

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).

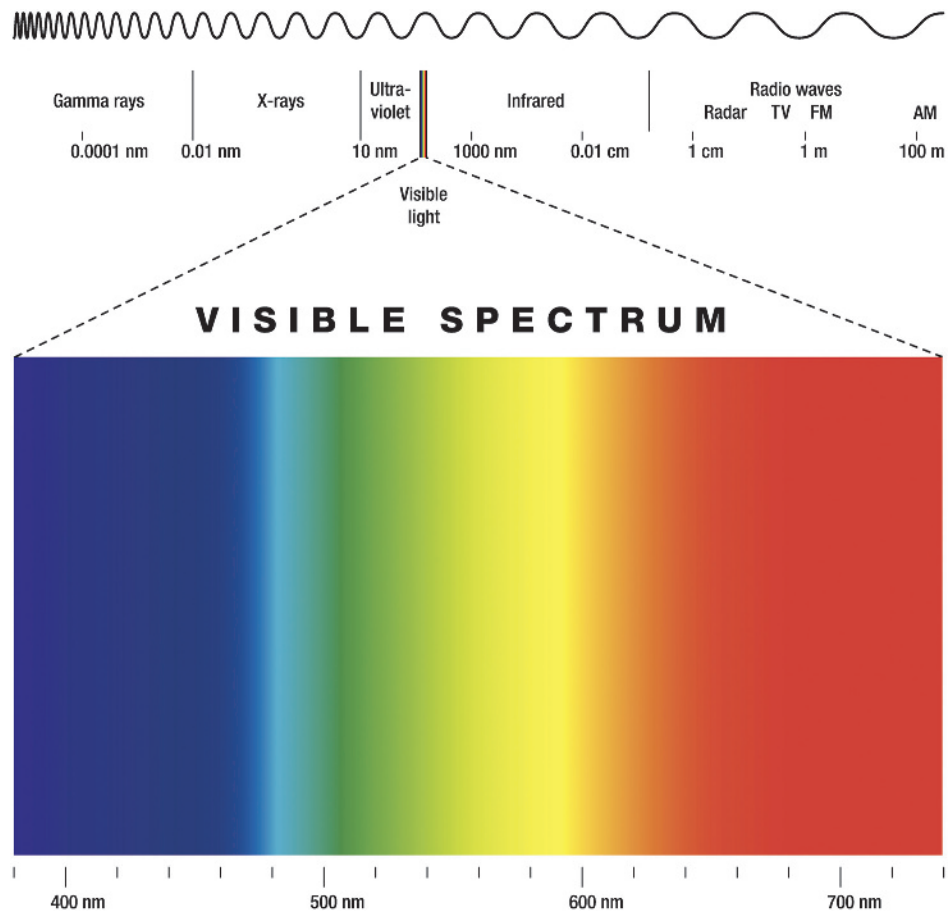


FIGURE 1.1 Light in the electromagnetic spectrum

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.

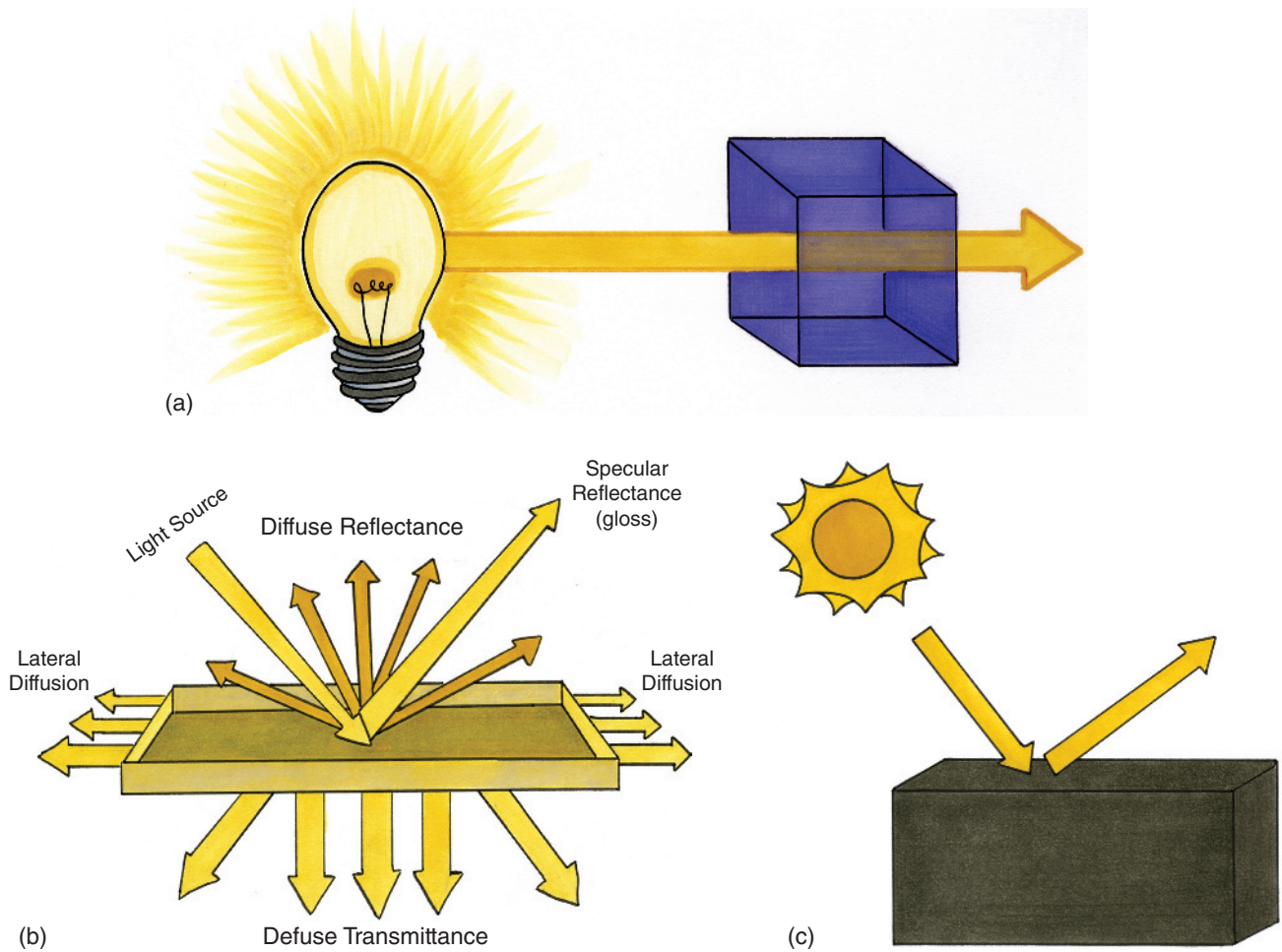


FIGURE 1.2 Transparent, translucent, opaque

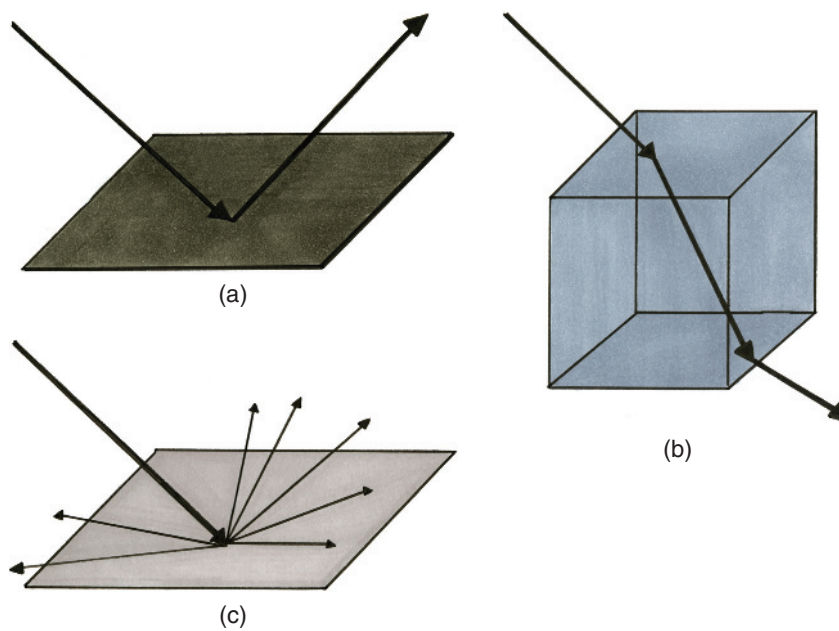


FIGURE 1.3 Reflection, refraction, scattering

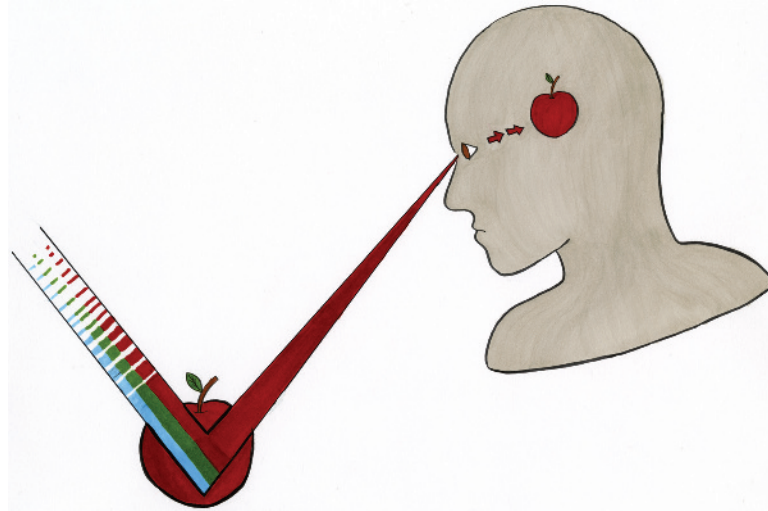


FIGURE 1.4 Light source, object, eye, brain

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.

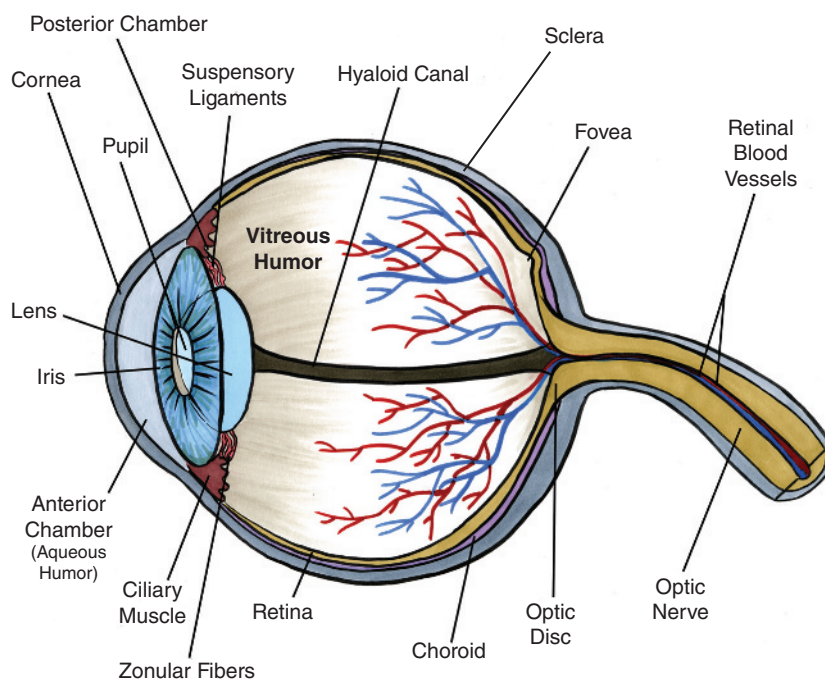


FIGURE 1.5 Diagram of the eye

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)