27 Light

The only thing we can really see is light. But what *is* light? We know that during the day the primary source of light is the sun, and the secondary source is the brightness of the sky. Other common sources are flames, and since modern times, white-hot filaments in lamps, and glowing gases in glass tubes.

Most objects we see, such as this page, are made visible by the light they reflect from such sources. Some materials, such as water and window glass, allow the passage of light in straight lines. Other materials, such as thin paper, allow the passage of light, but in diffused directions so that you cannot see objects through them. The majority of materials do not allow the passage of light, except when very thin layers of them are used.

Why do things such as water and glass allow light straight through, while things such as wood and steel block light? Before you can answer these questions, you must know something about light itself.

27.1 Early Concepts of Light

The study of the nature of light has extended over thousands of years. In the fifth century B.C., philosophers such as Socrates and Plato in Greece speculated that light was made up of streamers or filaments emitted by the eye. They believed that seeing takes place when these streamers, acting like antennas, make contact with an object. This view was supported by Euclid, when he asked how else can we explain why we do not see a needle on the floor until our eyes fall upon it. As late as the fifteenth cen-

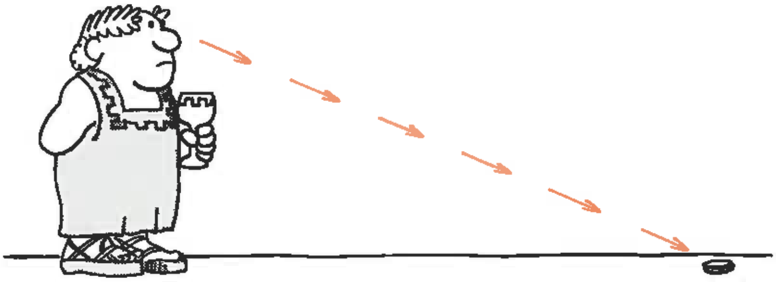


Fig. 27-1 The ancients believed that light traveled from our eyes to the objects we look at, rather than from the objects to our eyes.

tury, René Descartes, the great French mathematician and philosopher, published a book that explained a similar theory.

Not all the ancients, however, held such views. The Pythagoreans from Greece believed that light traveled from luminous objects to the eye in the form of tiny particles. Another Greek, Empedocles, taught that light traveled in waves. In more recent history, a particle theory of light was championed by Newton and widely accepted by other scientists. The particle theory was supported by the fact that light seemed to move in straight lines instead of spreading out as waves do.

Not everyone in Newton's time believed in the particle theory. One of Newton's contemporaries, the Dutch scientist Christian Huygens, stated that light was a wave. He supported this theory with evidence that under some circumstances light does spread out (this is *diffraction*, which is covered in Chapter 31). Other scientists later found more evidence to support the wave theory. Then in 1905 Einstein published a theory concerning what was called the *photoelectric effect*. According to this theory, light consists of particles—massless bundles of concentrated electromagnetic energy—called **photons**.

Scientists now agree that light has a dual nature, part particle and part wave. This chapter discusses the wave nature of light, and leaves the particle nature of light to Chapter 38 (and your next physics course).

27.2 The Speed of Light

It was not known whether light travels instantaneously or with finite speed until almost the end of the seventeenth century. Galileo had tried to measure the time a light beam takes to travel to a distant mirror and back, but the time interval—if one existed at all—was so short he couldn't begin to measure it. Others tried the experiment at longer distances with lanterns they blinked on and off between distant mountain tops. All they succeeded in doing was measuring their own reaction times.

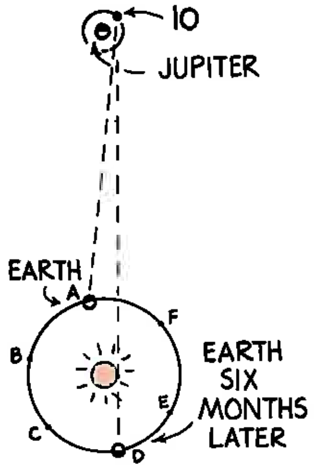


Fig. 27-2 Roemer's method of measuring the speed of light. Light coming from Jupiter's moon Io takes a longer time to reach the earth at position D than at position A. The extra distance that the light travels divided by the extra time it takes gives the speed of light.

Experimental evidence for the first successful measurement of the speed of light was supplied by the Danish astronomer Olaus Roemer about 1675. Roemer made very careful measurements of the periods of Jupiter's moons. The innermost moon, Io, is visible through a small telescope and was measured to revolve around Jupiter in 42.5 hours. Io disappears periodically into the shadow of Jupiter, so this period could be measured with great precision. Roemer was puzzled to find an irregularity in the measurements of the period of Io. He found that when the earth moved away from Jupiter, say from position B to C in Figure 27-2, the measured periods of Io were all somewhat longer than average. When the earth moved toward Jupiter, say from position E to F, the measured periods were shorter than average. Roemer estimated that the cumulative discrepancy between positions A and D amounted to about 22 min. That is, when the earth was at position D, Io would pass into Jupiter's shadow 22 min late with respect to observations at position A.*

The Dutch physicist Christian Huygens correctly interpreted this discrepancy. When the earth was farther away from Jupiter, it was the *light* that was late, not the *moon*. Io passed into Jupiter's shadow at the predicted time, but the light carrying the message did not reach Roemer until it had traveled the extra distance across the diameter of the earth's orbit. There is some doubt as to whether Huygens knew the value of this distance. In any event, this distance is now known to be 300 000 000 km. Using the correct travel time of 1000 s for light to move across the earth's orbit makes the calculation of the speed of light quite simple:

$$\text{speed of light} = \frac{\text{extra distance traveled}}{\text{extra time measured}}$$

$$= \frac{300\,000\,000\ \text{km}}{1000\ \text{s}} = 300\,000\ \text{km/s}$$

The most famous experiment measuring the speed of light was performed by the American physicist Albert Michelson in 1880. Figure 27-3 is a simplified diagram of his experiment. Light from an intense source was directed by a lens to an octagonal mirror initially at rest. The mirror was carefully adjusted so that a beam of light was reflected to a stationary mirror located on a mountain 35 km away, and then reflected back to the octagonal mirror and into the eye of an observer. The distance the light had to travel to the distant mountain was carefully surveyed, so Michelson had only to find the time it took to make a round trip. He accomplished this by spinning the octagonal mirror at a high rate.

---

* Roemer's estimate was not quite correct. The correct value is 16 min, or about 1000 seconds.

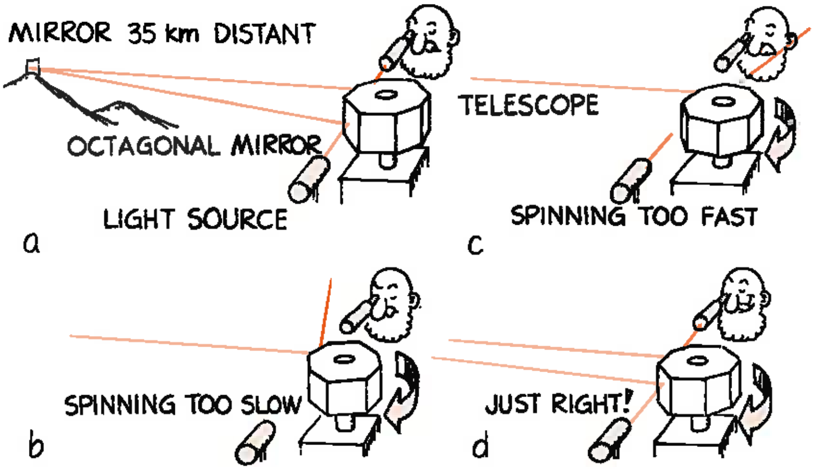


Fig. 27-3 The mirror arrangement used by Michelson to measure the speed of light. Light is reflected back to the eyepiece when the mirror is at rest (a). Reflected light fails to enter the eyepiece when the mirror is spinning too slowly (b) or too fast (c). When it is rotating at the correct speed (d), light reaches the eyepiece.

When the mirror was spun, the continuous beam of light was chopped up so that only discrete bursts of light reached the mountain mirror to be reflected back to the spinning octagonal mirror. If the rotating mirror made exactly one-eighth rotation in the time the light made the trip to the distant mountain and back, the mirror would be in a position to reflect light into the eyepiece of the observer. If the mirror was rotated too slowly or too quickly, it would not be in a position to reflect light into the eyepiece. When the speed of rotation of the mirror was adjusted so that the light entered the eyepiece, Michelson knew that the time for the light to make the round trip and the time for the octagonal mirror to make one eighth of a rotation was the same. He divided the 70-km round trip distance by this time. Michelson's experimental value for the speed of light was 299 920 km/s, which we round off to 300 000 km/s. Michelson received the 1907 Nobel prize in physics for this experiment. He was the first American scientist to receive the prize.

▸ **Question**

Light entered the eyepiece when Michelson's octagonal mirror made exactly one eighth of a rotation during the time light reflected to the distant mountain and back. Would light enter the eyepiece if the mirror turned one quarter of a rotation in this time?

▸

Answer

Yes, light would enter the eyepiece whenever the octagonal mirror turned in multiples of $\frac{1}{8}$ rotations—$\frac{1}{4}$, $\frac{1}{2}$, 1, etc.—in the time the light made its round trip. What is required is that any of the eight faces is in place when the reflected flash returns from the mountain.

We now know that the speed of light in a vacuum is a universal constant. Light is so fast that if a beam of light could travel around the earth, it would make 7.5 trips in one second. Light takes 8 minutes to travel from the sun to the earth, and 4 years from the next nearest star, Alpha Centauri. The distance light travels in one year is called a **light year**.

So Alpha Centauri is 4 light years away. Our galaxy has a diameter of 100 000 light years, which means that light takes 100 000 years just to travel across the galaxy. Some galaxies are 10 billion light years from earth. If one of those galaxies had exploded 5 billion years ago, this information would not reach earth for another 5 billion years to come. Light is fast and the universe is big!

Fig. 27-4 Light would take 30 000 years to reach us from the center of our galaxy. So the center of our galaxy is 30 000 light years distant.

Computational Example

How far, in kilometers, would a beam of uninterrupted light travel in one year?

The speed of light is a constant, so its instantaneous speed and average speed are the same. From the equation $\overline{v} = d/t$, we can say

$$\begin{aligned} d &= \overline{v}t \\ &= (300\,000\ \text{km/s}) \times (1\ \text{yr}) \end{aligned}$$

By the technique of dimensional analysis we convert 1 year to seconds, and find

$$d = \left(\frac{300\,000\ \text{km}}{1\ \cancel{\text{s}}}\right) \times (1\ \cancel{\text{yr}}) \times \left(\frac{365\ \cancel{\text{d}}}{1\ \cancel{\text{yr}}}\right) \times \left(\frac{24\ \cancel{\text{h}}}{1\ \cancel{\text{d}}}\right) \times \left(\frac{3600\ \cancel{\text{s}}}{1\ \cancel{\text{h}}}\right)$$

$$= 9.5 \times 10^{12}\ \text{km}$$

This distance is one light year.

27.3 Electromagnetic Waves

Light is energy that is emitted by vibrating electric charges in atoms. This energy travels in a wave that is partly electric and partly magnetic. Such a wave is called an **electromagnetic wave**. Light is a small portion of the broad family of electromagnetic waves that includes such familiar forms as radio waves, microwaves, and X rays, which are all radiated by vibrating electrons within the atom. The range of electromagnetic waves, or the **electromagnetic spectrum**, as it is called, is shown in Figure 27-5.

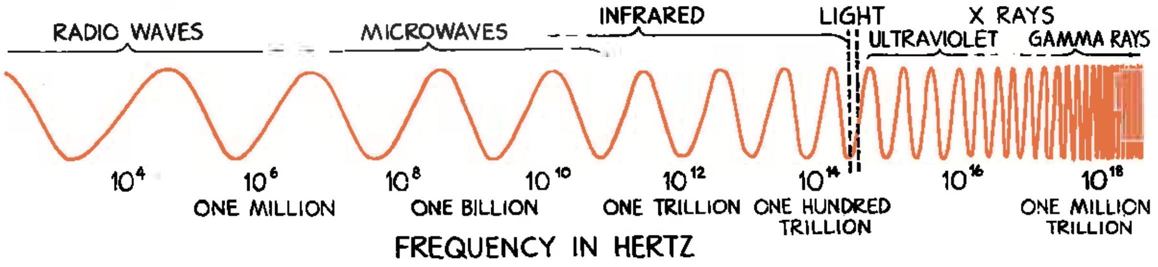


Fig. 27-5 The electromagnetic spectrum is a continuous range of waves extending from radio waves to gamma rays. The descriptive names of the sections are merely a historical classification, for all waves are the same in nature, differing principally in frequency and wavelength; all have the same speed.

The lowest frequency of light we can see with our eyes appears red. The highest visible frequencies are nearly twice the ~~frequency~~ of red and appear violet. Electromagnetic waves of frequencies lower than the red of visible light are called **infrared**. Many heat lamps give off infrared waves. Electromagnetic waves of frequencies higher than those of violet are called **ultraviolet**. These higher-frequency waves are more energetic and are responsible for sunburns.

▸ **Question**

Is it correct to say that a radio wave is a low-frequency light wave? Is a radio wave also a sound wave?

27.4 Light and Transparent Materials

Light is energy carried in an electromagnetic wave that is made by vibrating electric charges ~~in atoms. When light is incident~~ upon matter, electric charges in the matter are forced into vibration. In effect, vibrations in the emitter are transferred to vibrations in the receiver. This is similar to the way that sound is received by ~~a receiver~~ (see Figure 27-6).

▸ **Answer**

Both a radio wave and a light wave are electromagnetic waves which originate from the vibrations of electrons. Radiowaves have lower frequencies of vibration than visible light waves, so a radio wave may be considered to be a low-frequency light wave. A sound wave, on the other hand, is a mechanical vibration of matter and is not electromagnetic. A sound wave is fundamentally different from an electromagnetic wave. Thus, a radio wave is not a sound wave.

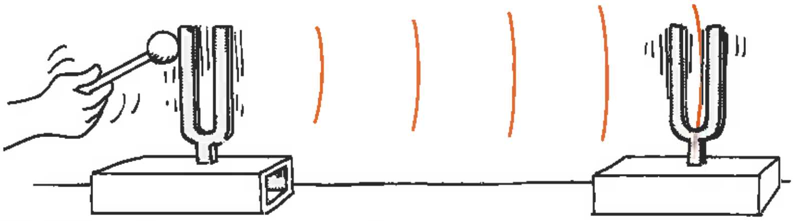


Fig. 27-6 Just as a sound wave can force a sound receiver into vibration, a light wave can force charged particles in materials into vibration.

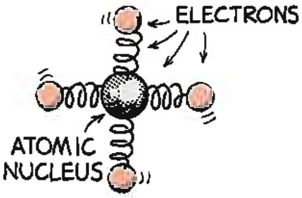


Fig. 27-7 The electrons of atoms in glass can be imagined to be bound to the atomic nucleus as if connected by springs.

Exactly how a receiving material responds when light is incident upon it depends on the frequency of the light and the natural frequency of the electric charges in the material. Visible light vibrates at a very high rate, some 100 trillion times per second (10^{14} hertz). If a charged object is to respond to these ultrafast vibrations, it must have very little inertia. Electrons have a small enough mass to vibrate this fast.

Glass and water are two materials that allow light to pass through in straight lines. They are said to be **transparent** to light. To understand how light gets through a transparent material such as glass, visualize the electrons in an atom as connected by imaginary springs (Figure 27-7). When a light wave is incident upon them, they are set into vibration.

All materials that are springy or elastic respond more to vibrations at some frequencies than others. Bells ring at a particular frequency, tuning forks vibrate at a particular frequency, and so do the electrons of atoms. The natural vibration frequencies of an electron depend on how strongly it is attached to its atom. Different atoms have different "spring strengths."

Electrons in glass have a natural vibration frequency in the ultraviolet range. When ultraviolet light shines on glass, resonance occurs as the wave builds and maintains a large vibration between the electron and the atomic nucleus, just as pushing someone at the resonant frequency on a swing builds a large vibration. The energy the atom receives can be passed on to neighboring atoms by collisions, or it can be re-emitted as light. If the atom is excited with ultraviolet light (which is at its natural frequency), the atom can hold onto this energy for quite a long time (about 1 million vibrations or 100 millionths of a second). During this time the atom makes many collisions with other atoms and gives up its energy in the form of heat. Glass is not transparent to ultraviolet.

Consider what happens when the electromagnetic wave has a lower frequency than ultraviolet, as does visible light. The electrons of the atom are forced into vibration, but not so strong as before. The atom holds the energy for less time, with less chance of collision with neighboring atoms, and less energy transferred as heat. The energy of the vibrating electrons is re-emitted as light. Glass is transparent to all the frequencies of visible light. The frequency of the re-emitted light that is passed from atom to atom is identical to that of the light that produced the vibration to begin with. The only principal difference is a slight time delay between absorption and re-emission.

This time delay results in a lower average speed of light through a transparent material (see Figure 27-8). Light travels at different average speeds through different materials. In a vacuum the speed of light is a constant 300 000 km/s; we call this speed of light *c*. Light travels very slightly more slowly than this in the atmosphere, but its speed there is usually rounded off as *c*. In water light travels at 75 percent of its speed in a vacuum, or 0.75*c*. In glass light travels at about 0.67*c*, depending on the type of glass. In a diamond light travels at only 0.41*c*, less than half its speed in a vacuum. When light emerges from these materials into the air, it travels at its original speed, *c*.

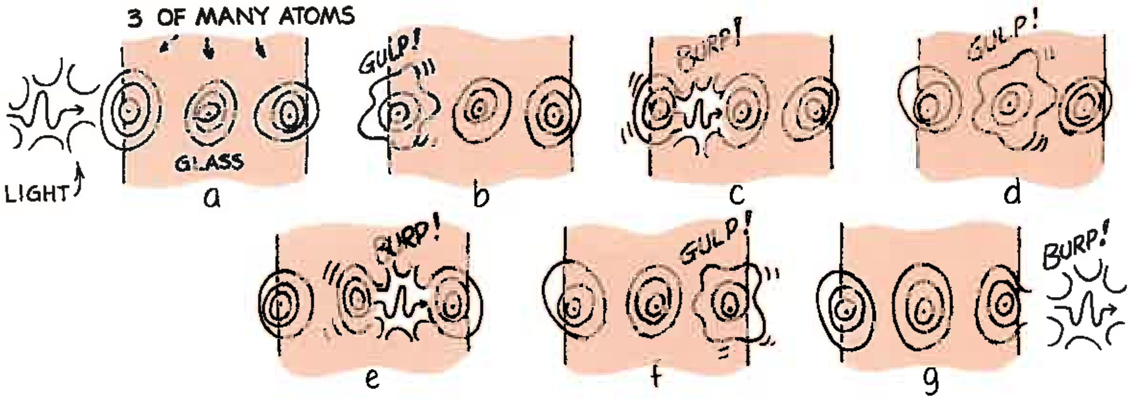


Fig. 27-8 A light wave incident upon a pane of glass sets up vibrations in the atoms that produce a chain of absorptions and re-emissions that pass the light energy through the material and out the other side. Because of the time delay between absorptions and re-emissions, the light travels more slowly in the glass.

Infrared waves, with frequencies lower than visible light, vibrate not only the electrons, but the entire structure of the glass. This vibration of the structure increases the internal energy of the glass and makes it warmer. In sum, glass is transparent to visible light, but not to ultraviolet and infrared light.

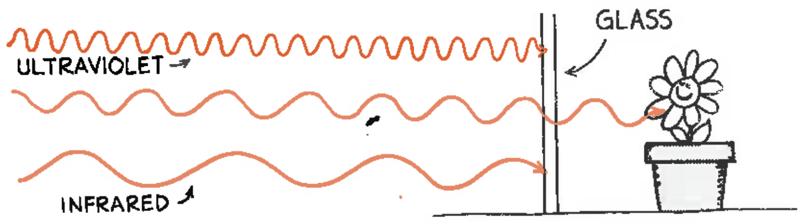


Fig. 27-9 Glass blocks both infrared and ultraviolet, but is transparent to all the frequencies of visible light.

27.5 Opaque Materials

Most materials absorb light without re-emission and thus allow no light through them; they are said to be **opaque**. Wood, stone, and people are opaque to visible light. In opaque materials, any coordinated vibrations given by light to the atoms and molecules are turned into random kinetic energy—that is, into internal energy. They become slightly warmer.

Metals are also opaque. Interestingly enough, the outer electrons of atoms in metals are not bound to any particular atom. They are free to wander with very little restraint throughout the material (which is why metal conducts electricity and heat so well). When light shines on metal and sets these free electrons into vibration, their energy does not "spring" from atom to atom in the material, but is re-emitted as visible light. This re-emitted light is seen as a reflection. That's why metals are shiny.

Fig. 27-10 Metals are shiny because light that shines on them forces free electrons into vibration. These electrons then emit their "own" light waves as a reflection.

Our atmosphere is transparent to visible light and some infrared, but fortunately, quite opaque to high-frequency ultraviolet waves. The small amount of ultraviolet that does get through is responsible for sunburns. If it all got through, we would be fried to a crisp. Clouds are semitransparent to ultraviolet, which is why you can get a sunburn on a cloudy day.

▶ **Question**

Why is glass transparent to visible light, but opaque to ultraviolet and infrared?

27.6 Shadows

A thin beam of light is often called a **ray**. Any beam of light—no matter how wide—can be thought of as made of a bundle of rays. When light shines on an object, some of the rays may be

---

▶ **Answer**

The natural frequency of vibration for electrons in glass matches the frequency of ultraviolet light, so resonance in the glass occurs when ultraviolet waves shine on it. These energetic vibrations of electrons generate heat instead of wave re-emission, so the glass is opaque to ultraviolet. In the range of visible light, the forced vibrations of electrons in the glass are more subtle, and re-emission of light rather than the generation of heat occurs, so that the glass is transparent. Lower-frequency infrared causes the whole structure, rather than electrons, to resonate, and again, heat is generated and the glass is opaque.

stopped while others pass on in a straight-line path. **A shadow** is formed where light rays cannot reach.

Sharp shadows are produced by a small light source nearby or by a larger source farther away. However, most shadows are somewhat blurry. There is usually a dark part on the inside and a lighter part around the edges. A total shadow is called an **umbra**, and a partial shadow a **penumbra**. A penumbra appears where some of the light is blocked, but where other light fills it in. This can happen where light from one source is blocked and light from another source fills in (Figure 27-12). Or a penumbra occurs where light from a broad source is only partially blocked.

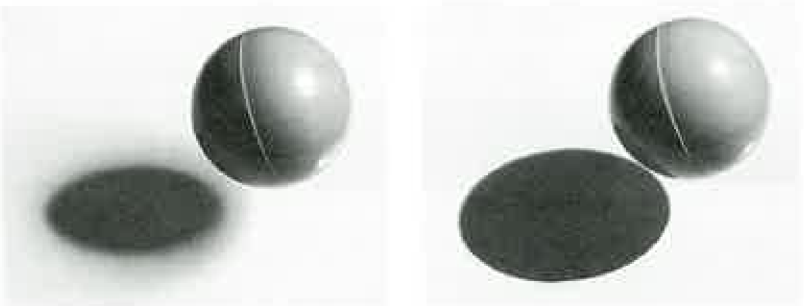


Fig. 27-11 A large light source produces a softer shadow than a smaller source.

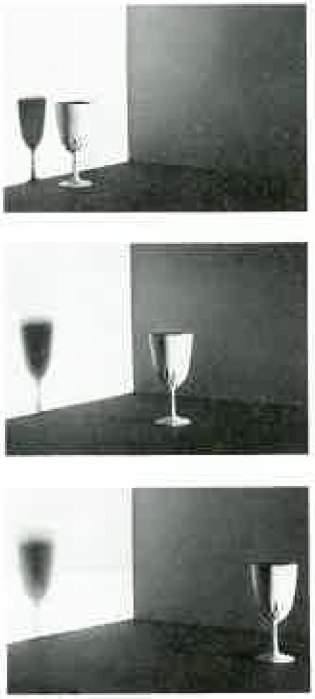


Fig. 27-12 An object held close to a wall casts a sharp shadow because no light can seep around to form penumbras. As the object is moved farther away, penumbras are formed and cut down on the umbra. When it is very far away, no shadow is evident because all the penumbras mix together into a big blur.

A dramatic example of this occurs when the moon passes between the earth and the sun—during a solar eclipse. Because of the large size of the sun, the rays taper to provide an umbra and a surrounding penumbra (Figure 27-13). The moon's shadow just reaches the earth. If you stand in the umbra part of the shadow, you experience brief darkness during the day. If you stand in the penumbra, you experience a partial eclipse. The sunlight is dimmed and the sun appears as a crescent.*

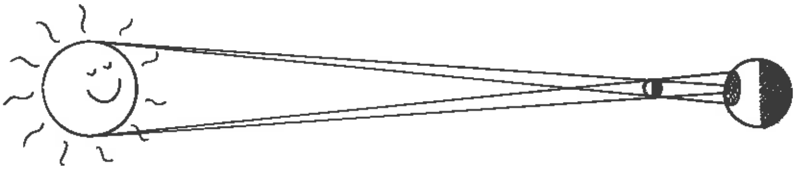


Fig. 27-13 An eclipse of the sun.

---

* People are cautioned not to look at the sun at the time of a solar eclipse because the brightness and ultraviolet radiation of direct sunlight is damaging to the eyes. This good advice is often misunderstood by those who then think that sunlight is more damaging at this special time. But staring at the sun when it is high in the sky is harmful whether or not an eclipse occurs. In fact, staring at the bare sun is more harmful than when part of the moon blocks it! The reason for special caution at the time of an eclipse is simply that more people are interested in looking at the sun during an eclipse.

The earth, like most objects in sunlight, casts a shadow. This shadow extends into space, and sometimes the moon passes into it. When this happens, we have a lunar eclipse. Whereas a solar eclipse can be observed only in a small region of the earth at a given time, a lunar eclipse can be seen by all observers on the nighttime half of the earth (Figure 27-14).

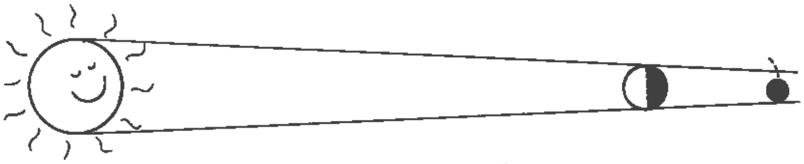


Fig. 27-14 An eclipse of the moon.

▶ **Question**

Why are lunar eclipses more commonly seen than solar eclipses?

Fig. 27-15 A heater at the tip of the submerged J-tube produces convection currents in the water, which are revealed by shadows cast by light that is deflected differently by the water of different temperatures.

Shadows occur when light is bent in passing through a transparent material such as water. In Figure 27-15 shadows are cast by turbulent, rising warm water. Light travels at slightly different speeds in warm and in cold water. The difference bends light, just as layers of warm and cool air in the night sky bend starlight and cause the twinkling of stars. Some of the light gets deflected a bit and leaves darker places on the wall. The shapes of the shadows depend on how the light is bent. Chapter 29 returns to the bending of light.

27.7 Polarization

Light travels in waves. The fact that the waves are transverse—and not longitudinal—is demonstrated by the phenomenon called **polarization**. If you shake the end of a horizontal rope, as in Figure 27-16, a transverse wave travels along the rope. The vibrations are to and fro in one direction, and the wave is said to be *polarized*. If the rope is shaken up and down, a vertically polar-

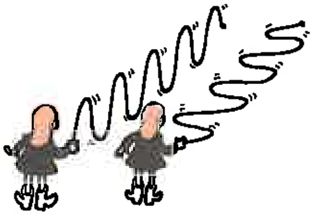


Fig. 27-16 A vertically polarized wave (left) and a horizontally polarized wave (right).

▶ **Answer**

There are usually two of each every year. However, the shadow of the moon on the earth is very small compared to the shadow of the larger earth on the smaller moon. Only a relatively few people are in the shadow of the moon (solar eclipse), while everybody who views the nighttime sky can see the shadow of the earth on the moon (lunar eclipse).

ized wave is produced; that is, the waves traveling along the rope are confined to a vertical plane. If the rope is shaken from side to side, a horizontally polarized wave is produced.

A single vibrating electron emits an electromagnetic wave that is also polarized. A vertically vibrating electron emits light that is vertically polarized, while a horizontally vibrating electron emits light that is horizontally polarized (Figure 27-17).

A common light source, such as an incandescent or fluorescent lamp, a candle flame, or the sun, emits light that is nonpolarized. This is because the vibrating electrons that produce the light vibrate in all different directions. When ordinary light shines on a polarizing filter, such as that from which Polaroid sunglasses are made, the light that is transmitted is polarized. The filter is said to have a *polarization axis* that is in the direction of the vibrations of the polarized light wave.

Light will pass through a pair of polarizing filters when their polarization axes are aligned, but not when they are crossed at right angles. This behavior is very much like the filtering of a vibrating rope that passes through a pair of picket fences (Figure 27-19).

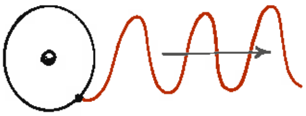


Fig. 27-17 Polarized light lies along the same plane as that of the vibrations of the electron that emits it.

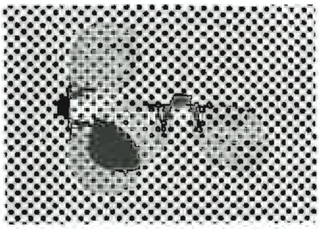


Fig. 27-18 Polaroid sunglasses block out horizontally vibrating light. When the lenses overlap at right angles, no light gets through.

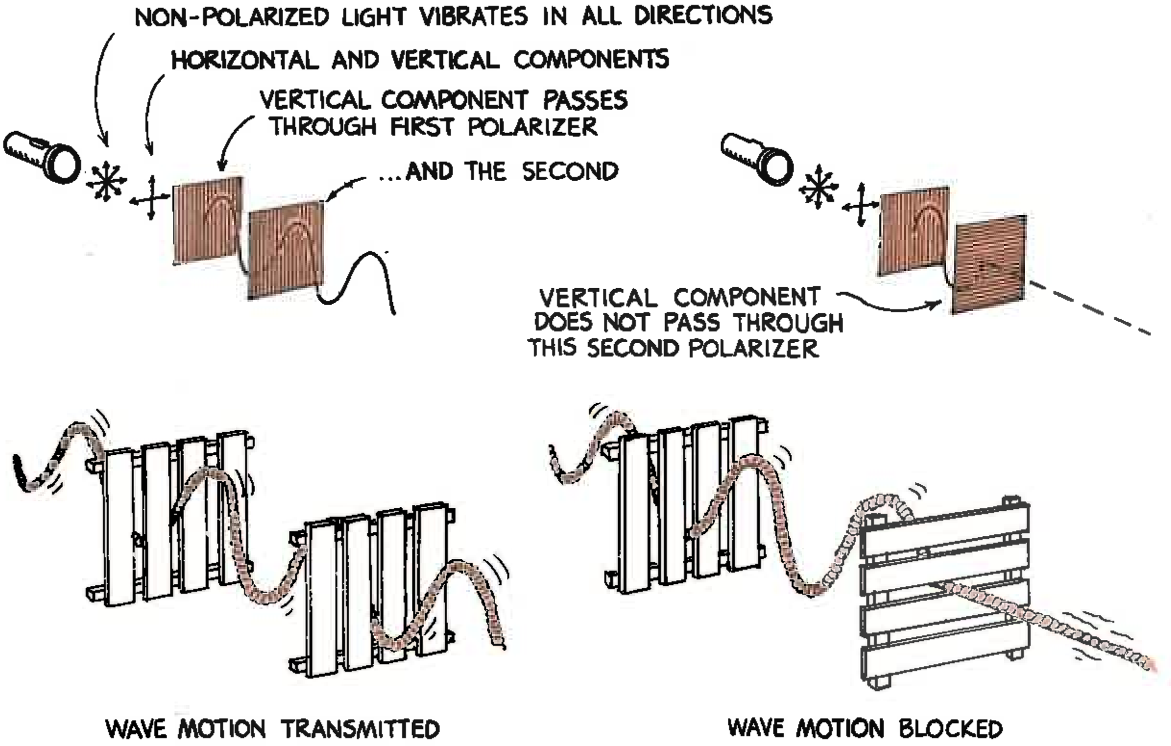


Fig. 27-19 A rope analogy illustrates the effect of crossed sheets of polarizing material.

Fig. 27-20 Light is transmitted when the axes of the Polaroids are aligned (left), but absorbed when they are at right angles to each other (center). Interestingly enough, when a third Polaroid is sandwiched between the crossed Polaroids (right), light is transmitted. Why? (To answer, you'll have to know more about vectors. See Appendix C, Vector Applications.)

Much of the glare reflected from nonmetallic surfaces, such as from glass, water, or a road surface, is polarized. The reflected light, especially for glancing angles, is primarily made up of light that vibrates in the same plane as the reflecting surface. So the glare from a horizontal surface is polarized horizontally. This is like skipping flat stones across the surface of a pond. When the stones hit the water with their flat sides parallel to the water, they bounce (they are reflected); but when they hit with their flat side at right angles to the surface, they penetrate into the water. Do you see why Polaroid sunglasses are oriented to block horizontal vibrations and transmit vertical vibrations? In this way, it is mainly the glare that is eliminated.

Not all polarizing eyeglasses are made for blocking horizontally polarized light. Three-dimensional slide shows or movies are projected through a pair of projectors fitted with polarizing filters (Figure 27-21). Their polarization axes are at right angles to each other—one is vertical and the other is horizontal. The projectors display a pair of pictures that were taken a short distance apart, just as the eyes are spaced a short distance apart. The pictures are displayed on the same screen and look blurry to the naked eye. To see 3-D, the viewer wears polarizing eyeglasses in which the axes of the two lenses are also at right angles. As a result, each eye sees a separate picture, just as in real life. The brain interprets the two pictures as a single picture with a feeling of depth. (Hand-held stereo viewers produce a similar effect, but the 3-D projector setup allows many people to see the pictures at once.)

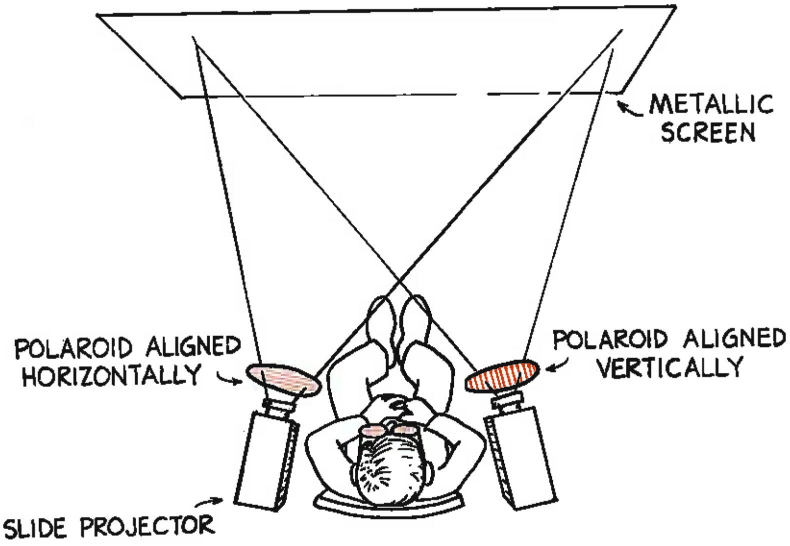
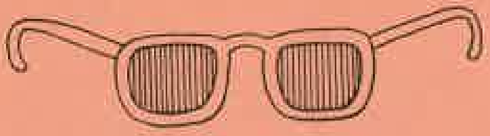


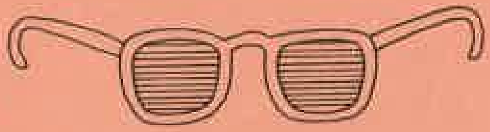
Fig. 27-21 A 3-D slide show using polarizing filters. The left eye sees only polarized light from the left projector; the right eye sees only polarized light from the right projector. Both views merge in the brain to produce an image with depth.

▶ **Question**

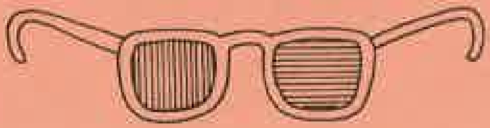
Which pair of glasses is best suited for automobile drivers? (The polarization axes are shown by the straight lines.)



A



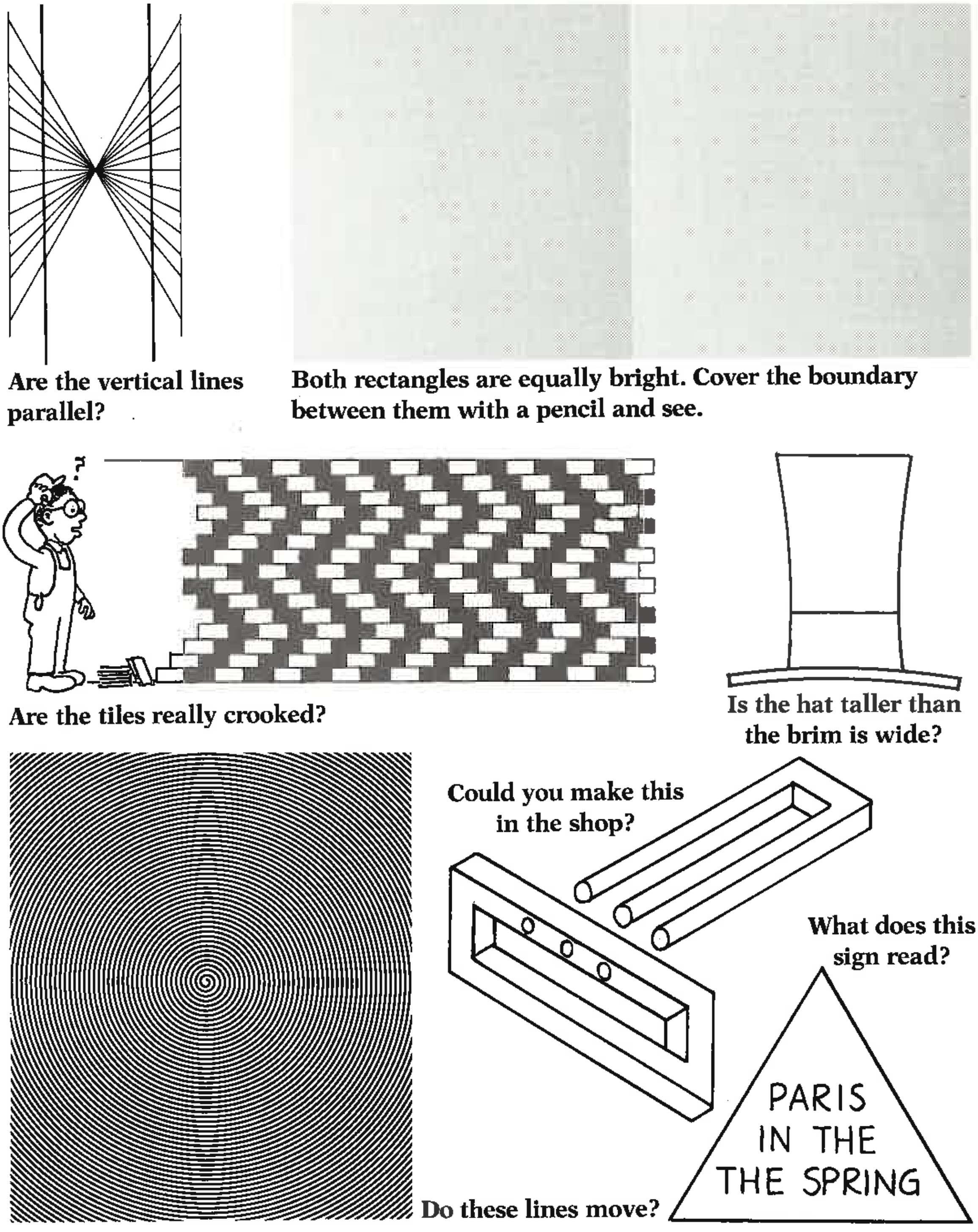
B



C

▶ **Answer**

Pair A is best suited because the vertical axis blocks horizontally polarized light that composes much of the glare from horizontal surfaces. (Pair C is suited for viewing 3-D movies.)



Are the vertical lines parallel?

Both rectangles are equally bright. Cover the boundary between them with a pencil and see.

Are the tiles really crooked?

Is the hat taller than the brim is wide?

Could you make this in the shop?

What does this sign read?

Do these lines move?

Fig. 27-22 Optical illusions.

27 Chapter Review

Concept Summary

Light has both a wave and a particle nature, but most everyday phenomena can be explained in terms of the wave nature.

Light has a speed of 300 000 km/s in a vacuum, and lower speeds in matter.

Light is energy that travels in electromagnetic waves within a certain range of frequencies.

- Light is produced by vibrating electric charges in atoms.
- Light passes through materials whose atoms are able to absorb the energy and immediately re-emit it as light.
- Light cannot pass through a material when the energy is changed to random kinetic energy of the atoms.

Because light waves are transverse, they can be polarized so that the vibrations are all in the same direction.

- Polarizing filters transmit components of incident nonpolarized light that are parallel to the polarization axis, and block components vibrating at right angles to the polarization axis. The result is the emergence of polarized light.

Important Terms

electromagnetic spectrum (27.3)
electromagnetic wave (27.3)
infrared (27.3)
light year (27.2)
opaque (27.5)
penumbra (27.6)
photon (27.1)
polarization (27.7)
ray (27.6)
shadow (27.6)
transparent (27.4)
ultraviolet (27.3)
umbra (27.6)

Review Questions

1. a. What is a photon?
   b. Which theory of light is the photon more consistent with—the wave theory or the particle theory? (27.1)

2. How long does it take for light to travel across the diameter of the earth's orbit around the sun? (27.2)

3. How did Michelson know the time that light took to make the round trip to the distant mountain? (27.2)

4. How long does light take to travel from the sun to the earth? From the star Alpha Centauri to the earth? (27.2)

5. How long does light take to travel a distance of one light year? (27.2)

6. What is the source of electromagnetic waves? (27.3)

7. Is the color spectrum simply a small segment of the electomagnetic spectrum? Defend your answer. (27.3)

8. How do the frequencies of infrared, visible, and ultraviolet light compare? (27.3)

9. How does the role of inertia relate to the rate at which electric charges can be forced into vibration? (27.4)

10. Different bells and tuning forks have their own natural vibrations, and emit their own

tones when struck. How is this analogous with atoms, molecules, and light? (27.4)

11. When light encounters a material, it can build up vibrations in the electrons of certain molecules that may be intense enough to last over a long period of time. Will the energy of these vibrations tend to be absorbed and turned into heat, or absorbed and re-emitted as light? (27.4)

12. Will glass be transparent to frequencies of light that match its own natural frequencies? (27.4)

13. Does the time delay between the absorption and re-emission of light affect the average speed of light in a material? Explain. (27.4)

14. Why would you expect the speed of light to be slightly less in the atmosphere than in a vacuum? (27.4)

15. Light incident upon a pane of glass slows down in passing through the glass. Does it emerge at a slower speed or at its initial speed? Explain (27.4).

16. What determine whether or not a material is transparent or opaque? (27.4-27.5)

17. Why are metals shiny in appearance? (27.5)

18. Distinguish between an umbra and a penumbra. (27.6)

19. a. Distinguish between a solar eclipse and a lunar eclipse.
    b. Which type of eclipse is dangerous to your eyes if viewed directly? (27.6)

20. What is the difference between light that is polarized and light that is not? (27.7)

21. Why is light from a common lamp or from a candle flame nonpolarized? (27.7)

22. In what direction is the polarization of the glare that reflects from a horizontal surface? (27.7)

23. How do polarizing filters allow each eye to see separate images in the projection of three-dimensional slides or movies? (27.7)

Think and Explain

1. What evidence can you cite to support the idea that light can travel through a vacuum?

2. If the octagonal mirror in the Michelson apparatus were spun at twice the speed that produced light in the eyepiece, would light still be seen? At 2.1 times the speed? Explain.

3. If the mirror in Michelson's apparatus had had six sides instead of eight, would it have had to spin faster or more slowly to measure the speed of light? Explain.

4. You can get a sunburn on a sunny day and on an overcast day. But you cannot get a sunburn if you are behind glass. Explain.

5. If you fire a bullet through a tree, it will slow down in the tree and emerge at less than its initial speed. But when light shines on a pane of glass, even though it slows down inside, its speed upon emerging is the same as its initial speed. Explain.

6. Short wavelengths of visible light interact more frequently with the atoms in glass than do longer wavelengths. Which do you suppose takes the longer time to get through glass—red light or blue light?

7. Suppose that sunlight is incident upon both a pair of reading glasses and a pair of sunglasses. Which pair would you expect to be warmer, and why?

8. An ideal polarizing filter transmits 50% of the incident nonpolarized light. Explain.

9. What percentage of light would be transmitted by two ideal polarizing filters, one atop the other, with their axes aligned? With their axes crossed at right angles?