



# INTERIOR LIGHTING FOR DESIGNERS | FIFTH EDITION

GARY GORDON

WILEY



# INTERIOR LIGHTING



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GARY GORDON, FIES, FIALD, LC

ILLUSTRATIONS BY GREGORY F. DAY, LC

WILEY

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to

*Caryl Becker Gordon and Robert Neil Gordon,  
with gratitude for their unwavering support*

“Light is the key to well-being.”

—Le Corbusier



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# PREFACE

This edition has been thoroughly revised, expanded, and updated with the latest developments in energy-effective electric light sources and lighting fixtures that provide the optimum quality of light and maximum energy efficiency. The basic principles of lighting design remain unchanged; the tools and equipment that we use to realize them continue to evolve.

This book is intended to serve both as a textbook for architecture and interior design students and as a manual for practicing professionals. It provides a simple framework for understanding the lighting design process. With clear, easy-to-grasp terms, the book is organized to reinforce the way in which this process is used in professional lighting design practice.

The design of light for interiors is emphasized; tools and techniques are presented as a means by which to achieve the design. This is an architectural approach to lighting design, based on my apprenticeship with the late architect and lighting designer Carroll Cline as well as almost thirty years of professional practice.

As with the previous editions, this one retains the profound imprint of the thorough copy and technical edit provided for the Third Edition by the late luminaire-design genius Edison Price. His vast knowledge, integrity, and friendship provided me with the solid foundation upon which to build a satisfying and rewarding career.

The lighting design process outlined in this book parallels the methodology used by lighting professionals to provide solutions for architectural interiors around the world. I developed the system for describing this process while teaching graduate and undergraduate students at the Parsons School of Design Lighting Institute in New York City. The success of this method is demonstrated by the great number of my former students who professionally practice lighting design today.

I hope you will discover in this book an increased awareness of how profoundly our lives are affected by the daily lighting conditions in which we find ourselves, and that you may be inspired by it to make improvements to your own surroundings.





# ACKNOWLEDGMENTS

All of the editions of this book that I have prepared owe an enormous debt to Gregory Day for his thoughtful contributions and expert illustrations. Greg was our company's first IALD intern in 1986; it gives me great pleasure to still be enjoying such a successful collaboration with him all these years later.

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The collaborative members of the Gary Gordon Lighting team who have contributed immeasurably to my further understanding of light and to the success of our projects include Eron Ashley, Andrew Brody, Susan Burak, Gregory Day, Margaret Doria, Kevin Frary, Damiano Geraci, Christine Kong, David Marini, Zac Moseley, Rachele Rossanese, Karen Solomon, Eli Stertz, Robert Thomas, David Weiner, Dan Weinreber, and Mike Zee. The construction documents included in Chapter 19 are the work of David Marini.

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Jean Paul Freyssonier provided an exceptionally thorough and thoughtful technical edit. At John Wiley & Sons, Margaret Cummins and Paul Drougas provided editorial guidance and steadfast patience; Kerstin Nasdeo and Mike New provided extraordinarily helpful assistance and ongoing support.

Gary Gordon, FIES, FIALD, LC  
New York, New York





# INTRODUCTION

In just 130 years, the world has experienced three revolutions in electric lighting. The first revolution began in 1879 when Thomas Alva Edison filed for a U.S. patent for an electric lamp using “a carbon filament or strip coiled and connected to platina contact wires.” The second revolution began in the late spring of 1938 when fluorescent lamps were introduced at the 1939–40 New York World’s Fair; it continued through the creation of other low- and high-intensity discharge sources, the invention of tungsten-halogen sources, and the continual improvements made to all electric light sources.

We are currently experiencing the third revolution of electric lighting with the introduction and continued development of solid-state lighting. At the same time, extensive biomedical research is also showing us that light has potent biological and behavioral effects on people.

To date, green building standards for lighting have focused on only one facet of electric light: energy consumption. As the U.S. Energy Information Administration estimates that lighting accounts for approximately 13 percent of total U.S. electrical use, much of this attention is warranted. Yet an energy-only focus leaves out two other fundamental considerations: (1) the design of a comfortable visual experience that enhances productivity, enjoyment, and well-being; and (2) the health effects of electric light.

Recent biomedical research into the influence of electric light sources on human biology and behavior is demanding that we reconsider the design of interior lighting. It is giving us knowledge to develop lighting solutions that are optimal not only for visual performance but also for physiological health *and* ecological impact.

The ability to manipulate solid-state lighting in ways not previously available to the designer, coinciding with the recent research into the biological and behavioral effects of natural and electric light, makes this third revolution of light one of the most exciting times to work in the field of architectural lighting design.





# PART I DESIGN FACTORS



# 1

## THE LIGHTING DESIGN PROCESS

Lighting design is a process. It is the process of integrating light into the fabric of architecture. Successful lighting solutions vary with each distinct building type and the particular needs of each project. Regardless of the space to be lighted—an office, classroom, gallery, restaurant, home, store—and regardless of the light sources available for use, the process is always the same.

Because lighting design is a process, it can be learned. This book traces the steps in the lighting design process much as a professional performs them in practice. Design, of course, is not always a linear process. At times some of these steps are performed simultaneously. Yet in large part the order of the material corresponds to professional practice.

This book does not describe *the* lighting design process; it describes *a* lighting design process—one that has been used successfully to provide effective solutions for thousands of architectural projects around the world. It is a process built upon the premise that the lighting condition has enormous emotional, psychological, and physiological impact on people.

A common mistake when providing light for buildings is to select the lighting equipment first. Selecting luminaires is the last step in the process. What is important is not what *makes* the light, but rather which objects and surfaces *receive* it. The key to successful lighting design is to decide what you want to light first, and then work backward to determine the solution.

1. The lighting design process begins with a thorough understanding of the human visual system: how the eye and brain work together to create our perception of the world around us. The higher the quality of information provided to the brain, the better the brain is able to interpret its surrounding environment (Chapter 2).
2. A foundation in photobiology and the nonvisual effects of electric light is now essential to the proper use of light in buildings (Chapter 3).

3. Next you establish the emotional background that is most attuned to the occupants and tasks to be performed. Much in the way you select background music to support the activities and environment of a room—classical music, jazz, or indie rock, for example—you establish the lighting composition to create a supporting psychological environment (Chapter 4).
4. The direction and distribution of light and patterns of brightness create the desired emotional environment and ensure that a comfortable visual experience is the result (Chapter 5).
5. Next, the designer selects the color spectrum suitable for the occupants and activities, with sensitivity to the color palette of the interior surface finishes and furnishings (Chapter 6).
6. Preliminary calculations are made to understand the quantity of light that is necessary and appropriate for the tasks, and that permits quick, accurate, and comfortable seeing (Chapter 7).
7. The available daylight is considered, not only because its use in interiors greatly reduces the power consumed by electric lighting but, equally importantly, because light from the sun and sky and views to the exterior significantly enhance the quality of the interior environment and our satisfaction with it (Chapter 8).
8. Only at this point, after the above considerations are carefully assessed and preliminary design decisions made, are you ready to select the electric light source(s) appropriate for each particular interior environment. In this text, light sources are presented in their approximate order of introduction to the marketplace, which roughly corresponds to their increasing initial cost.

Like many twenty-first-century global corporations, which have increasing responsibility to their shareholders, the marketing departments of most lighting manufacturers emphasize products with the highest profit margins, not necessarily those that provide the highest quality of light. It is essential that you be able to evaluate the relative merits of the different sources available based on their physiological and psychological impacts and benefits to the end user (Chapters 9–13).

9. Almost all electric sources generate light in a distribution poorly suited to architectural lighting. Methods of optical control of the primary light source are established next (Chapter 14).
10. With the light source(s) and method(s) of optical control determined, you now have all of the information at hand to select from the wide range of luminaires available in the marketplace the specific ones that will achieve your desired objectives (Chapter 15).
11. At last, you are in a position to create the lighting design and the lighting layout that communicates it. “Sustainable design” is and has always been one of the cornerstones of effective lighting practice—using the fewest number of watts

to provide the optimum quantity and highest quality of light and, therefore, the maximum benefits to the occupants. All successful lighting design is sustainable design.

Design is rarely accomplished on the first attempt. The “best” solution to a design problem seldom presents itself immediately; it is far more likely to be discovered on the fifth or tenth try. Design requires the patience to make multiple attempts. And your final solutions are only applicable to the particular needs of that project. The design process begins all over again with the next project (Chapter 16).

12. Every lighting design must be verified with computer-aided photometric calculations to ensure that the target illuminance values are met. Creating full-size mock-ups, building scale models, and making post-occupancy evaluations are among other methods designers might use to verify that their design will work (Chapter 17).
13. Upon completion of the lighting design and lighting layouts, the switching controls, dimming controls, and energy management systems are evaluated and selected (Chapter 18).
14. Finally, construction documents are produced that contain the designer’s complete written and drawn plans and specifications to communicate with the utmost clarity all of the information required by the installing contractor to deliver the designer’s intent (Chapter 19).

This architectural lighting design process yields an environment where casual observers are unaware of the mechanics of light production; they perceive only a comfortable environment that supports their activities and enhances their well-being. With practice, the designer learns to apply this process in ways that go even further, creating environments that stimulate the mind and inspire the spirit.

# 2

## PERCEPTION AND VISION

### Visible Light

What we perceive as light is a narrow band of electromagnetic energy, ranging from approximately 380 to 760 nanometers (nm), technically known as *optical radiation*. Only wavelengths in this range stimulate receptors in the eye that permit vision (Figure 2.1). These wavelengths are also called *visible energy*, even though we cannot directly see them.

In a perfect vacuum, light travels at approximately 186,000 miles per second. When light travels through glass or water or another transparent substance, it is slowed down to a velocity that depends on the density of the medium through which it is transmitted (Figure 2.2). This slowing down of light is what causes prisms to bend light and lenses to form images.

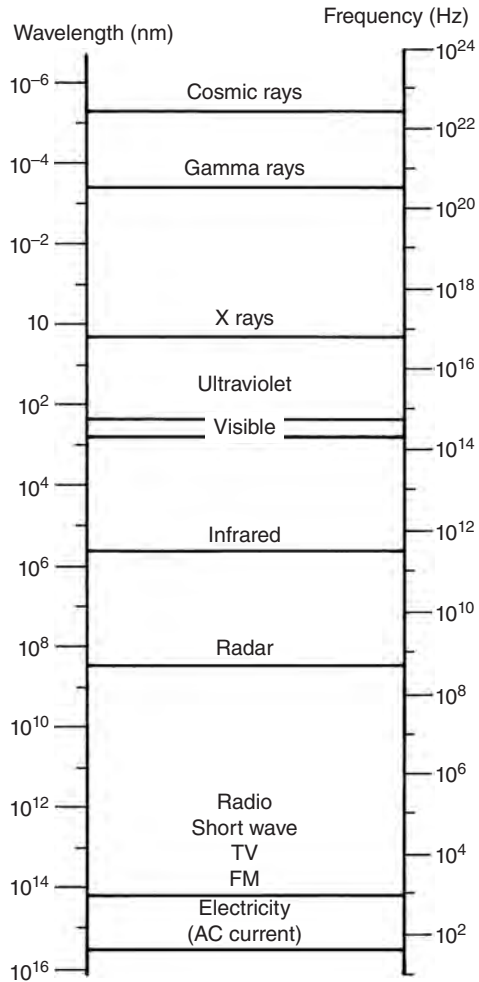
When light is bent by a prism, each wavelength is refracted at a different angle so that the emergent beam emanates from the prism as a fan of light, yielding all of the spectral colors (see Color Plate 8).

All electromagnetic radiation is similar. The physical difference between radio waves, infrared, visible light, ultraviolet, and X rays is their wavelength. A *spectral color* is light of a specific wavelength; it exhibits deep chromatic saturation. *Hue* is the attribute of color perception denoted by what we call violet, indigo, blue, green, yellow, orange, and red. (Isaac Newton had chosen these seven colors in the spectrum somewhat arbitrarily by analogy with the seven notes of the musical scale.)

### The Eye and Brain

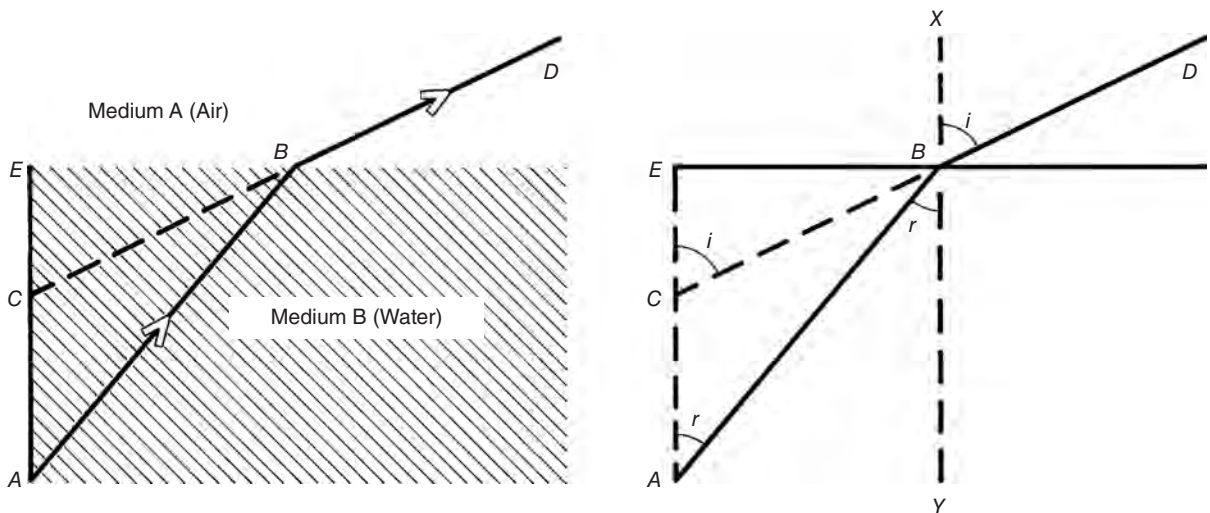
A parallel is often drawn between the human eye and a camera. Yet visual perception involves much more than an optical image projected on the retina of the eye and transferred “photographically” by the brain. Rather than superior optics, visual perception is mostly the result of brain interpretation.

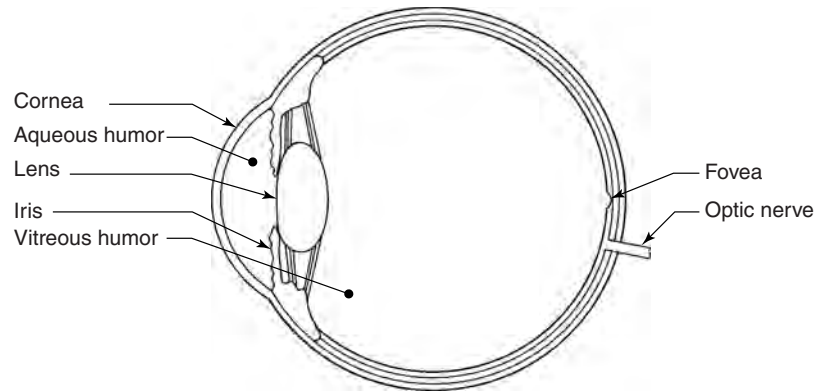




**Figure 2.1** Visible light is a narrow region of the total electromagnetic spectrum, which includes radio waves, infrared, ultraviolet, and X rays. The physical difference is purely the wavelength of the radiation, but the effects are very different. Within the narrow band to which the eye is sensitive, different wavelengths give different colors. See also Color Plate 7.

**Figure 2.2** The law of refraction (Snell's law) states that when light passes from medium A into medium B, the sine of the angle of incidence ( $i$ ) bears a constant ratio to the sine of the angle of refraction ( $r$ ).





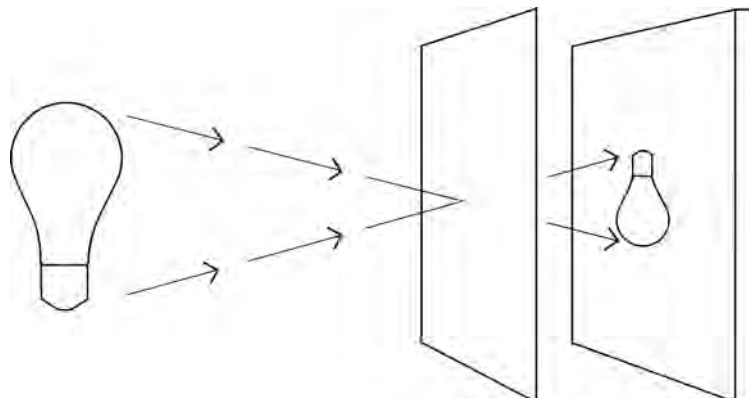
**Figure 2.3** Cross section of the human eye.

The human eye is primarily a device that gathers information about the outside world. Its focusing *lens* throws a minute inverted image onto a dense mosaic of light-sensitive receptors, which convert the patterns of light energy into chains of electrical impulses that the brain will interpret (Figure 2.3).

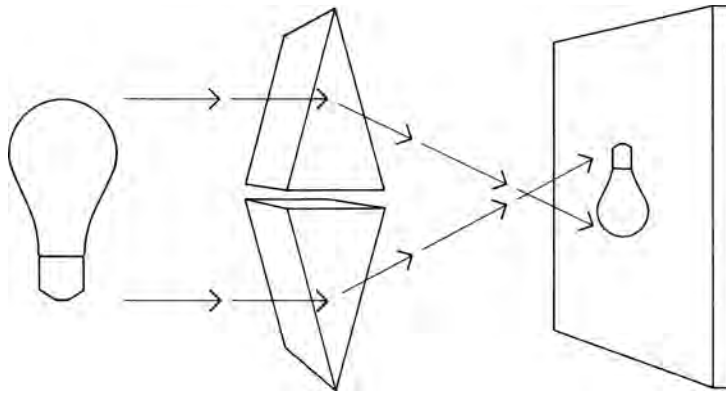
The simplest way to form an image is not with a lens, however, but with a pinhole. In Figure 2.4, a ray from each point of the object reaches only a single point on the screen, the two parts being connected by a straight line passing through the pinhole. Each part of the object illuminates a corresponding part of the screen, so that an upside-down image of the object is formed. The pinhole image is dim, however, because the hole must be small (allowing little light to pass through) if the image is to be sharp.

A lens is able to form a much brighter image. It collects a bundle of light rays from each point of the object and directs them to corresponding points on the screen, thus giving a bright image (Figure 2.5).

The lens of the human eye is built up from its center, with cells being added all through life, although growth gradually slows down. The center is thus the oldest



**Figure 2.4** Forming an image with a pinhole.

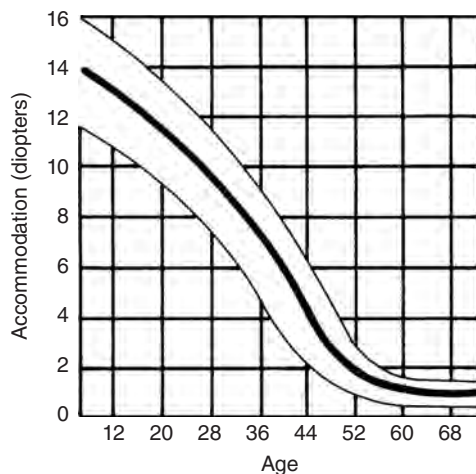


**Figure 2.5** Forming an image with a lens. The lens shown is a pair of prisms; image-forming lenses have curved surfaces.

part, and as the cells age they become more compact and they harden. As a result, the lens stiffens and is less able to change its shape to accommodate varying distances (*presbyopia*) (Figure 2.6).

Lenses only work well when they fit properly and are adjusted correctly. Sometimes the lens is not suited to the eye in which it finds itself: (1) the lens focuses the image in front of or behind the retina instead of on it, giving “short” sight (near-sighted or *myopic*) or “long” sight (farsighted or *hyperopic*); (2) the lens is not truly spherical, giving distortion and, in some directions, blurring of the image (*astigmatic*); or (3) the cornea is irregular or pitted.

Fortunately, almost all optical defects can be corrected by adding artificial lenses, which we call *eyeglasses*. Eyeglasses correct for errors of focus (called *accommodation*) by changing the power of the lens of the eye; they correct for distortion (called *astigmatism*) by adding a nonspherical component. Ordinary glasses do not correct damage to the surface of the cornea, but *corneal lenses*, fitted to the eye itself, serve to give a fresh surface to the cornea.



**Figure 2.6** Loss of accommodation of the lens of the eye with aging.

The *iris* is the pigmented part of the eye. It is found in a wide range of colors, but the color has no impact on vision as long as it is opaque. The iris is a muscle that forms the *pupil*. Light passes through the pupil to the lens, which lies immediately behind it. This muscle contracts to reduce the aperture of the lens in bright light as well as when the eyes converge to view near objects.

People with light-colored eyes lack pigment in their *macula*, the small dot about the size of a pinhead that sits conveniently in the most centralized portion of the eye as light passes through the pupil to reach the retina. The more pigmented the macula, the better it handles the impact of light: light-eyed people are more affected by glare. (Approximately 16 percent of Americans have light-colored eyes; there is also evidence that they are more likely to have cataracts as they age.)

The *retina* is a thin sheet of interconnected nerve cells, which include the light-sensitive cells that convert light into electrical impulses. The two kinds of light-receptor cells—*rods* and *cones*—are named after their appearance as viewed under a microscope (Figure 2.7).

Until recently, it was assumed that the cones function in high levels of illumination, providing color vision, and that the rods function under low levels of illumination, yielding only shades of gray. Color vision, using the cones of the retina, is called *photopic*; the gray world given by the rods in dim light (such as under starlight at night) is called *scotopic*.

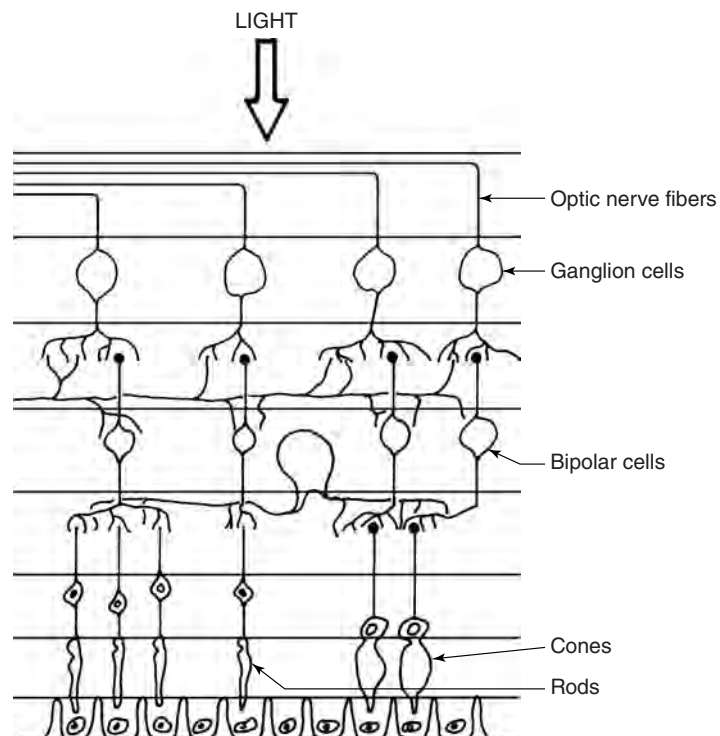
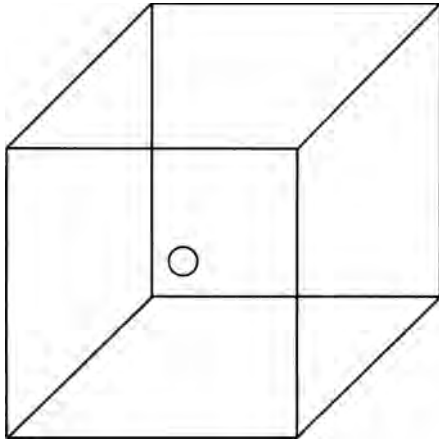
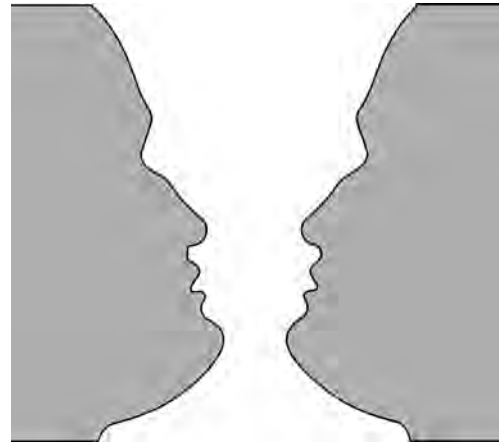


Figure 2.7 The retina.



**Figure 2.8** Necker cube. When you stare at the dot, the cube flips as the brain entertains two different depth hypotheses.



**Figure 2.9** Ambiguous shapes. Is it a vase or two faces in profile?

Recent research, however, suggests that both rods and cones are active at high illuminance, with each contributing to different aspects of vision. When both rods and cones are active (such as under street lighting at night), vision is called *mesopic*.

The eyes supply the brain with information coded into chains of electrical impulses. But the “seeing” of objects is determined only partially by these neural signals. The brain searches for the best interpretation of available data. The perception of an object is a hypothesis, suggested and tested by sensory signals and knowledge derived from previous experience.

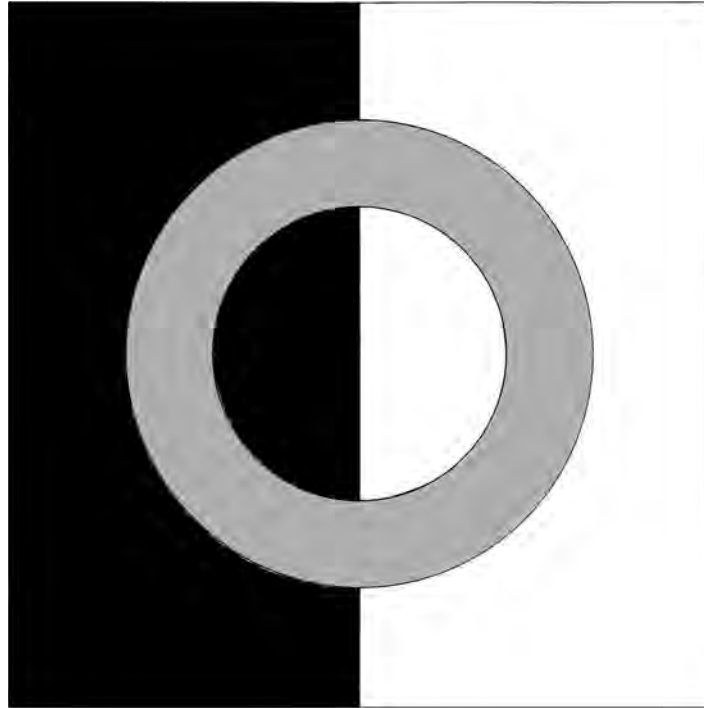
Usually the hypothesis is correct, and we perceive a world of separate solid objects in a surrounding space. Sometimes the evaluation is incorrect; we call this an *illusion*. The ambiguous shapes seen in Figures 2.8 and 2.9 illustrate how the same pattern of stimulation at the eye gives rise to different perceptions.

## Brightness Perception

We speak of light entering the eye, called *luminance*, which gives rise to the sensation of *brightness*. *Illuminance*, which is the density of light received on a surface, is measured by various kinds of photometers, including the familiar photographer’s exposure meter.

Brightness is a subjective experience. We hear someone say, “What a bright day!” and we know what is meant by that. But this sensation of brightness can only be partly attributed to the intensity of light entering the eyes.

Brightness is a result of: (1) the intensity of light falling on a given region of the retina at a certain time, (2) the intensity of light to which the retina has been subjected



**Figure 2.10** Simultaneous contrast.

in the recent past (called *adaptation*), and (3) the intensities of light falling on other regions of the retina (called *contrast*).

Figure 2.10 demonstrates how the intensity of surrounding areas affects the perception of brightness. A given region looks brighter if its surroundings are dark, and a given color looks more intense if it is surrounded by its complementary color.

If the eyes are kept in low light for some time, they grow more sensitive, and a given quantity of light will seem brighter. This “dark adaptation” is rapid for the first few seconds and then slows down. As the eye becomes dark-adapted, it loses *acuity* while it gains sensitivity: with a decrease of intensity and the compensating dark adaptation, the ability to make out fine detail is lost.

The cone and rod receptor cells adapt at different rates: cone adaptation is completed in about seven minutes; rod adaptation continues for an hour or more. This is demonstrated by the difference between leaving a dark movie theater and emerging into bright daylight (cone or light adaptation), and its reverse: entering a dark theater from a bright, sunny day (rod or dark adaptation).

## Color Perception

Brightness is also a function of color. For a given intensity, the colors at the middle of the spectrum look brighter than those at the ends. The sensitivity curves for rods