Perception 1

Perception of the world around us is based not on the quantity of light entering the eye, but on the quantity of contrast.

VISIBLE LIGHT

What we perceive as light is a narrow band of electromagnetic energy, ranging from approximately 380 nanometers (nm) to 760 nm. Only wavelengths in this range stimulate receptors in the eye that permit vision (figure 1.1 and color plate 1). These wavelengths are 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 1.2). 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 the emergent beam emanates from the

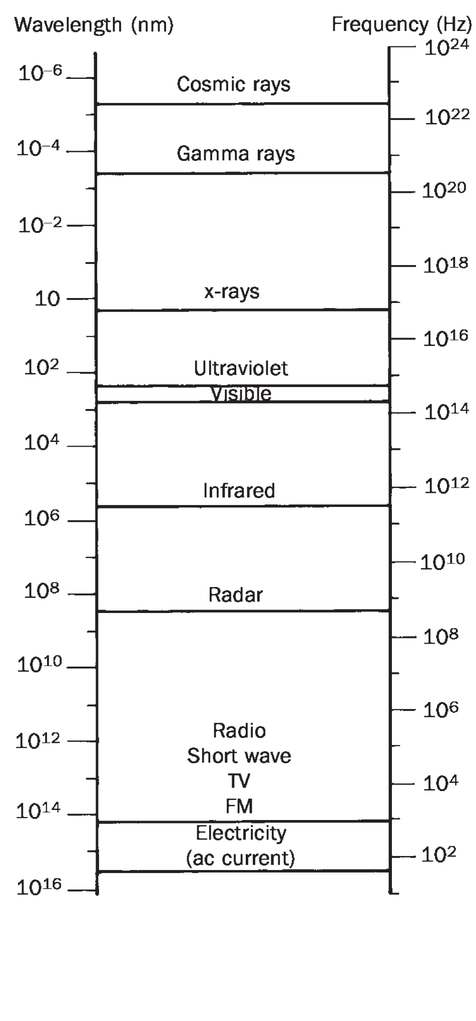

Figure 1.1 Visible light is a narrow region of the total electromagnetic spectrum, which includes radio waves, infrared, ultraviolet, and x-rays. The physical difference is purely the wavelength of the radiation, but the effects are very different. Within the narrow band to which the eye is sensitive, different wavelengths give different colors. See also color plate 1.

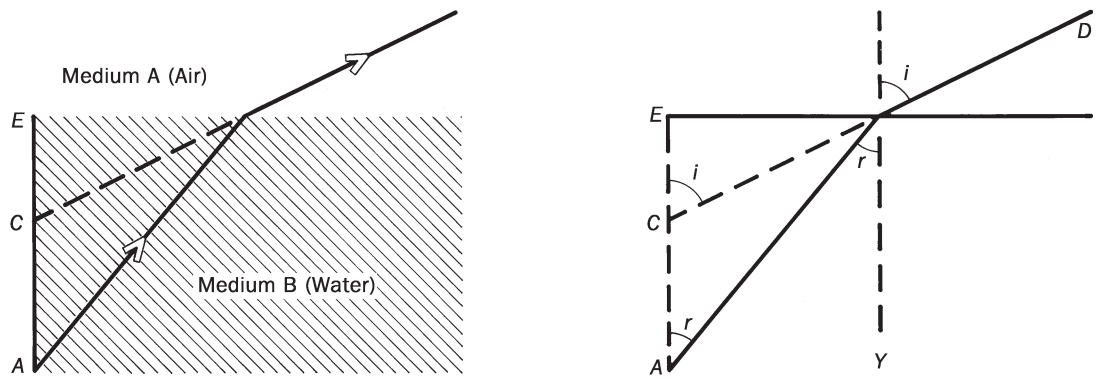

Figure 1.2 The law of refraction (Snell's law) states that when light passes from medium A into medium B the sine of the angle of incidence (*i*) bears a constant ratio to the sine of the angle of refraction (*r*).

prism as a fan of light, yielding all of the spectral colors (see color plate 2).

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 red, orange, yellow, green, blue, and violet.

THE EYE

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 interpreted "photographically" by the brain.

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 1.3).

The simplest way to form an image is not with a lens, however, but with a pinhole. In figure 1.4, a ray from each point of the object reaches only a single point on the

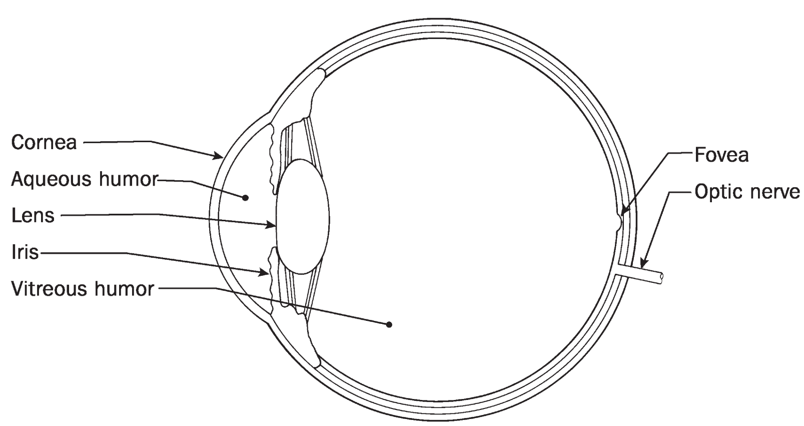

Figure 1.3 Cross section of the human eye.

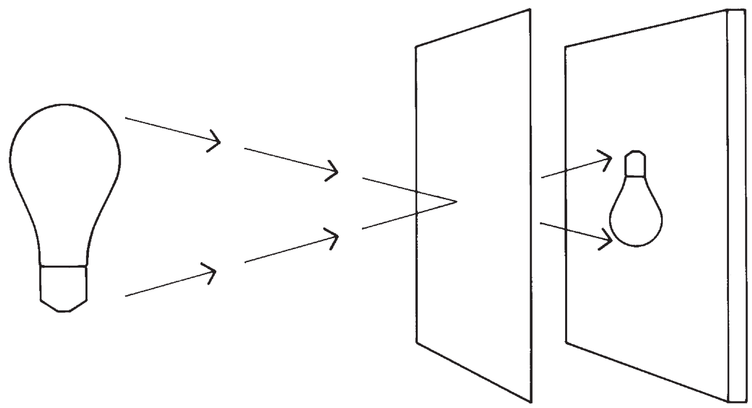

Figure 1.4 Forming an image with a pinhole.

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 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 1.5).

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 part, and as the cells age they become more compact and harden. As a result, the lens stiffens and is less able to change its shape to accommodate varying distances (*presbyopia*) (figure 1.6).

Lenses work well only 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

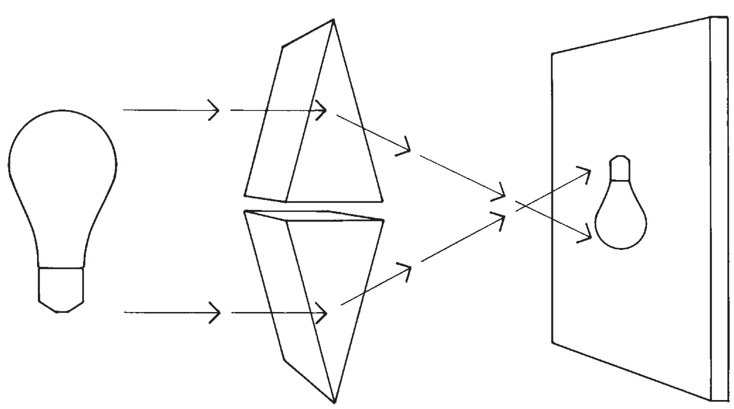

Figure 1.5 Forming an image with a lens. The lens shown is a pair of prisms; image-forming lenses have curved surfaces.

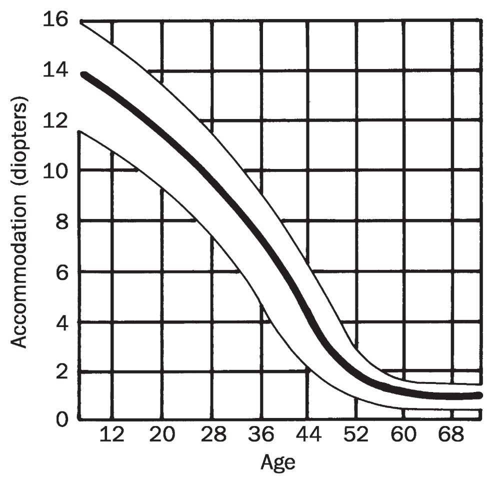

Figure 1.6 Loss of accommodation of the lens of the eye with aging.

front of or behind the retina instead of on it, giving "short" sight (nearsighted 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.

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 and also when the eyes converge to view near objects.

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 1.7).

Until recently, it was assumed that the cones function in high *illuminance*, providing color vision, and the rods function under low illuminance, 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 is called *scotopic*.

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, vision is called *mesopic*.

THE BRAIN

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 1.8 and 1.9 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

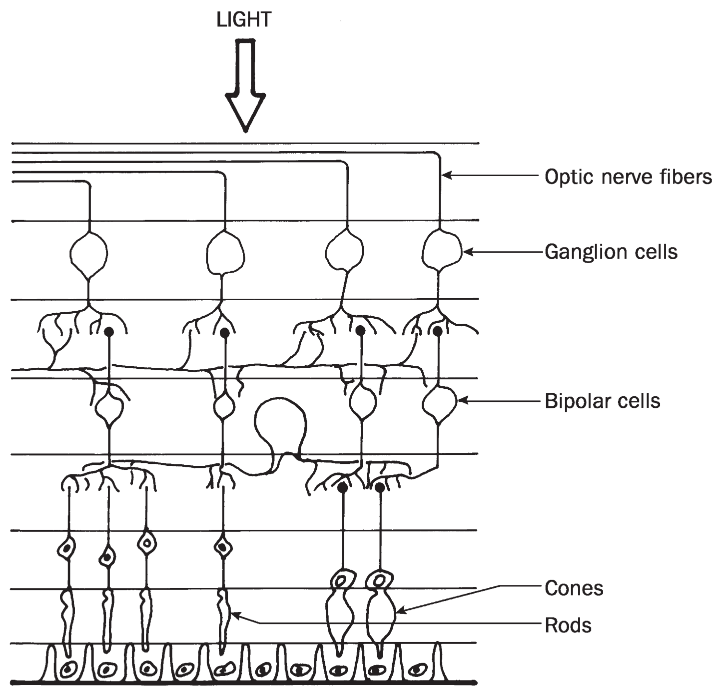

Figure 1.7 The retina.

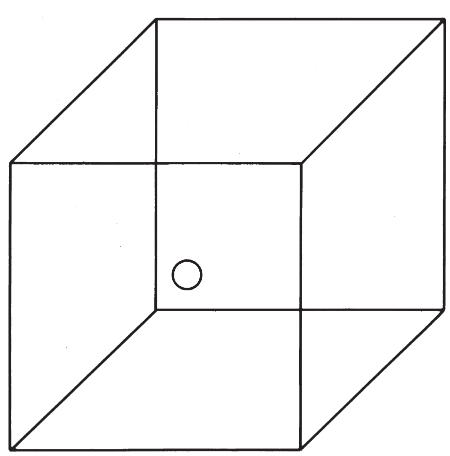

Figure 1.8 Necker cube. When you stare at the dot, the cube flips as the brain entertains two different depth hypotheses.

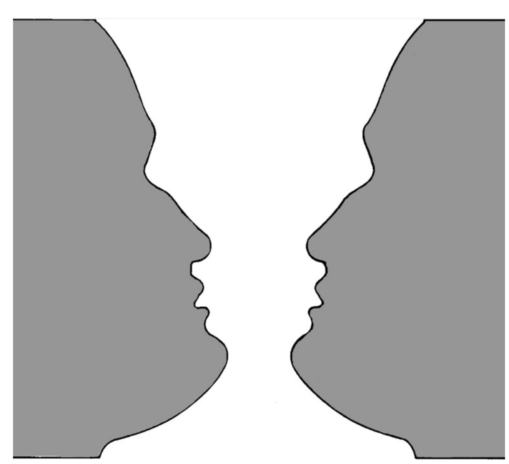

Figure 1.9 Ambiguous shapes. Is it a vase or two faces in profile?

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 be only 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 that the retina has been subject to in the recent past (called *adaptation*), and (3) the intensities of light falling on other regions of the retina (called *contrast*).

Figure 1.10 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, 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 theatre and emerging into bright daylight (cone or light adaptation), and its reverse: entering a dark theatre from a bright, sunny day (rod or dark adaptation).

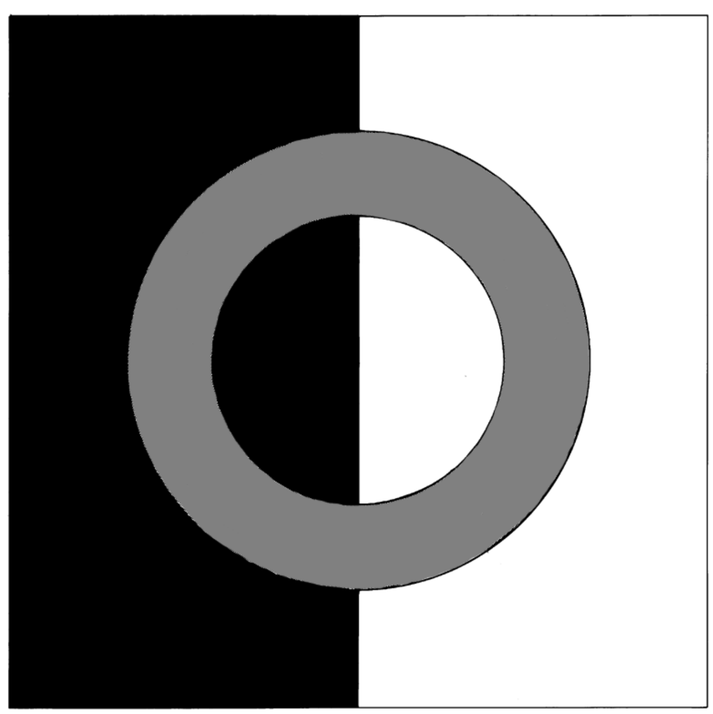

Figure 1.10 Simultaneous contrast.

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 and cones are different. Their shape is similar, but the cones are most sensitive to yellow, and the rods are most sensitive to green. This change with increasing intensity is known as the *Purkinje Shift* (figure 1.11).

The visible spectrum is comprised of five colors of light (see color plate 3) (not of pigment [see color plate 4]): violet, blue, green, yellow, and red. These colors can be mixed: for example, yellow is obtained by combining red with green light.

Mixing colors of light is achieved by using filters, prisms, or diffraction gratings. By mixing two colors of light, a third color is formed in which the two mixed colors cannot be identified.

By mixing three colors of light and adjusting their intensities, any spectral hue can be produced. White can be made, but not black or nonspectral colors such as brown (see color plate 3).

When speaking technically about color vision, we do not refer to "colors" but rather to "hues." This is to avoid difficulty with the term colors, which is descriptive of the physiological sensations to which we give specific names, such as "red" or "blue." We therefore speak technically of spectral hues rather than spectral colors.

Another important distinction is to be found between color as a *sensation* and color as a *wavelength* (or a set of wavelengths) of light entering the eye. Technically, light itself is not colored: it gives rise to sensations of brightness and color, but only in conjunction with a suitable eye and nervous system. When we speak of "yellow light," it means light that gives rise to a sensation described by the majority of people as "yellow."

All the colors of the spectrum are interpreted by the brain from only three kinds of receptors in the eyes: violet, green, and red. These three kinds of color-sensitive receptors (cones) respond to blue-violet, pure green, and orange-red; all colors are "seen" by a mixture of signals from the three systems.

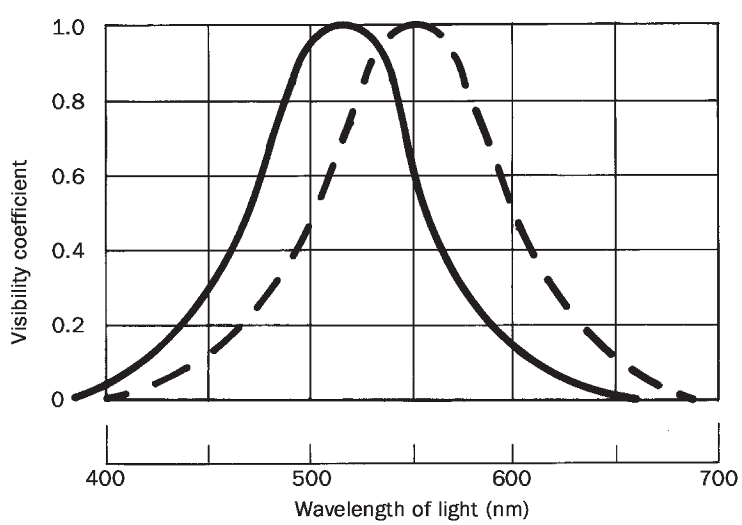

Figure 1.11 The Purkinje Shift.

What we perceive as white is not a particular mixture of colors, but rather the general illumination, whatever this is. A candle or lamplight that looks white by itself appears yellow when "white" electric light or daylight is present for comparison.

The reference for what is taken as white shifts. Knowledge of the normal color of objects is called *color constancy*; it leads us to expect that a tomato will be red. The brain's stored knowledge and expectations exert a strong influence on color perception: objects such as oranges and lemons, for example, take on a richer color because they are recognized as orange and yellow.

Grass is a plant found on lawns and we call the sensation of color it gives "green," but we identify grass by characteristics other than its color: its presence as a lawn, the form and density of the blades, and so forth. If we do confuse the color, sufficient additional evidence is available to identify it as grass. We know it is supposed to be green and we call it green, even when this is doubtful as in the dim light of dusk.

In 1992, neurophysiologists discovered that an alignment of brain cells forms the basis of visual memory. The cells are stacked in columns; depending on which columns are excited by an object, the brain is able to instantly recognize complex images such as faces, even when presented at odd angles or when only part of the face is visible.

Yet it remains a mystery how the contributions from separate channels for brightness, color, shape, and movement—with their own locations in different regions of the brain—come together to form consistent perceptions.

THE SENSE OF SIGHT

We do know that perception is independent of the quantity of light entering the eye; it is based on the quantity of contrast: the differences between light and dark. A certain quantity of light is necessary for a person to see, yet the eye responds not to the total intensity, but to the average intensity in the field of view.

The sense of sight, therefore, is contrast sensitive. It is a mechanism for the detection of differences: of figures on a ground, of objects in a surround. Subjective impressions of space are a function of the degree of contrast present in the environment.