

ANSI/IES **LS-3-20**



Illuminating
ENGINEERING SOCIETY

**LIGHTING SCIENCE:
PHYSICS AND OPTICS
OF RADIANT ENERGY**
AN AMERICAN NATIONAL STANDARD

Currently in preview, click buy full version



www.ies.org

ANSI/IES LS-3-20

**LIGHTING SCIENCE:
PHYSICS AND OPTICS OF RADIANT ENERGY**
AN AMERICAN NATIONAL STANDARD

Publication of this Recommended Practice
has been approved by IES.
Suggestions for revisions
should be directed to IES.

Prepared by
The IES Testing Procedures Committee



Copyright 2020 by the Illuminating Engineering Society.

Approved by the IES Standards Committee February 13, 2020 as a Transaction of the Illuminating Engineering Society.

Approved April 21, 2020 as an American National Standard.

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 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, they should be forwarded to Brian Liebel, Director Standards, at standards@ies.org or the above address for verification and correction. The IES welcomes and urges feedback and comments.

Printed in the United States of America.

ISBN# 978-0-87995-365-2

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.

AMERICAN NATIONAL STANDARD

Approval of an American National Standard requires verification by ANSI that the requirements for due process, consensus, and other criteria have been met by the standards developer.

Consensus is established when, in the judgment of the ANSI Board of Standards Review, substantial agreement has been reached by directly and materially affected interests. Substantial agreement means much more than a simple majority, but not necessarily unanimity. Consensus requires that all views and objections be considered, and that a concerted effort be made toward their resolution.

The use of American National Standards is completely voluntary; their existence does not in any respect preclude anyone, whether that person has approved the standards or not, from manufacturing, marketing, purchasing, or using products, processes, or procedures not conforming to the standards.

The American National Standards Institute does not develop standards and will in no circumstances give an interpretation to any American National Standard. Moreover, no person shall have the right or authority to issue an interpretation of an American National Standard in the name of the American National Standards Institute. Requests for interpretations should be addressed to the secretariat or sponsor whose name appears on the title page of this standard.

CAUTION NOTICE: This American National Standard may be revised at any time. The procedures of the American National Standards Institute require that action be taken to reaffirm, revise, or withdraw this standard no later than five years from the date of approval. Purchasers of American National Standards may receive current information on all standards by calling or writing the American National Standards Institute.

Prepared by the IES Testing Procedures Committee.

Becky Kuebler, *Chair*

Andrew Jackson, *Vice Chair*

David N. Randolph, *Secretary*

Jianzhong Jiao, *Treasurer*

Members

C. K. Andersen

R. P. Bergin

R. S. Bergman

E. Bretschneider

D. J. Ellis

K. C. Fletcher

M. L. Grather

Y. H. Hiebert

J. Hospodarsky

J. N. Hulett

P.-C. Hung

M. Kotrebai

J. E. Leland

K. M. Liepmann

S. Longo

J. P. Marella

P. McCarthy

G. McKee

C. C. Miller

S. Mitsuhashi

E. Radkow

D. Rogers

M. B. S. S. S. S.

J. C. Volter

Advisory Members

L. M. Ayers

J. Baker

C. A. Bloomfield

B. Boudreaux

P.-T. Chou

M. Cruz

M. Damle

L. Davis

M. E. Duffy

J. J. Demirjian

V. Eberhard

P. Elizondo

J. Frazer

K. J. Hemmi

S. Hua

G. John

J. Juhasz

H. Kashaninejad

T. Kawabata

R. Kelley

J. D. Kramer

K. C. Lerbs

J. Lockner

Y. Nichia

Y. Ohno

E. Page

D. Park

E. S. Perkins

M. Piscitelli

T. W. Robinson

M. P. Royer

T. Schneider

A. W. Serres

C. A. Steinberg

J. Swainston

J. S. Swiernik

S.-H. Teoh

A. Thorseth

R. C. Tuttle

J. E. Walker

Y. Zong

CONTENTS

1.0	Introduction and Scope	1
1.1	Introduction	1
1.2	Scope	1
2.0	Optical Radiation	1
2.1	Physical Models of Optical Radiation	1
2.2	Maxwell's Waves	1
2.3	Einstein's Photons	2
3.0	Working Models of Optical Radiation	3
3.1	Quantum Optics	3
3.2	Physical Optics	3
3.3	Geometric Optics	3
3.4	Radiative Transfer	3
4.0	Properties of Optical Radiation	3
4.1	Propagation	3
4.2	Transported Power	4
4.3	Wavelength	4
4.4	Polarization	4
5.0	Production of Optical Radiation	5
5.1	Atomic Structure and Optical Radiation	5
5.2	Spectral Power Data	6
5.3	Gas Discharge Production of Optical Radiation	8
5.3.1	Characteristics of Gas Discharges	8
5.3.2	Practical Gas Discharge Sources	9
5.4	Incandescent Production of Optical Radiation	9
5.4.1	Blackbody Radiation	9
5.4.2	Spectral Emissivity	10
5.4.3	Graybody Radiation	10
5.4.4	Selective Radiators	11

5.5	Luminescent Production of Optical Radiation	11
5.5.1	Photoluminescence: Fluorescence	12
5.5.2	Photoluminescence: Phosphorescence	12
5.5.3	Electroluminescence: Electroluminescent Lamps	13
5.5.4	Electroluminescence: Light-Emitting Diodes	13
5.5.5	Electroluminescence: Organic Light Emitting Diodes	15
6.0	Optics for Lighting	15
6.1	Important Optical Phenomena	15
6.1.1	Reflection	15
6.1.2	Absorption	19
6.1.3	Transmission	20
6.1.4	Refraction	21
6.1.5	Polarization	22
6.1.6	Interference	24
6.1.7	Diffraction	24
6.1.8	Dispersion	25
6.2	Optical Elements in Lighting	25
6.2.1	Reflectors	25
6.2.2	Lenses	26
6.2.3	Prisms	28
6.2.4	Diffusers	28
6.2.5	Thin Films	29
References		30

For the rest of my life I want to reflect on what light is.

– Albert Einstein 1916

1.0 Introduction and Scope

1.1 Introduction

Anyone dealing with lighting profits greatly from a basic understanding of the physics of light. Even if only qualitative, such an understanding makes clear how light stimulates the visual system and ultimately produces perceptions, how light interacts with materials to provide for its own control and distribution by luminaires, how light makes materials luminous and participates in the generation of color perceptions, how light is produced by electric light sources, and why light from the sun and sky can greatly enhance the quality of an interior environment.

1.2 Scope

This document describes the physics of radiant energy for various light source types, as well as the physical optics used for manipulating light.

2.0 Optical Radiation

For the sake of clarity, the term *optical radiation* is used here to name that phenomenon which transports energy by radiant means. That phenomenon can be described as a shower of photons, propagating electromagnetic radiation, or a bundle of rays, depending on the detail of description that is required. Optical radiation is a physical quantity.

The term *light* is reserved to describe optical radiation that has been evaluated with respect to its ability to stimulate the visual system. Light is a psychophysical quantity and is fundamentally a perception.

2.1 Physical Models of Optical Radiation

Two physical models have long been used to explain the properties of optical radiation and how it interacts with materials. These are the *wave model* and the *particle*

model. In 1690 Christiaan Huygens proposed that optical radiation be considered advancing waves in an ethereal medium.^{1,2} In later editions of his 1704 work on optics, Isaac Newton proposed that optical radiation be considered a stream of very small particles.³ Although Newton proposed optical radiation was a stream of very small particles, he also saw a correlation between musical notes (frequency) and the color of light. In a sense he was proposing particles that had a frequency. It was only in the 20th century that wave-particle duality was formally proposed and accepted. Modern concepts conceive optical radiation as a wave-particle duality that manifests wave or particle properties depending on circumstances.

In illuminating engineering and lighting design the wave model underpins the understanding and use of optical radiation, while in the physics and chemistry of light source development the particle model is the underpinning.

Sidebar: A Historical Note

Isaac Newton systematically studied the properties of dispersed light, correctly theorizing that the light of different colors has different “refrangibility.” He was the first to note that light of different colors had different brightness and varied in its power to invoke a visual sensation.

2.2 Maxwell’s Waves

Various forms of the wave model of optical radiation were developed and worked on by Leonard Euler,^{3,4} Thomas Young,⁵ and Augustin Fresnel.⁶ In 1873 James Clerk Maxwell described an electromagnetic model of optical radiation that is still used today.⁷ In its modern form, Maxwell’s model has an electric vector and a magnetic vector oriented perpendicular to each other, oscillating in phase, and propagating in the direction perpendicular to their oscillations. As these vectors propagate and oscillate they can be considered to define an electric wave and a magnetic wave. In some special circumstances the orientation of the planes in which these vectors oscillate is fixed, and this simple, though special, case is shown in **Figure 2-1**.