Chapter One

SHEDDING LIGHT ON LIGHT

If the human race had been born blind, everything that we know about our surroundings would have had to be discovered through touching, smelling, tasting, and hearing. However, our eyes detect light. Light has been a source of information about our immediate world and has added immeasurably to our understanding of it. In addition, light has been our main source of information about the sun, planets, stars, and other heavenly bodies. Only the moon has been explored directly, and that's been in recent times. It is very human to wonder about things—like the universe—that are bigger than ourselves. It is also human to wonder about the nature of light, which brings the universe to us.

Vision, our ability to detect light, is the most dominant of our five senses. One measure of this is that we have more receptor cells in our eyes to detect light than we have receptor cells for all our other senses combined. Another is the enormous range of things we perceive, including brightness, color, contrast, depth, and motion. We are aware of light every conscious moment of our lives. So it is no surprise that many people have spent time thinking about the nature of light.

Some ideas about light go back thousands of years. In the first century A.D., a Greek engineer named Hero (20?A.D.–?) wrote a book about mirrors and light. He believed that light was a kind of "feeler" or antenna sent out by the eyes to detect the things we saw. Hero thought that light traveled infinitely fast.

About nine hundred years later, an Arabian physicist named Alhazen (965?–1039) figured out that light comes from a source, such as the sun, and that everything we see reflects light from the source to our eyes. Alhazen wrote a book about light that was translated into Latin in the thirteenth century, three hundred years after he wrote it. It had a powerful influence on scientists who studied light.

Two theories arose about the nature of light. One theory said that light was a stream of particles that traveled in straight lines. The other said that light was made of waves. Evidence for both ideas came as scientists observed the behavior of light in their laboratories and in nature. Through experimentation they found that light can be blocked, bent, bounced, broken up, caught, filtered, and scattered. Everything we do with light reveals something about its nature. All the information we have collected about light is called the science of *optics.* The word "optics" comes from a Greek word (*optikos*) meaning "of the eye or seeing."

Any study of light begins with a source of light. The most obvious and most important source of light is the sun. Through the ages we have created other sources of light to be able to go about our business when sunlight was not available. First, there was light produced by fire. Candles and oil, and then gas lamps, illuminated people's homes for centuries. In 1879, Thomas Edison (1847–1931) introduced the first incandescent electrical lamp. An incandescent lamp uses a wire thread that is heated by an electric current until it glows. Other forms of electrical light sources are arc lamps, in which the light is a series of bright sparks, and fluorescent lamps.

The science of optics has given us the power to do some amazing things: Grocery checkout devices use a scanning laser beam to identify an item by its code, made of black bars; the checkout device then displays the price of the item on a screen. Compact disc players also use lasers to read music that has been encoded on special optical discs. Credit cards now have holograms,

The Anatomy of a Shadow

Materials & Equipment

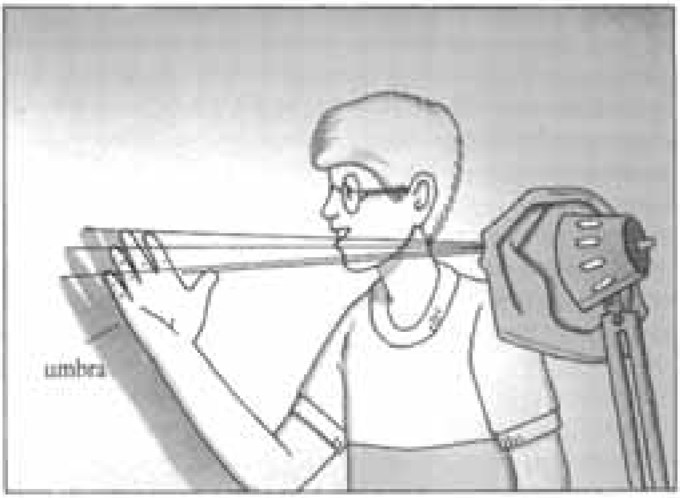
- a large desk lamp with a flexible neck that can be put in a variety of positions
- a white wall or screen
- a pencil
- aluminum foil
- a magnifying glass

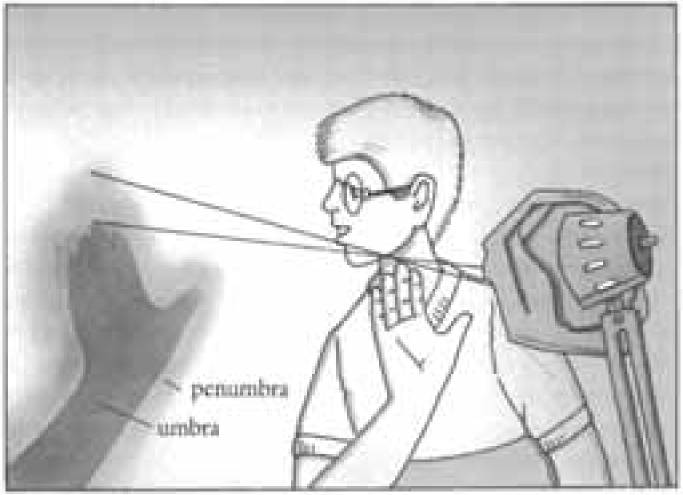
Procedure #1

Cover the opening of the lampshade with the aluminum foil so that no light gets out and place the lamp as far from the wall or screen as you can. Poke a half-inch to one-inch hole in the center of the foil with the pencil so that light escapes from the lamp. Point this light toward the wall. This light will be your light source for shadow making. Next, remove all other light sources. Close the curtains or blinds and make the room as dark as possible. Turn off any other lamps in the room. The room will be only dimly illuminated.

Hold your hand a few inches away from the wall and examine the shadow it casts. Notice how sharp and well defined the edges of the shadow are. Now step back from the wall toward the lamp and see how the shadow changes. What happens to its size? What happens to the crispness of its edges? See two parts of a shadow emerge as you move. The darkest part of the shadow is called the ***umbra***. The lighter area that surrounds the umbra is called the ***penumbra***.

Be aware that the lamp can get hot. Be sure to





Chapter Three

BENDING LIGHT

Shadows are evidence that light travels in straight lines. Because light travels in straight lines, you can't see around corners. But light can be bent, as you'll see in the next two chapters. The bending of light depends on another property of light—namely, its speed. Measuring the speed of light is one of the great breakthroughs of science.

You see a flash of lightning and you hear its thunder seconds later. You see a batter swing at a baseball from your seat high in the stands and, after a noticeable pause, you hear the crack of the bat. These observations lead to the conclusion that it takes sound longer to reach your ears than it takes light to reach your eyes. Clearly, sound takes time to travel. The question is, how fast does light travel? If light does take time to travel from one place to another, it must move so fast that its speed seems impossible to measure. The ancient Greek engineer Hero believed the speed of light to be infinitely fast. This means that you should be able see light simultaneously at the beginning and end of its journey, but that doesn't make sense. So about sixteen hundred years after Hero, scientists began to tackle the enormous task of determining the speed of light.

One of the first scientists to make an attempt was the Italian astronomer and physicist Galileo Galilei (1564–1642). He took a lantern to the top of one hill while his assistant took a lantern to the top of another. Galileo opened the shutter on his own lantern. The assistant opened the shutter on his lantern as soon as he saw Galileo's light. Galileo knew the distance between the two hilltops. He hoped that he could measure the time interval between the opening of his lantern and the appearance of the assistant's light. If he knew the distance and the time, he could calculate the speed. Galileo made many measurements between different pairs of hills. But his measurement of time was very inaccurate. All he really measured was how long it took his partner to react to his light and for him to react to his partner's light. The speed of light proved to be much too fast to be measured in this crude manner.

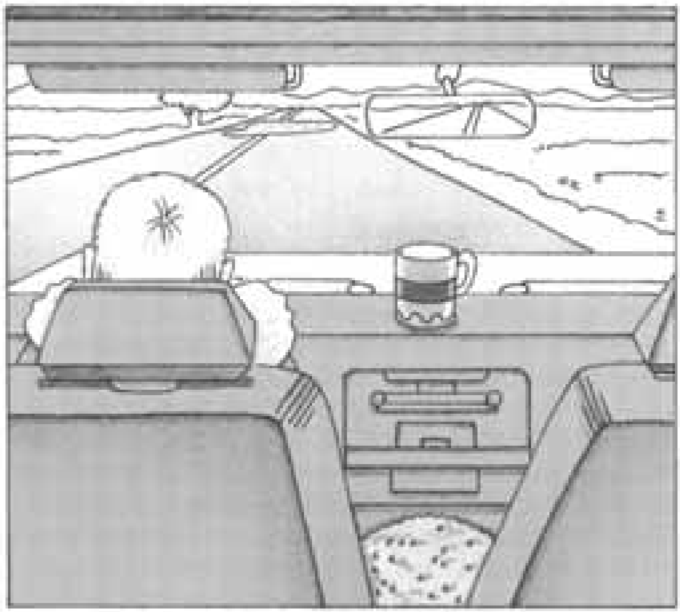
The first reasonable estimate of the speed of

HOT-AIR MIRAGES . . . WITHOUT A DESERT!

Procedure

This is something to watch for on a sunny, hot summer day. When you happen to be on a long, straight road, take a look at the surface of the road up ahead of the car. It often appears that there are pools of water on the road. You may even see the "reflections" of cars in these "pools."

When you drive closer to these "pools," you will see that they disappear. You have been the



victim of a mirage. This is the same illusion that fools many thirsty wanderers in the desert.

Here's What's Happening

Glass and water are not the only substances that can bend light. The temperature of the air affects the speed of light also. When light travels through air of one temperature into air of another, its speed changes, and the light bends.

The air near the ground is much hotter than the air higher up. Light that is coming from above is refracted when it meets this hotter air. Instead of continuing in its path toward the road, the light is bent up toward your eyes. You see an image of the blue sky where you would normally see the road. It looks as if the road is covered with a pool of water. Often you can see what appears to be the reflection of the car as if the car is driving on water. This is not a reflection at all, but a bending of the light as it meets different air temperatures.

LOSE A GLASS IN A GLASS

Materials & Equipment

- a clear glass jar free of labels or other marking patterns
- a smaller clear glass jar that fits inside the larger one
- paint thinner—also known as petroleum distil-