Chapter 8

LIGHT

More information by far reaches the human brain through the eyes than through any other sense organ. The carrier of this information is what we call light, a "something" that can be detected by its effects on the retina of the eye, or on a photographic film. But, what is this "something", and how does it behave? The first question has led to mystery after mystery, but centuries of observations have provided a wealth of answers to the second question.

Some General Properties of Light

Whatever it is, light seems to propagate in straight lines: sharp objects have sharp shadows. Strangely, light - the messenger of information - is itself invisible. When we do "see" a beam of light in the darkness, it is only because suspended particles reflect the light. Light travels through air as well as the vacuum of outer space. It travels through some substances, such as glass or water, but not through others, such as metals.

When a beam of light strikes a polished surface, such as a mirror, it is "reflected" like a billiard ball bouncing off a pool table's side.

When a light beam goes from, say, air to water, some of the light is reflected, and some passes into the water, where it is "refracted" (bent in direction). Because of refraction, a straight stick appears bent when partially immersed in water.

Speed of light

Because its speed is so unimaginably high, light appears to travel instantly from source to observer. In the 17th-century, the Danish astronomer Olaf Roemer was the first to estimate the speed of light, by studying one of Jupiter's satellites. This satellite is periodically eclipsed as it moves behind its parent. Roemer noticed that the time between eclipses became shorter as Earth moved closer to Jupiter, and then longer, as the two planets moved farther apart.

He correctly concluded that the discrepancies were due to the time taken by light to cross the distance between the two planets. Over half a year, as Earth moved from a point on its orbit closest to Jupiter to a point diametrically opposite, the total discrepancy had to be the time taken by light to move across the diameter of Earth's orbit. In 1676, Roemer announced that, according to his observations, the speed of light was 140,000 miles per second!

Actually, more accurate modern measurements show that the speed of light is about 186,000 miles per second. Light does not propagate instantly. This fact becomes very important with the immense distances of outer space. Looking into a telescope, an astronomer may observe events that actually occurred millions or even billions of years ago.

Dispersion

As previously mentioned, Newton was the first to observe that the refraction of white light through a glass prism results in its "dispersion" into the colors of the rainbow.

Figure 8.1 shows a beam of white light striking a prism. What emerges is a divergent, multicolored beam. This is due to the fact that the various components of light are refracted differently.

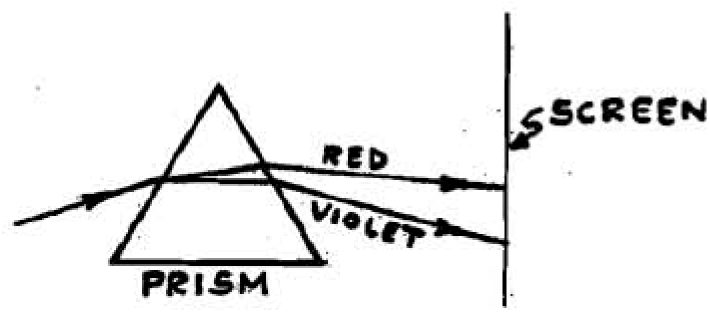

Figure 8.1 - A beam of sunlight through a prism

The composition of white light is more complex than suggested by the prism experiment. The colors of the rainbow from red to violet are merely those components of light that can be detected by the retina of the human eye. Photographic films of various types can "see" additional components that are invisible to the eye: "infrared" components below the red end of the visible spectrum, "ultraviolet" components above the violet end.

Theories of Light: Particles vs. Waves

In Newton's time, there were two theories that attempted to explain the nature of light. One viewed light as a hail of tiny particles; the other, as a wave phenomenon.

In 1690, the Dutch mathematician, astronomer and physicist Christian Huygens presented a theory of light as the propagation of waves. These moved at Roemer's incredibly high speed through "ether", a medium assumed to consist of tiny particles, pervading the entire universe.

In Huygens' wave theory, each particle of the medium did not move much itself, but passed its movement to the next particle in the direction of propagation. (Huygens' waves are said to be "longitudinal" because the displacement of particles occurs in the direction of wave propagation.) In the particle theory, instead, light was seen as a stream of tiny particles, each of which actually moved across great distances.

Newton supported the particle theory and, in the century after his death, his great authority was invoked to support that theory. It was not until the 19th-century that the competing wave theory became firmly established. In 1801, the English physicist and physician Thomas Young performed an experiment that was crucial in proving the wave nature of light. See **Figure 8.2**.

Starting about 1816, Augustin-Jean Fresnel, working independently in France, developed his own wave theory of light, which predicted such effects as diffraction and interference. The key point made by Young and Fresnel in support of a wave theory was that adding one beam of light to another can produce darkness. It is difficult to imagine how particles can cancel one another: by adding particles to particles, one should get more particles. Waves, instead, can cancel as well as reinforce one another.

Fresnel proposed that light waves are "transverse" waves, i.e., with displacements perpendicular to the direction of propagation, as in the waves generated in Chapter 7 by flipping a hand holding one end of a rope. The hypothesis of transverse waves made it possible to account for known phenomena of light polarization. The essence of these phenomena is that, when a beam of light passes through crystals of certain types, its behavior can be affected by the orientation of the crystal. Light that can go through, if the crystal has one orientation, is totally blocked, if the crystal is rotated by 90 degrees.

The hypothesis of transverse waves, however, had some appalling implications. A displacement in the direction of propagation (as in Huygens' longitudinal waves) can be supported by a gas or a liquid. Particles, which are being pushed from behind, in turn push neighboring particles in front, in a pattern that repeats along the direction of propagation. A displacement perpendicular to the direction of propagation (as in transverse waves), however, seems possible only in a solid, where particles are linked together.

For light to be able to propagate through the emptiness of outer space at tremendous speed as a transverse wave, it was necessary to postulate a medium, the ether, which was as tenuous as vacuum, pervaded all space, could penetrate almost any substance, and was not only elastic but solid!

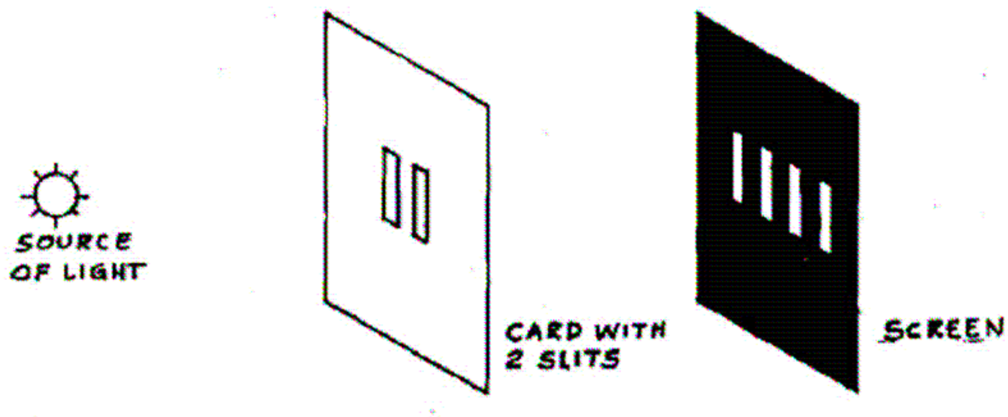

Figure 8.2 - Young's experiment

As shown schematically above, a beam of light is shined in the dark on a barrier, a card with two very narrow slits close together. The light that goes through the slits falls on a screen. If light consisted of tiny particles, we would expect the screen to be totally dark except for two illuminated areas, where the particles that go through the slits strike the screen. What we see, instead, is an alternating pattern of several dark and light fringes (the figure shows only a few, and much sharper than they should be).

The light waves shined on the barrier are diffracted by each of the two slits. On the other side of the barrier, because of diffraction, the two slits act as two identical sources of light waves (remember Figure 7.3). Two sets of waves spread out in a semicircular pattern, interfering with one another. There are points where the waves from the two slits reinforce one another. On the other hand, there are points where the two waves cancel one another. As a result, on the screen we see a series of dark and light fringes.

(From Blanpied Figure 9-24 pg 375)

With a transverse-wave theory, a wide variety of optical phenomena could be explained in a consistent way. At the same time, the new theory raised some very perplexing questions: What was the nature of the "displacement" associated with a light wave? What was it that was displaced? The experiments of Young and Fresnel, however, were found conclusive at the time, and light came to be recognized as a wave phenomenon. This was not to be, however, the last word about the nature of light.