5.8 Lamp Holder and Mounting Hardware	7
5.9 Temperature Sensor	8
5.10 Electrical Circuits	8
6.0 CALIBRATION STANDARDS	8
6.1 Incandescent Standard Lamps	8
6.2 Incandescent Reflector Lamps	8
6.3 Discharge Standard Lamps	9
6.4 Solid-State Lighting Standard Products	9
6.5 Handling of Standards Lamps	9
6.6 Operation of Standard Lamps	9
7.0 TEST PROCEDURES	10
7.1 Total Luminous and Total Spectral Radiant Flux Calibration	10
7.1.1 Integrating Sphere with Photometer	10
7.1.2 Integrating Sphere with Spectroradiometer	10
7.2 Test Lamp Measurement Procedure	10
7.2.1 Integrating Sphere with Photometer	10
7.2.2 Integrating Sphere with Spectroradiometer	11
7.3 Sources of Error	11
7.3.1 Self-Absorption	11
7.3.2 Spectral Mismatch	12
7.3.3 Sphere Angular Non-uniformity	12



Documents

Document Sharing Hub

7.3.4	Near-Field Absorption	13
7.3.4	Temperature Effects	13
8.0	UNCERTAINTY EVALUATION	14
9.0	MAINTENANCE OF INTEGRATING SPHERES	14
	INFORMATIVE REFERENCES	15
	ANNEX A – BASIC INTEGRATING SPHERE THEORY	15
	ANNEX B – MEASUREMENT OF THE RELATIVE SPECTRAL THROUGHPUT OF AN INTEGRATING SPHERE.....	17
	ANNEX C – CORRECTION FOR THE ANGULAR NON-UNIFORMITY ERRORS OF AN INTEGRATING SPHERE.....	18
	ANNEX D – ALTERNATIVE GEOMETRIES AND CALIBRATION METHODS.....	18

Copyrighted material

FOREWORD

This document is one of a continuing series of IES Approved Methods prepared to define a baseline for acceptable photometric procedures leading to improved agreement among laboratories. This Approved Method document explains a particular technique for total flux measurement of all types of lamps and luminaires using integrating spheres. The main improvement in this document compared to IES LM-78-2007 is the addition of spectral measurements. While most statements are written using *lamp*, they apply to lamps and luminaires.

INTRODUCTION

Total luminous flux is the angularly integrated, photopically weighted, total light output from a lamp. Total luminous flux is one of the most important parameters for non-directional, general lighting products. While luminous intensity and beam angle are typically more important for directional lamps, such as reflector lamps, and luminaires, total luminous flux is still an important quantity. Regulations are usually based on luminous efficacy (lm/W), which is the total luminous flux divided by the electrical input power of the light-emitting device. This document describes techniques for measuring the total flux of lamps and luminaires. One method is exclusive to total luminous flux measurements: an integrating sphere system using a photometer. The second method described, an integrating sphere system using a spectroradiometer, is used to measure a variety of angularly integrated quantities. The integrating sphere system has the advantage of fast measurements 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. The approved method is based on the comparison of the total luminous flux or total spectral radiant flux of a test lamp or luminaire to the total luminous flux or total spectral radiant flux of a standard lamp in an integrating sphere system.

While photometric and spectral integrating sphere measurement systems are very similar, they each have positive and negative aspects. Photometric measurement systems use a $V(\lambda)$ -corrected photometer head, which suffers from spectral mismatch errors. Spectral mismatch errors occur because relative spectral responsivity of the integrating sphere photometric system deviates from the $V(\lambda)$ function. The spectral integrating

sphere measurement system does not have spectral mismatch errors. Spectral integrating sphere measurement systems are capable of measuring the integrated color quantities of a light-emitting device; however, they are susceptible to spectral stray light and stability concerns. The two measurement techniques are compared and contrasted in this document along with the techniques required to make high quality measurements.

1.0 SCOPE

This approved method describes the procedures to be followed and precautions to be observed in performing reproducible measurements of total flux of lamps and luminaires using integrating sphere measurement systems. Two types of integrating sphere systems are presented, one employing a $V(\lambda)$ -corrected photometer head, and another employing a spectroradiometer as the detector. In addition to the specifics of the two measurement systems, the common qualities and measurement techniques are discussed along with calibration and uncertainty analysis considerations.

2.0 NORMATIVE REFERENCES

IES. ANSI/IES RP-16-17. Nomenclature and Definitions for Illuminating Engineering. New York: Illuminating Engineering Society; 2017.

3.0 NOMENCLATURE AND DEFINITIONS

3.1 Total Luminous Flux

While the luminous flux (Φ_v) is defined in the International Lighting Vocabulary (ILV; CIE 2011) as the quantity derived from the radiant flux, Φ_e by evaluating the radiation according to its action upon the CIE standard photometric observer, the total luminous flux is the cumulative luminous flux of a light emitting device over the solid angle of 4π sr. The total luminous flux is often called "luminous flux" in photometry practice. The unit of total luminous flux is the lumen.

3.2 Sphere Efficacy

Sphere efficacy (E_d/Φ_v) is the ratio of the illuminance E_d at the detector port to the total luminous flux Φ_v of a light emitting device in the sphere, in units of lm/W.

3.3 Sphere Responsivity

The sphere responsivity (y_d/Φ_v) of the system is the ratio of the photometer signal y_d to the total luminous flux Φ_v of a light emitting device in the sphere.

4.0 PHYSICAL AND ENVIRONMENTAL TEST CONDITIONS

The integrating sphere efficacy can be slightly affected by changes in temperature or humidity. The responsivity of the photometer head on the integrating sphere is also affected by changes of temperature (typically approximately 0.1 percent per degree Celsius of change). Further integrating sphere efficacy is affected by dust and particulates that accumulate on the integrating sphere coating. Thus, it is preferred to place the integrating sphere in a clean, reasonably temperature-controlled environment. For lighting devices that emit a significant amount of heat, the integrating sphere may be slightly ajar during the stabilization time. Once the lighting device is stabilized, the sphere should be closed and the measurements made as quickly as possible.

The ambient conditions are more critical for measurements of particular types of discharge lamps and solid-state lighting products. For example, fluorescent lamps are required to be operated in an ambient temperature of 25 °C ± 1 °C. (Refer to the appropriate LM document for the required ambient conditions for each lamp type to be measured.)

5.0 INTEGRATING SPHERE EQUIPMENT

5.1 Integrating Sphere Geometry: 4π

Figure 1 shows the geometry of a typical integrating sphere system for total flux measurements where the test lamp is mounted in the center of the sphere and the light output is measured in all directions (4π steradians, sr). The integrating sphere is equipped with a photometer head or spectroradiometer, a baffle, an auxiliary lamp assembly, a diffusely reflective sphere coating, lamp mounting hardware, lamp holder and associated electrical wiring.

The optimum size of the sphere should be chosen by considering the following factors:

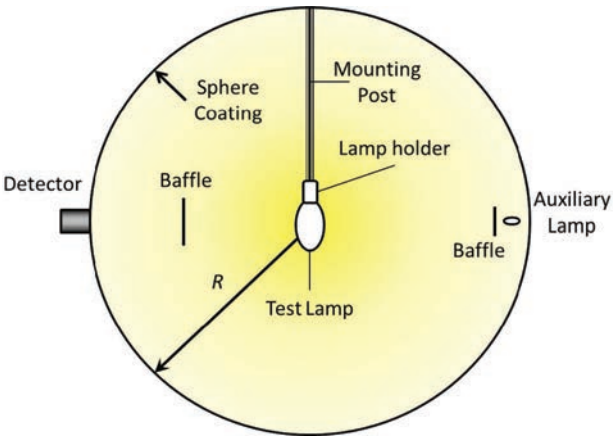


Figure 1: Basic geometry of a 4π integrating sphere measurement system. (Image courtesy of Yoshi Ohno and Cameron Miller.)

- A. Size of the Lamp (thus, required size of the baffle)
- B. Self-absorption of the lamp, lamp holder and lamp mounting hardware (see Section 7.3.1)
- C. Internal sphere temperature
- D. Sphere responsivity (lowest measurable total flux)

Factors A, B, and C drive the sphere to be as large as possible, while factor D limits the sphere size. Factors B and D are affected by the chosen reflectivity of the sphere coating. In the 4π geometry, as a guideline, the total surface area of the lamp should be less than 2 percent of the total area of the sphere wall.^a A general rule is to have the sphere diameter larger than 10 times the *largest dimension* of small lamps and 1.5 times the length of linear lamps to be measured. When linear fluorescent lamps and other linear lamps are measured in an integrating sphere against an incandescent standard lamp, an error occurs due to the difference in geometrical shape (length) of the lamp. If a part of the light source is near the sphere wall, the sphere responsivity for that part of the source will be slightly higher because the emitted light is incident at larger angles than normal, and the coating reflectance increases as the angle of incidence increases (e.g., approximately 0.4 percent increase at 45° incidence for pressed barium sulfate). The angular dependence of the diffuse reflectance of the coating depends on the material and surface conditions. If the size of the sphere is determined as recommended (sphere diameter larger than 1.5 times the length of the linear lamp), this error should be negligible. Commercial integrating spheres of 1 m to 3 m in diameter are used for total flux measurements of lamps.

^a This corresponds to, for example, a spherical object less than 30 cm in diameter in a 2-m integrating sphere.