

KITCHEN & BATH LIGHTING

Concepts • Design • Light



Daniel Blitzer
Tammy MacKay, AKBD, NCIDQ, LEED Green Associate

KITCHEN & BATH LIGHTING

KITCHEN & BATH
LIGHTING
Concepts, Design, Light

DANIEL BLITZER

TAMMY MACKAY, AKBD, NCIDQ, LEED GREEN ASSOCIATE

WILEY

NKBA[®]
National Kitchen & Bath Association

Cover image: Kitchen photo: Kitchen design by Joseph A. Giorgi, Jr., CKD; codesigners Erin Paige Pitts and Dru Hinterleiter. Photo by Peter Leach.
Bathroom photo: Bathroom design by Paul Knutson. Photo by Troy Thies

Cover design: Wiley

This book is printed on acid-free paper. ♻️

National Kitchen & Bath Association
687 Willow Grove Street
Hackettstown, NJ 07840
Phone: 800-THE-NKBA (800-843-6522)
Fax: 908-852-1695
Website: NKBA.org

Copyright © 2015 National Kitchen and Bath Association. All rights reserved.

Published by John Wiley & Sons, Inc., Hoboken, New Jersey.
Published simultaneously in Canada.

No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, scanning, or otherwise, except as permitted under Section 107 or 108 of the 1976 United States Copyright Act, without either the prior written permission of the Publisher, or authorization through payment of the appropriate per-copy fee to the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923, (978) 750-8400, fax (978) 646-8600, or on the web at www.copyright.com. Requests to the Publisher for permission should be addressed to the Permissions Department, John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, (201) 748-6011, fax (201) 748-6008, or online at www.wiley.com/go/permissions.

Limit of Liability/Disclaimer of Warranty: While the publisher and author have used their best efforts in preparing this book, they make no representations or warranties with the respect to the accuracy or completeness of the contents of this book and specifically disclaim any implied warranties of merchantability or fitness for a particular purpose. No warranty may be created or extended by sales representatives or written sales materials. The advice and strategies contained herein may not be suitable for your situation. You should consult with a professional where appropriate. Neither the publisher nor the author shall be liable for damages arising herefrom.

For general information about our other products and services, please contact our Customer Care Department within the United States at (800) 762-2974, outside the United States at (317) 572-3993 or fax (317) 572-4002.

Wiley publishes in a variety of print and electronic formats and by print-on-demand. Some material included with standard print versions of this book may not be included in e-books or in print-on-demand. If this book refers to media such as a CD or DVD that is not included in the version you purchased, you may download this material at <http://booksupport.wiley.com>. For more information about Wiley products, visit www.wiley.com.

Library of Congress cataloging-in-publication data is available upon request.

ISBN 978-1-118-45454-1 (cloth); 978-1-119-12456-6 (ebk.); 978-1-119-12455-9 (ebk.)

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

Sponsors

The National Kitchen & Bath Association recognizes, with gratitude, the following companies whose generous contribution supported the development of *Kitchen & Bath Lighting*.

PLATINUM SPONSOR

The logo for Häfele, featuring the word "HÄFELE" in a bold, sans-serif font. The letter "A" is red, while the other letters are grey. The "H" and "E" have a distinctive shape with a small square cutout at the top.

WWW.HAFELE.COM

GOLD SPONSORS

DELTA FAUCET COMPANY

TRESCO LIGHTING

About the National Kitchen & Bath Association

The National Kitchen & Bath Association (NKBA) is the only nonprofit trade association dedicated exclusively to the kitchen and bath industry and is the leading source of information and education for professionals in the field. Fifty years after its inception, the NKBA has a membership of more than 60,000 and is the proud owner of the Kitchen & Bath Industry Show (KBIS).

The NKBA's mission is to enhance member success and excellence, promote professionalism and ethical business practices, and provide leadership and direction for the kitchen and bath industry worldwide.

The NKBA has pioneered innovative industry research, developed effective business management tools, and set groundbreaking design standards for safe, functional, and comfortable kitchens and baths.

Recognized as the kitchen and bath industry's leader in learning and professional development, the NKBA offers professionals of all levels of experience essential reference materials, conferences, virtual learning opportunities, marketing assistance, design competitions, consumer referrals, internships, and opportunities to serve in leadership positions.

The NKBA's internationally recognized certification program provides professionals the opportunity to demonstrate knowledge and excellence as Associate Kitchen & Bath Designer (AKBD), Certified Kitchen Designer (CKD), Certified Bath Designer (CBD), and Certified Master Kitchen & Bath Designer (CMKBD).

For students entering the industry, the NKBA offers Accredited and Supported Programs, which provide NKBA-approved curriculum at more than 60 learning institutions throughout the United States and Canada.

For consumers, the NKBA showcases award-winning designs and provides information on remodeling, green design, safety, and more at NKBA.org. The NKBA Pro Search tool helps consumers locate kitchen and bath professionals in their area.

The NKBA offers membership in 11 different industry segments: dealers, designers, manufacturers and suppliers, multi-branch retailers and home centers, decorative plumbing and hardware, manufacturer's representatives, builders and remodelers, installers, fabricators, cabinet shops, and distributors. For more information, visit NKBA.org.

Table of Contents

PREFACE	xv
ACKNOWLEDGMENTS	xvii
CHAPTER 1	
HOW WE SEE	1
Physics of Light	1
Vision	2
Measuring Light	5
Measurement versus Perception	7
Summary	8
Review Questions	8
CHAPTER 2	
SEEING MATERIALS	9
Color	9
Form and Texture	12
Matte and Gloss	14
Summary	15
Review Questions	15
CHAPTER 3	
SEEING THE SPACE AND EACH OTHER	17
Appearance of Light	17
Light and Our Sense of Space	20

Light and People 21
Summary 22
Review Questions 22

CHAPTER 4

SEEING THE WORK.....23

Task Visibility 23
Visual Performance 28
Illuminance 28
Challenges to Task Visibility 30
Summary 33
Review Questions 33

CHAPTER 5

SEEING AS WE AGE35

Vince Butler, CGR, GMB, CAPS
How Vision Changes with Age 35
Lighting and Safety 39
Summary 41
Review Questions 42

CHAPTER 6

SPEAKING ABOUT LIGHTING43

Lighting Effects, Not Equipment 43
How Should a Space Feel? 44
Layering 48
Experiential Layers of Light 48
Functional Layers of Light 54
Applying Light 59
Summary 65
Review Questions 65

CHAPTER 7

SUSTAINABLE LIGHTING67

Definition of Sustainability 67
Environmental Impacts of Lighting 68
Sustainability and the Cost of Lighting 74

Sustainable Lighting Strategies 77

Summary 79

Review Questions 80

**CHAPTER 8
THE IMPORTANCE OF DAYLIGHT.....81**

Daylight and Human Experience 81

From the Outside In 82

Daylight in Different Forms 85

Characteristics of Daylight 86

Admitting Daylight 88

Integrating Daylight and Electric Lighting 97

Summary 103

Review Questions 103

**CHAPTER 9
SCHEMATIC DESIGN 105**

Program 105

Schematic Design 106

Lighting for Kitchen Activities 108

Lighting for Bathroom Activities 113

Experience 123

Architectural Integration 127

Communicating the Concept 133

Summary 135

Review Questions 135

**CHAPTER 10
CHOOSING ELECTRIC LIGHT SOURCES..... 137**

Light Sources for Kitchens and Baths 137

Attributes of Light Sources 138

Summary 145

Review Questions 145

**CHAPTER 11
COMPARING ELECTRIC LIGHT SOURCES 147**

Light Sources for Kitchens and Baths 147

Incandescent Sources 148

- Fluorescent Sources 157
- LED Sources 164
- Product Quality 169
- Summary 171
- Review Questions 171

**CHAPTER 12
LIGHT FIXTURES..... 173**

- Light Fixture Selection Criteria 173
- Types of Fixtures (Luminaires) 180
- Summary 191
- Review Questions 191

**CHAPTER 13
LIGHTING CONTROLS..... 193**

- Benefits and Objectives 193
- The Language of Controls 195
- How Dimmers Work 198
- Sensors 203
- Control Systems 206
- Wireless Control of LED Lamps 211
- Applying Controls 211
- Summary 212
- Review Questions 212

**CHAPTER 14
DESIGN DEVELOPMENT 213**

- Developing the Design 213
- Code Compliance 214
- Locating Luminaires 217
- Selecting Luminaires 228
- Sizing the Light Source 235
- Controls 238
- Summary 241
- Review Questions 241

CHAPTER 15	
DOCUMENTING THE LIGHTING DESIGN.....	243
Lighting and Controls Plans	243
Summary	252
Review Questions	252
CHAPTER 16	
GETTING LIGHTING BUILT	253
Lighting in the Construction Process	253
Submittals	256
Lighting Supply Channel	257
Summary	262
Review Questions	262
GLOSSARY	263
INDEX.....	265

Preface

Welcome to *Kitchen & Bath Lighting*. As vision is our most significant sense, so lighting is critical to our perception of the world around us and to our effective performance, attractive appearance, and healthy emotions.

Lighting is one of the elements of design. Some might say it is *the* most important as without it we would not be able to see the other elements. It can enhance the look and feel of a space or detract from it if done incorrectly.

Kitchens and baths represent the residential spaces where lighting is used most often and most critically. The principles of lighting kitchen tasks and social areas often can be applied to other work and living spaces, while understanding how to light at a bathroom vanity can inform attractive lighting for conversations throughout the home.

ORGANIZATION

This book is intended both to provide a sound basis in the fundamentals of lighting and to guide in the application of lighting to the two most critical task spaces of the home. We approach kitchen and bath lighting in several broad categories familiar to designers.

In chapters 1 through 6 we focus on the fundamentals of lighting and discuss how we see materials, spaces, and each other; how to calibrate lighting for different tasks; and how to modulate lighting as we age.

Chapters 7 and 8 explore the importance of sustainable lighting and daylighting.

In Chapter 9 we cover schematic design by presenting a visual vocabulary for speaking about lighting and applying these ideas to conceptualizing lighting for kitchen and bath spaces.

Chapters 10 through 12 provide important information on choosing and comparing light sources and fixtures and in Chapter 13 lighting controls are discussed.

Chapter 14 explains the many aspects of design development including the selection of light sources, luminaires, and controls and the processes involved in locating equipment, calculating illumination, and addressing code compliance.

Chapter 15 covers the important topics of documenting the lighting design and communicating the design to the construction team and finally, in Chapter 16 we explain the process and critical issues involved with getting lighting built in the real world.

SOME CURRENT ISSUES

Three critical issues stand out today: changing lighting technology, sustainable design approaches, and lighting for older eyes.

If this book had been written 50 years ago, the lighting *principles*—how we see and how to arrange lighting—would have been largely the same. But, of course, technology in the twentieth century would have been significantly different. Indeed, if the book had been written even just a few years ago, light sources, luminaires, and controls would be considerably different.

Most notably, LEDs—light-emitting diodes—are rapidly changing what we light with, how light colors what we see, how it looks in our homes, and how it affects the natural environment. At the same time, control over lighting has become both more convenient and more sophisticated. The combination of digital light sources (LEDs) and digital controls promises a future of lighting that adapts readily to different needs, uses, and preferences. With the majority of the population working and playing on video displays of some kind, the way we light spaces has changed completely as well.

Around the globe, developing economies are trying to meet the fast-rising expectations of their populations. A peaceful world will need *sustainable lighting*—lighting that meets the human needs of today with the least impact on energy and other natural resources so as not to compromise future generations.

Young people often can work without any electric lighting. As people age, we typically use lighting more often and in greater quantity. This progression is inevitable, at least for most of us. And for much of the developing world, it is true not only for individuals but for the population as a whole. Providing for the range of needs required by residents of varying ages is a critical challenge for lighting design.

We pick up the strands of these issues throughout the book. Woven together, they help us to think about lighting holistically: who the lighting is for, what their needs and desires are, and how we can use design and technology to meet their needs and even exceed their expectations.

Dan Blitzer

I feel very grateful to have the opportunity to share my knowledge of and enthusiasm for the interior design industry, specifically kitchen and bath design. The National Kitchen & Bath Association's commitment to education in this area of expertise has been incredible. Johanna Baars, Publications Specialist, Lisa H-Millard, Course Developer, and Debby Mayberry, Learning and Development Implementation Specialist, have been instrumental in providing support and encouragement to me throughout this process.

The team at my firm and my family at home have also been supportive and excited about this new book added to the series. Thanks to all. I give my best to future kitchen and bath designers. I hope you enjoy your journey as much as I have enjoyed mine so far.

Tammy MacKay

Acknowledgments

The NKBA gratefully acknowledges the following peer reviewers of this book:

Kristen Arnold

Jeff Dross

Robert Dupuy

Cheryl A. Glazier, CKD, CBD

Corey Klassen, CKD, CBD

Anna Mahan

Natalia Pierce, AKBD

How We See



Light, how it enables us to see, and lighting terminology together provide the necessary foundation for understanding lighting. In this chapter, we begin to consider these fundamental concepts. In subsequent chapters, we investigate lighting fundamentals in more detail.

Learning Objective 1: Describe the physics of light and the physiology of the eye.

Learning Objective 2: Explain in plain language how we see.

Learning Objective 3: Recognize and use key lighting terms and metrics.

Learning Objective 4: Distinguish between perceived and measured illumination.

PHYSICS OF LIGHT

Light is the *energy* that enables us to see. Technically, light is part of the broad spectrum of electromagnetic energy and is defined as visually evaluated radiant energy (see Figure 1.1).

As you may recall from classes in physics, light exhibits the properties of both waves and particles. As a radiating wave, light can be described by its wavelength, which ranges from about 380 to 760 nanometers (billionths of a meter), the limits of human visual sensitivity. In the next chapter, we explain that describing light by its wavelength helps us to understand the interaction of light and materials. Later, when we look at light sources, we encounter the particle nature of light—especially in understanding LED technology.

A few observations:

- Light itself is invisible. We see it only when it interacts with materials (e.g., the filament of an electric light source, fabrics, or faces). More on this important idea shortly.
- Light can travel through some materials.
 - *Transparent* materials allow the passage of light without significant distortion so you can see the details of objects behind them (see Figure 1.2a).
 - *Translucent* materials allow light through but mix it up so that the details are obscured. (The entire object may be obscured, depending on the translucent material and the nature and location of the object.) (see Figure 1.2b).
 - *Opaque* materials block the passage of light altogether (see Figure 1.2c).

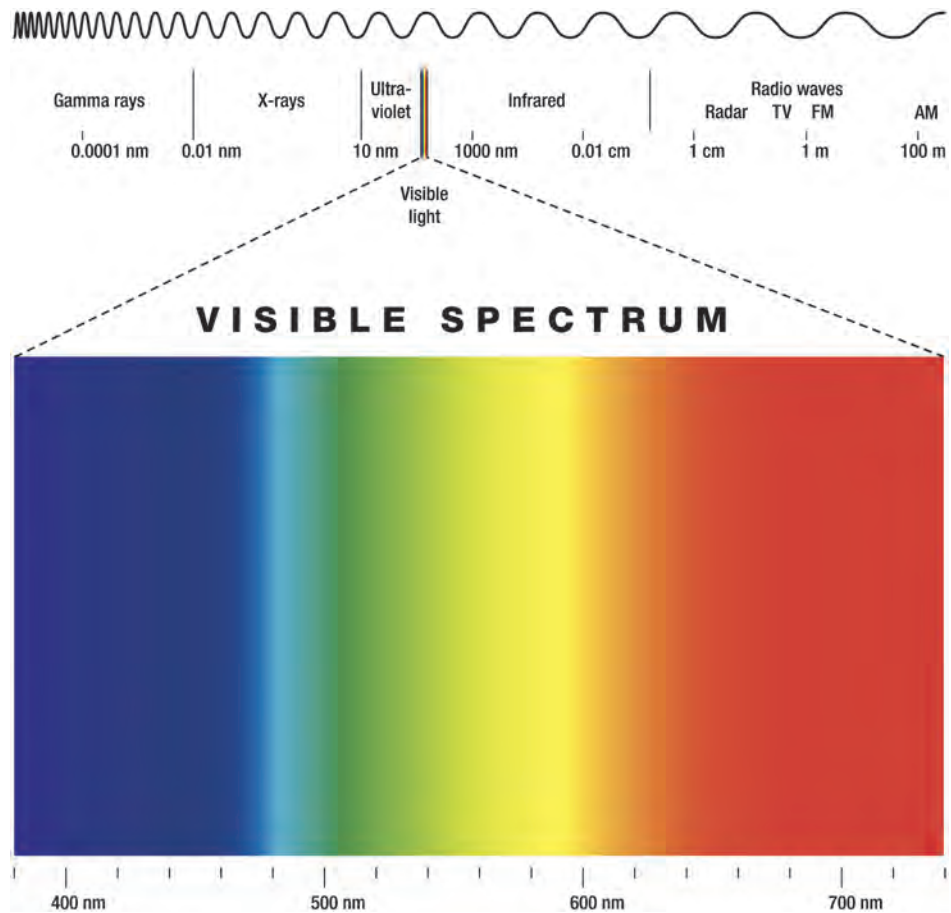


FIGURE 1.1 Light in the electromagnetic spectrum

Courtesy of Peter Hermes Furian

- Light changes direction when it reflects off surfaces or when it passes through materials, refracting (bending) or scattering (see Figure 1.3).
- Light that neither passes through nor reflects off materials is absorbed. Its energy becomes heat. Some light is absorbed in virtually every encounter with materials. Put your hand on the hood of a car that has been sitting in sunlight and see for yourself.

VISION

Although vision is not our oldest sense (we touch before we see), it dominates our perception. Basically, human vision is simple: Light interacts with objects; travels to, then enters, our eyes, where it is transformed into electrical signals; these signals travel neurological pathways to reach our brain, where they are interpreted into visual perception. Another way to express this basic process is by its four essential components (see Figure 1.4):

1. Light source
2. Object
3. Eye
4. Brain

We know a great deal about the physics of light and how it interacts with objects. We also know a great deal about the physiology of the human eye, how it receives light and creates neurological connections. We know considerably less about the complexities of how our neurological signals are combined with memory and interpretive algorithms into dynamic, three-dimensional perception.

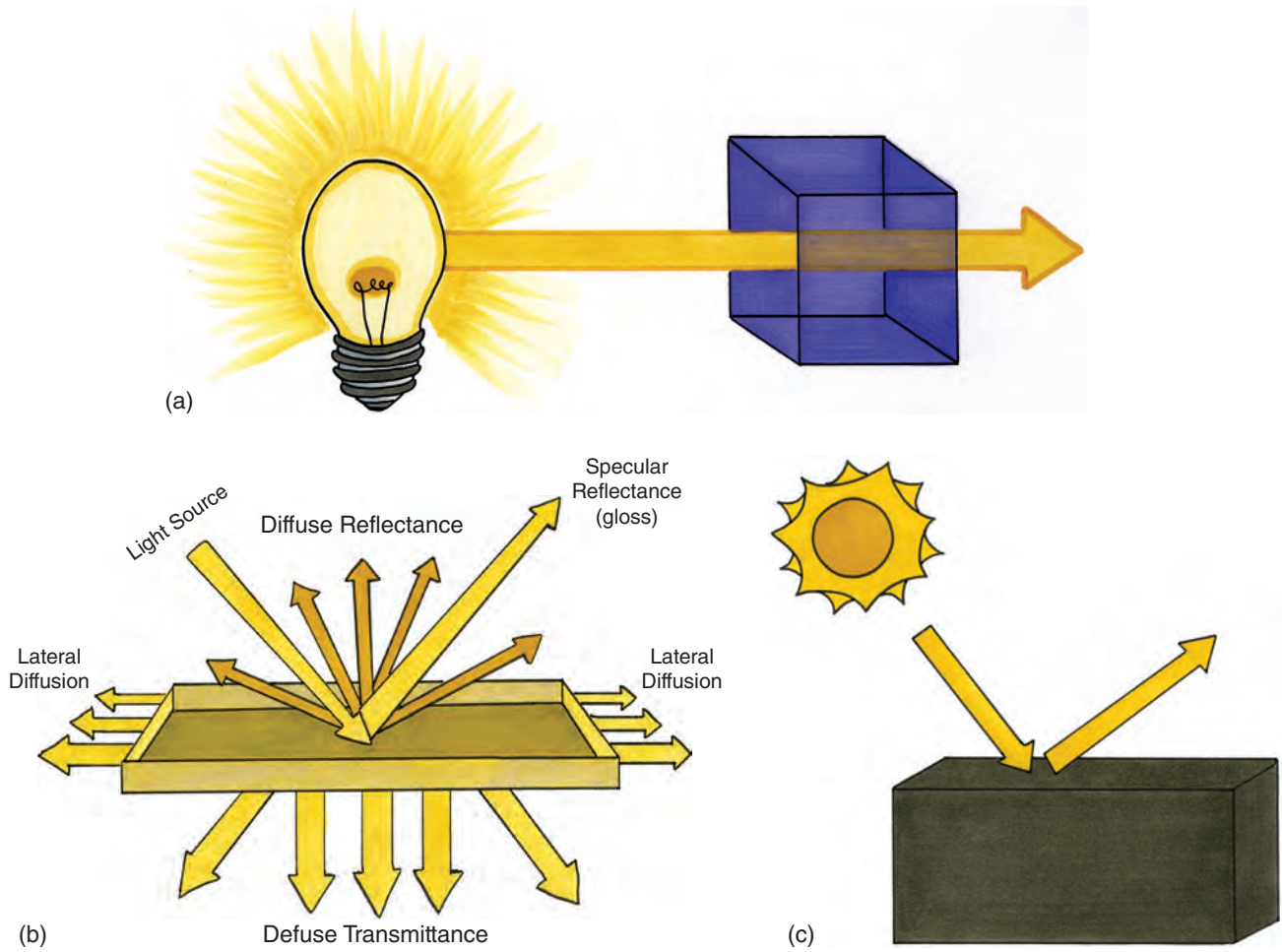


FIGURE 1.2 Transparent, translucent, opaque

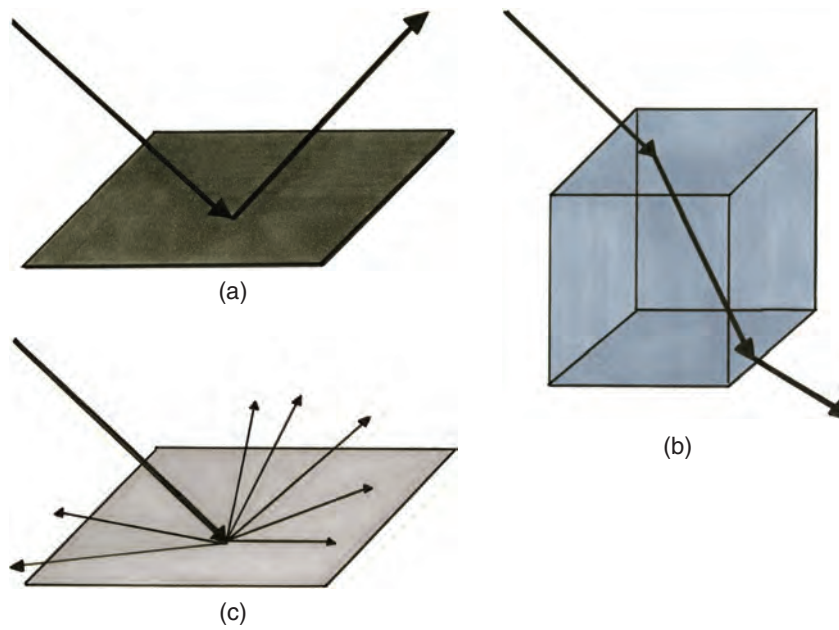


FIGURE 1.3 Reflection, refraction, scattering

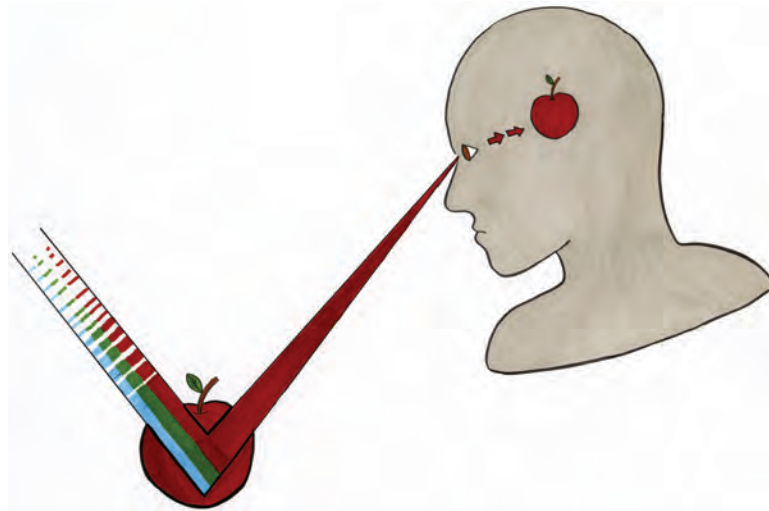


FIGURE 1.4 Light source, object, eye, brain

Pause for a moment to consider the following. The signals received on the two-dimensional “screen” of our retina are fundamentally ambiguous: Is the retinal image a small object close by or a large one at a distance? Yet, apart from some notable optical illusions, we see the world *unambiguously*. This is only the most obvious example of our remarkable powers of visual perception. Good lighting can enhance these powers, while poorly designed lighting just makes seeing that much harder.

Contrast

Our visual system compares the incoming signals, searching for differences in light intensity and color. It does not measure or quantify them in technical photometric (light measurement) terms. Instead, the essence of how we see is the contrast between dark and light or among various colors.

Later in this chapter, we discuss how we measure light and all the technical terms associated with these quantities. When we do this, we also discuss the problems created by measurements that do not adequately represent perception.

Adaptation

Remarkably, our visual system operates effectively in a range of about 20,000:1, that is, from a bright sunny day to a starlit night. We manage to see in such a broad range by adjusting both the amount of light reaching the eye and the sensitivity of the photoreceptors. In darkened conditions, our pupils dilate to admit more light, and the eye's chemistry becomes more sensitive to the limited amount of light available. In bright conditions, in contrast, pupils contract, and sensitivity diminishes to avoid overload.

Adaptation takes time; it takes as much as 30 minutes to adapt to darkened conditions. Adapting to bright conditions takes less time. However, rushing the process (e.g., by emerging from a darkened theater to a bright afternoon) can prove painful.

Indoors, your vision adapts as you move from darker spaces to brighter ones and back again. Shifting your gaze from a brightly lighted task to a much darker surface also involves adaptation. Frequent and extreme adaptation can cause eye fatigue and discomfort.

Physiology of the Eye

The physiology of the eye helps us understand lighting—and how to design it for different applications and users of different ages and visual impairments. Take a moment to study the diagram of the human eye in Figure 1.5.

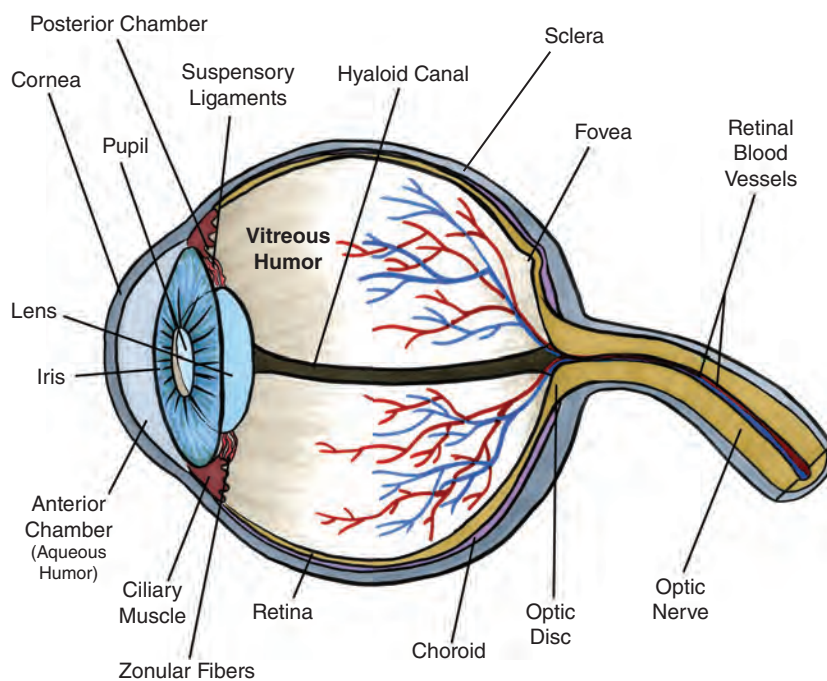


FIGURE 1.5 Diagram of the eye

We have already discussed an important function for the pupil: regulating the quantity of light received. The rays of light ultimately enter the eye through a lens that receives them onto the retina, which contains the photo sensors and connective neural networks that translate incident light into neurological signals. When the lens malfunctions (focuses improperly or simply loses clarity), vision is impaired.

Inside the eye, light travels through liquid from the lens to the retina. Impurities can disrupt light's passage and, with it, vision. Degradation in the retina (macular degeneration is one important example) also diminishes vision.

The retina contains three basic types of photoreceptors:

1. Those capable of detecting only the quantity of light, not its color, are called *rods* due to their shape. They are also capable of sensing very small quantities of light; we rely on them to see in the (near) dark. Located throughout the retina, rods also provide peripheral vision.
2. Those capable of detecting color are called *cones*. They require more stimulation than rods, so we enjoy very limited color vision in darkened conditions. Concentrated in an area called the *fovea*, cones provide the visual acuity to distinguish small tasks.
3. The third type of photoreceptor is not part of the visual system but detects light as part of our circadian, or 24-hour, clock system.

We return to the photoreceptors in more detail when we discuss color in Chapter 2, "Seeing Materials" (and to nonvisual photoreceptors when we discuss lighting for aging eyes).

Finally, notice how an overhanging brow protects the entire eye, limiting the glare from overhead sources of bright light—to some degree at least.

MEASURING LIGHT

Light emanates from a source and (some of it) arrives at an object. Light then leaves that object (reflects off or passes through it) and travels to the next object, and so on. Thus, if we want to measure light, we need to do so at the various points in its travel.

Lumen—the Flow of Light

Let's start with the source itself. A *lumen* is a unit of measure for quantifying the amount of light energy emitted by a light source. A typical light source in your dining room might emit 800 lumens, one in the laundry room might emit 2500 lumens, and one in the streetlight outside might emit 16,000 lumens.

LUMEN VALUES FOR VARIOUS LIGHT SOURCES

Light Source	Luminous Flux (lumens)	Typical Use
LED light bulb (12W)	800 lumens	Table fixture
Halogen flood (60W)	1100 lumens	Retail display
Linear fluorescent (28W)	2500 lumens	Office lighting
High-pressure sodium (150W)	16,000 lumens	Street lighting

Since light can flow in any direction, luminous flux (lumens) can be measured anywhere. The most common measurements are made at lamps (light sources) and fixtures (technically, *luminaires*, which are fixtures with light sources in them). You will find lumen ratings in lamp and luminaire catalogs, specification sheets, and websites, as well as on many lamp packages (see Figure 1.6).



FIGURE 1.6 Lamp package label
 Courtesy of American Lighting Association

Candela—The Intensity of Light

If the flow of light (lumens) is concentrated into a tight beam, we say that it is intense (strong in that single direction). This is called *luminous intensity* and is measured in *candela*. Light sources and luminaires with distinct beams of light (whether concentrated as spots or diffused as floods) typically are measured in both lumens and candela.

With light sources that direct light into beams, candela measurements will vary significantly according to the angle at which the intensity is measured. With light sources that distribute light more or less evenly in all directions, the candela measurements will be very similar.

The word “intensity” has the common meaning of “strength.” In lighting, luminous intensity has the technical meaning of “strength in a specific direction.” We use the term “lumens” to measure the total flow of light, regardless of direction.

Footcandle/Lux—Light Falling on a Surface

When light falls on a surface, it is called *illuminance*. Technically, we measure the density of the illuminance that is the quantity of lumens falling on a surface. One lumen per square foot equals 1 *footcandle*. This is an imperial measurement. Its metric equivalent is *lux*. One lumen per square meter equals 1 lux. The conversion of footcandle (FC) to lux is 1 footcandle = 10.764 lux.

If 100 lumens fall on 1 square foot of countertop, we would measure that as 100 footcandles. If those lumens were spread over 10 square feet, we would measure it as 10 footcandles. The same comparison can be made for lux. If 100 lumens fall on 1 square meter of countertop, we would measure that at 100 lux.

Illuminance is measured with a luminance meter (also called an *illuminance meter*). The Illuminating Engineering Society has established recommended illuminance targets (in footcandles) for almost every room or setting.

Brightness—The Perception of Light

So far, none of our measurements represents what we see. Lumens and candela measure light at the source; footcandles (lux) measure light falling on the surface of an object. We see when light reflects from (or passes through) an object and reaches our eye. We can measure the amount of light detected by the eye from a surface at a particular angle; this is called *luminance*.

In practice, luminance measurements are cumbersome and costly, and so are rarely used in everyday design. Instead, we use the term *brightness* to express our perception of light, including the many non-quantified factors that influence our visual process.

MEASUREMENT VERSUS PERCEPTION

It is worth emphasizing that most of what we measure in lighting—the lumens flowing from a light source, the candela at the center of a beam of light, the footcandles falling on a surface—do *not* represent what we see when we look at a room, a task, or a person.

Our perception depends on the materials we are lighting, what we see around the space, how we are adapted to the brightness of the space, the color of the light, and other factors, which we discuss in later chapters.

What good are these measurements then? As you will learn, we apply the measurements of lighting to *predict* how well lighting will meet our objectives. By themselves, these measurements are of little use. But together with an understanding of how light interacts with materials, people, and task demands, they can help us judge how to provide appropriate lighting.

Using Lighting Terms

1. Look at a room in your home or place of business. Write a description of the lighting present using the terms “luminous flux,” “intensity,” and “illuminance.”
2. Think about a recent day in your life. What is the brightest environment in which you can see easily? What is the dimmest?
3. What is the unit of measure for illuminance?
4. Look up the word “footcandle” online. What is its origin? Do the same for the word “lux.”

SUMMARY

Light is the energy that enables us to see. It travels invisibly, and when it encounters a material, it reflects, refracts, or is absorbed by it. We see when light reaches the photoreceptors in our eyes, stimulating signals that are interpreted by our brain. Our visual system responds to contrast (rather than absolute levels of light) and adapts to variations in ambient brightness. We measure light in three widely used measurements: luminous flux (lumens), which refers to the flow of light; intensity (candela), which refers to the strength of light in a specific direction; and illuminance (footcandle/lux), which refers to the amount of light falling on a surface.

REVIEW QUESTIONS

1. What are the four elements in human vision? (See “Vision,” page 2)
2. What is the role of contrast in vision? (See “Contrast,” page 4)
3. What is the role of adaptation in vision? (See “Adaptation,” page 4)
4. In what part of the eye are the photoreceptors located? (See “Physiology of the Eye,” page 5)
5. What are the units of measure for luminous flux, intensity, and illuminance? (See “Footcandle/Lux,” page 7)

Seeing Materials



Light has distinctive qualities of color and form. Materials also present different qualities of color, form, and texture. In this chapter, we explore the different qualities of light and begin to see how those qualities interact with materials.

Learning Objective 1: Explain in plain language how we see color.

Learning Objective 2: Identify the primary colors of light, and explain why they are primary.

Learning Objective 3: Compare concentrated and diffuse light.

Learning Objective 4: Describe how light is reflected by matte and shiny surfaces.

Learning Objective 5: Distinguish between specularly and reflectivity.

COLOR

If light is invisible, how can it be said to have color? Observe the changing quality of skylight, the progression of sunlight from dawn to noon to dusk. Do you doubt that light indeed has color?

We explain this puzzle by dividing the subject of color into two parts:

1. The makeup of light itself—color in the energy that enables us to see
2. The interaction of light and material—color as we experience it

Color in Light

Look at the sky after a rainstorm. Pick up a prism and capture sunlight on its way to a nearby wall. You will see the familiar spectrum (see Figure 2.1) and perhaps remember ROYGBIV from school. ROYGBIV is the mnemonic for red, orange, yellow, green, blue, indigo, and violet, the colors we see as the sunlight separates by wavelength.

What we call *white light*—daylight and most electric light sources—combines light at different wavelengths. As light passes through refractive materials (e.g., droplets of water or a crystal prism), the constituent wavelengths are bent to differing degrees. Shorter wavelengths (blue) bend more than longer ones (red).

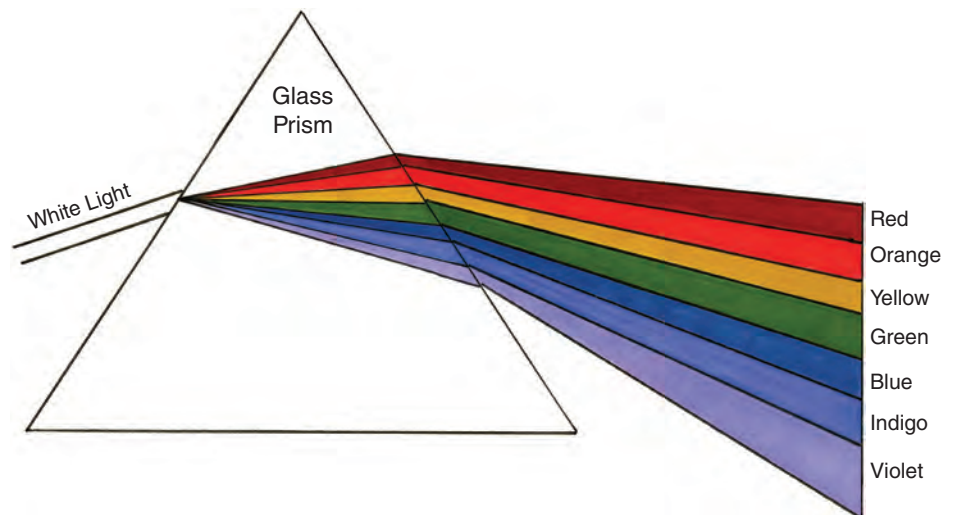


FIGURE 2.1 Spectrum from a prism

Refraction and Wavelength

You can see the varying refraction of wavelengths in the rainbow, where the inner bands are blue-violet and the outer band is red. In simple terms, this also explains why the sky is blue: Light entering Earth's atmosphere refracts slightly. Shorter blue wavelengths bend more than the others and so become visible as skylight.

Rainbows have been around since the dawn of time, but understanding what they mean with regard to light is relatively recent. You can replicate Isaac Newton's experiment by using two prisms. The first one separates light into different wavelengths; the second one reassembles those wavelengths to create white light and demonstrates that the "white" of light is nothing more than the combination of all colors of the spectrum.

Returning to our first question—What makes light appear in different tones of white?—it is the proportion of different wavelengths of energy. Afternoon skylight with its bluish tint, as seen in Figure 2.2, has a strong component of short wavelengths. At dawn or dusk, longer wavelengths predominate, and the light acquires a reddish tinge (see Figure 2.3). We call this the *spectral power distribution of the light source*.



FIGURE 2.2 Daylight in the afternoon
Photo by Dodge + Burn Photography