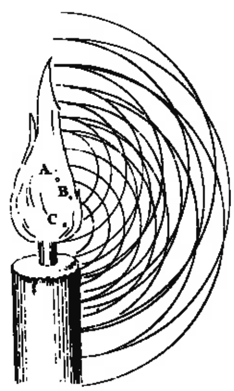
31 Diffraction and Interference

Reflection and refraction of light can be understood in terms of either a particle model or a wave model of light. Whether light travels in straight lines as little particles called photons, or as waves that spread out from a source, either model can explain reflection and refraction. This chapter investigates properties of light—diffraction and interference—that can be understood only by a wave model. These properties are closely related.

31.1 Huygens' Principle

In the late 1600s a Dutch mathematician-scientist, Christian Huygens, proposed a very interesting idea about waves. Huygens stated that light waves spreading out from a point source may be regarded as the overlapping of tiny secondary wavelets, and that every point on any wave front may be regarded as a new point source of secondary waves (Figure 31–1). In other words, wave fronts are made up of tinier wave fronts. This idea is called **Huygens' principle**.



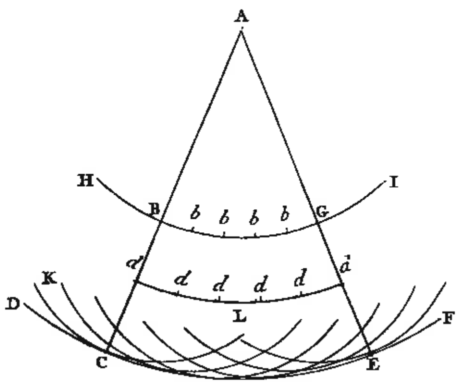


Fig. 31–1 These drawings are from from Huygens' book *Treatise on Light*. Light from A (left) expands in wavefronts, every point of which (right) behaves as if it were a new source of waves. Secondary wavelets starting at *b,b,b,b* form a new wave front (*d,d,d,d*); secondary wavelets starting at *d,d,d,d* form still another new wave front (DCEF).

Look at the spherical wave front in Figure 31–2. Each point along the wave front AA' is the source of a new wavelet that spreads out in a sphere from that point. Only a few of the infinite number of wavelets are shown in the figure. The new wave front BB' can be regarded as a smooth surface enclosing the infinite number of overlapping wavelets that started from AA' a short time earlier.

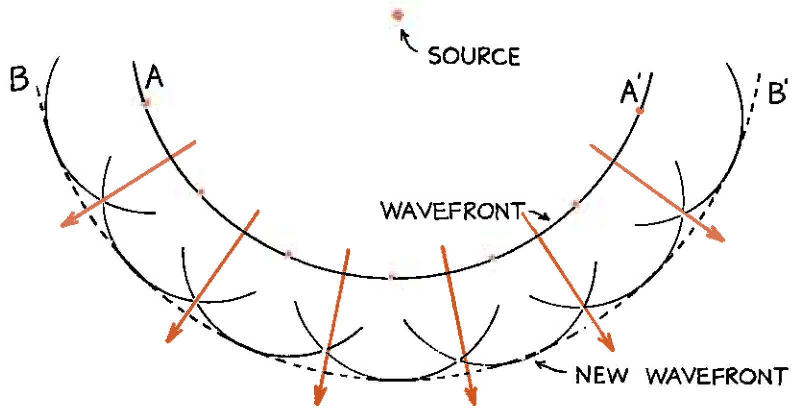


Fig. 31–2 Huygens' principle applied to a spherical wave front.

As a wave front spreads, it appears less curved. Very far from the original source, the wave fronts seem to form a plane. A good example is the plane waves that arrive from the sun. A Huygens' wavelet construction for plane waves is shown in Figure 31–3. (In a two-dimensional drawing, the planes are shown as straight lines.)

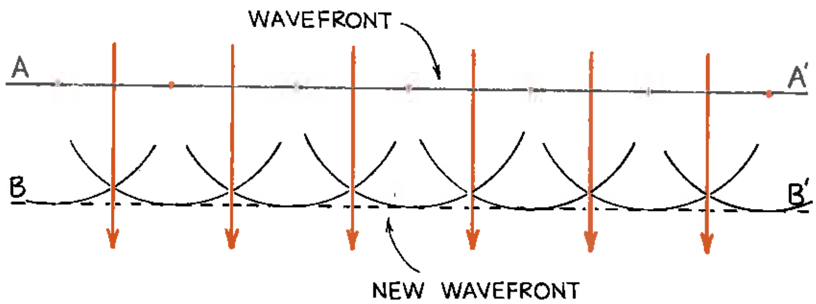


Fig. 31–3 Huygens' principle applied to a plane wave front.

The laws of reflection and refraction are illustrated via Huygens' principle in Figure 31–4.

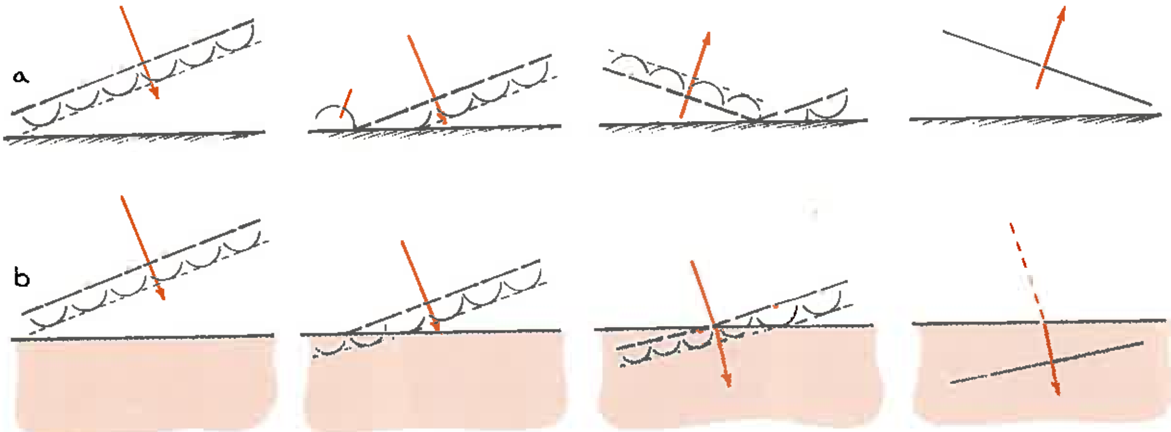


Fig. 31–4 Huygens' principle applied to (a) reflection and (b) refraction.

You can observe Huygens' principle in water waves that are made to pass through a narrow opening. A wave with straight wave fronts can be generated in water by successively dipping a stick lengthwise into the water (Figure 31–5). A ruler works well. When the straight wave fronts pass through the opening in a barrier, interesting wave patterns result.

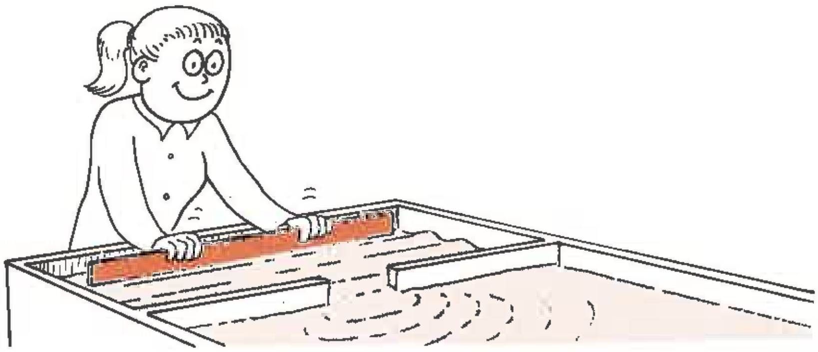


Fig. 31–5 Making plane waves in a tank of water and watching the pattern they produce when they pass though an opening in a barrier.

When the opening is wide, you'll see straight wave fronts pass through without change—except at the corners, where the wave fronts are bent into the "shadow region" in accord with Huygens' principle. If you narrow the width of the opening, less of the wave gets through, and the spreading into the shadow region is more pronounced. When the opening is small compared to the wavelength of the waves, Huygens' idea that every part of a wave front can be regarded as a source of new wavelets becomes quite apparent. As the waves move into the narrow opening, the water sloshing up and down in the opening is easily seen to act as a point source of circular waves that fan out on the other side of the barrier. The photos in Figure 31–6 are top views of water waves generated by a vibrating stick. Note how the waves fan out as the hole through which they pass becomes smaller.

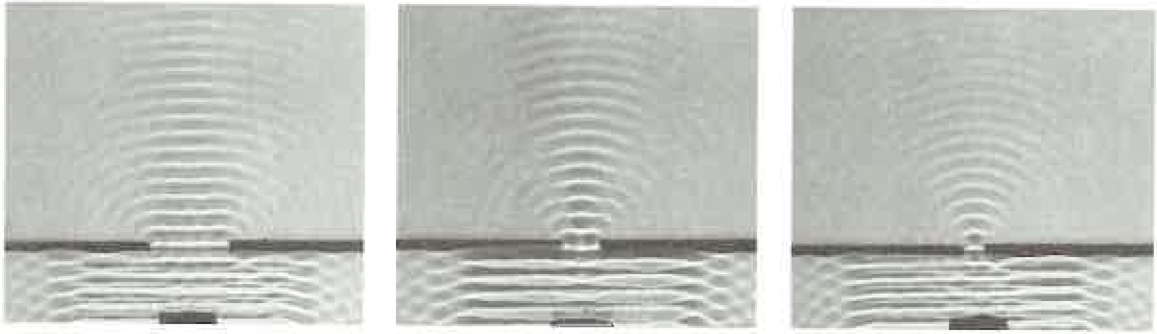


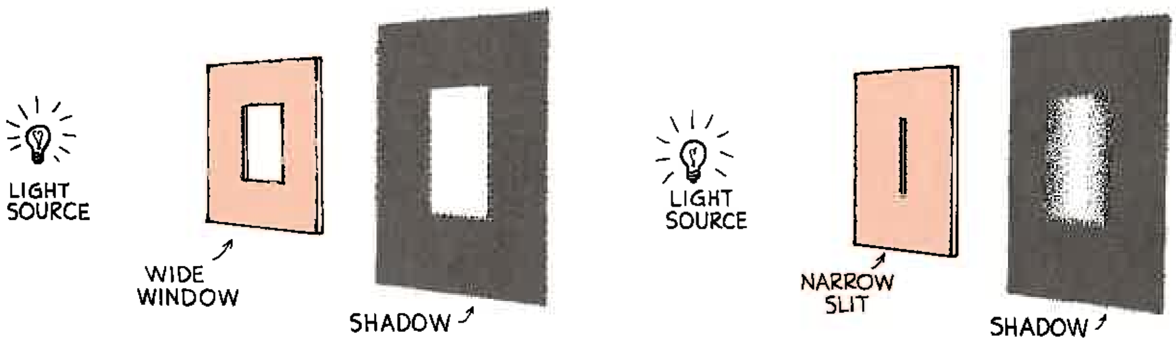
Fig. 31–6 Straight waves passing through openings of various sizes. The smaller the opening, the greater the bending of the waves at the edges.

31.2 Diffraction

Any bending of a wave by means other than reflection or refraction is called **diffraction**. The photos of Figure 31–6 show the diffraction of straight water waves through various openings. When the opening is wide compared to the wavelength, the spreading effect is small. As the opening becomes narrower, the spreading of waves is more pronounced. The same occurs for all kinds of waves, including light waves.

When light passes though an opening that is large compared to the wavelength of light, it casts a rather sharp shadow (Figure 31–7). When light passes through a thin razor slit in a piece of opaque material, it casts a fuzzy shadow, for the light fans out like the water through the narrow opening in Figure 31–6. The light is diffracted by the thin slit.

Fig. 31–7 Light casts a sharp shadow when the opening is large compared to the wavelength of the light. It casts a fuzzy shadow because of diffraction when the opening is extremely narrow.



Diffraction is not confined to the spreading of light through narrow slits or to openings in general. Diffraction occurs to some degree for all shadows. On close examination, even the sharpest shadow is blurred at the edge (Figure 31–8). The fuzzy edges of most shadows are diffraction patterns too fine ordinarily to be seen.

Diffraction occurs for radio waves. Longer wavelengths diffract more readily around buildings—and thus can reach more places—than shorter wavelengths. AM radio waves have longer wavelengths than FM waves, so AM radio reception comes in loud and clear in many localities where FM reception is poor. TV waves are really short-wavelength radio waves, so diffraction is not as pronounced, and antennas must be put on rooftops in many localities. Diffraction aids radio reception.

Diffraction is not an asset in viewing things through a microscope. The shadows of small objects become less and less well defined as the size of the object approaches the wavelength of the light illuminating it. If the object is smaller than the wavelength of light, no structure can be seen. Any image is lost due to diffraction. No amount of magnification or perfection of microscope design can defeat this fundamental diffraction limit.

To minimize this problem, microscopists illuminate tiny objects with shorter wavelengths. It turns out that a beam of electrons has a wavelength associated with it. This wavelength is very much shorter than the wavelengths of visible light. Microscopes that use beams of electrons to illuminate tiny things are called *electron microscopes*. The diffraction limit of an electron microscope is much less than that of an optical microscope.

Fig. 31–8 Diffraction fringes are evident in the shadows of laser light, which is of a single frequency. These fringes would be filled in by multitudes of other fringes if the source were white light.

Fig. 31–9 Minimal diffraction by a very-short-wavelength electron beam in an electron microscope produces extraordinary detail.

► **Question**
Why is blue light used to view tiny objects in an optical microscope?

31.3 Interference

The idea of wave interference was introduced in Chapter 25, and applied to sound in Chapter 26. The idea is important enough to summarize here before applying it to light waves.

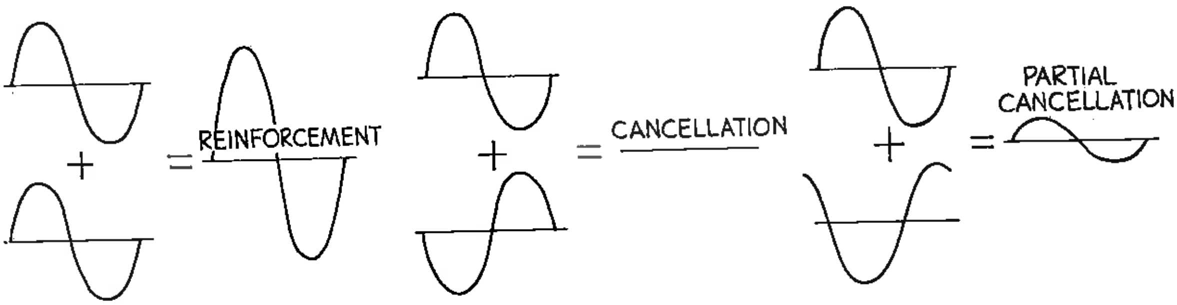


Fig. 31–10 Interference.

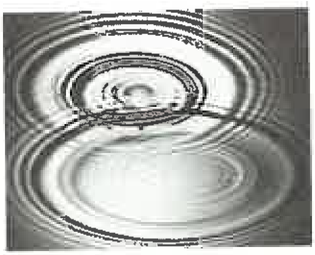


Fig. 31–11 Interference of water waves produced by two stones dropped into water.

If you drop a couple of stones into water at the same time, the two sets of waves that result cross each other and produce what is called an *interference pattern*. Within the pattern, wave effects may be increased, decreased, or neutralized. When the crest of one wave overlaps the crest of another, their individual effects add together; this is *constructive interference*. When the crest of one wave overlaps the trough of another, their individual effects are reduced; this is *destructive interference*.

Water waves can be produced in shallow tanks of water known as *ripple tanks* under more carefully controlled conditions. Interesting patterns are produced when two sources of waves are placed side by side. Small spheres are made to vibrate at a controlled frequency in the water while the wave patterns are photographed from above (see Figure 31–12). The gray "spokes" are regions of destructive interference. The dark and light striped

► **Answer**
Less diffraction results from the short wavelengths of blue light compared to other longer wavelengths.

regions are regions of constructive interference. The greater the frequency of the vibrating spheres, the closer together the stripes (and the shorter the wavelength). Note how the number of regions of destructive interference depends on the wavelength and on the distance between the wave sources.

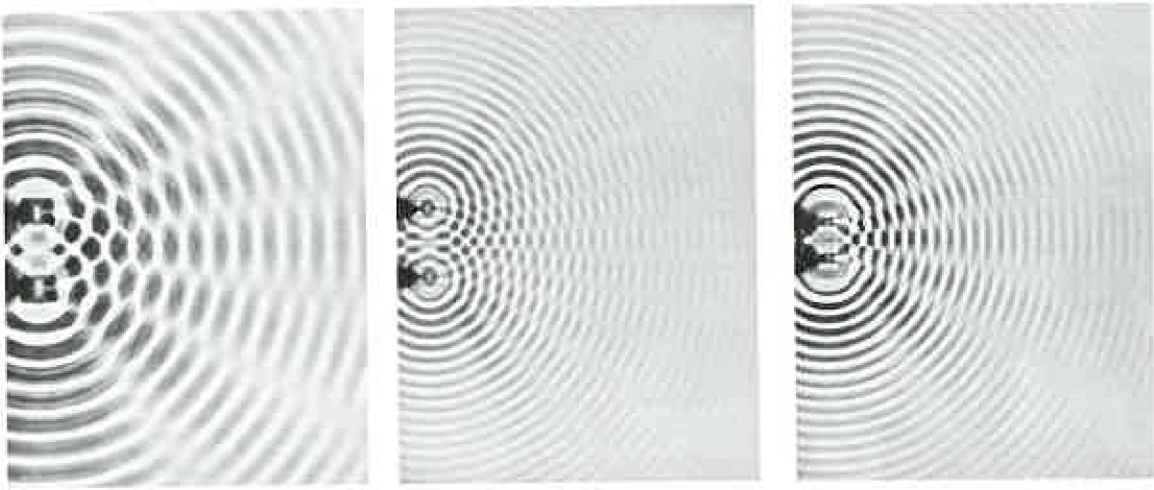


Fig. 31–12 Interference patterns of overlapping water waves from two vibrating sources.

31.4 Young's Interference Experiment

In 1801 the British physicist and physician Thomas Young performed an experiment that was to make him famous.* Young discovered that when **monochromatic** light—light of a single color—was directed through two closely spaced pinholes, fringes of brightness and darkness were produced on a screen behind. He realized that the bright fringes of light resulted from light waves from both holes arriving crest to crest (constructive interference—more light). Similarly, the dark areas resulted from light waves arriving trough to crest (destructive interference—no light). Young had convincingly demonstrated the wave nature of light that Huygens had proposed earlier.

* Young read fluently at the age of two; by four, he had read the Bible twice; by fourteen, he knew eight languages. During his adult life he contributed to an understanding of fluids, work and energy, and the elastic properties of materials. He was also the first person to make progress in deciphering Egyptian hieroglyphics. No doubt about it: Thomas Young was smart—very smart.

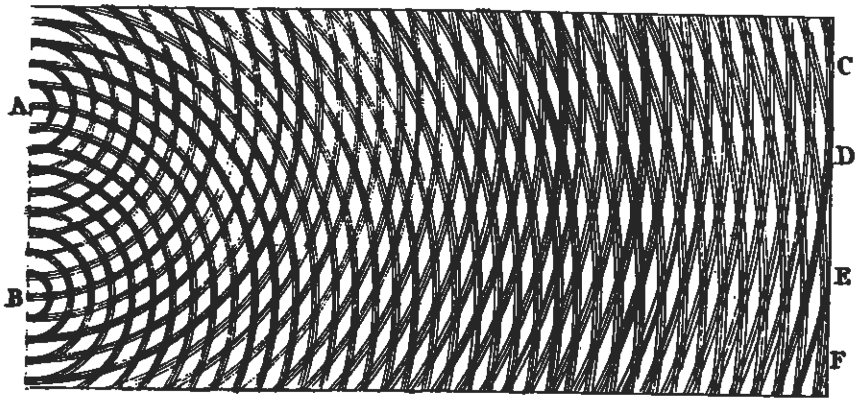


Fig. 31–13 Thomas Young's original drawing of a two-source interference pattern. The crests lie atop each other in the right half. Letters *C*, *D*, *E*, and *F* mark regions of destructive interference.

Young's experiment is now done with two closely spaced slits instead of pinholes, so the fringes are straight lines. A sodium vapor lamp provides a good source of monochromatic light, and a laser is even better. The arrangement is shown in Figure 31–14. Note the similarity of this to the arrangement of sound speakers back in Figure 26–14 in Chapter 26. The effects are similar.

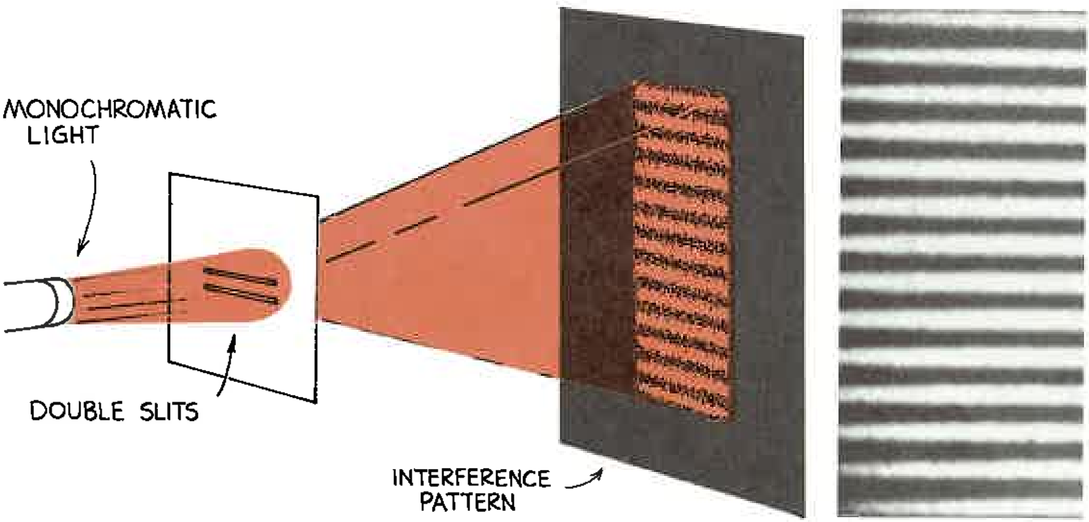


Fig. 31–14 When monochromatic light is passed through two closely spaced slits, a striped interference pattern is produced.

Figure 31–15 shows how the series of bright and dark lines results from the different path lengths from the slits to the screen. A bright fringe occurs when waves from both slits arrive in phase. Dark regions occur when waves arrive out of phase.

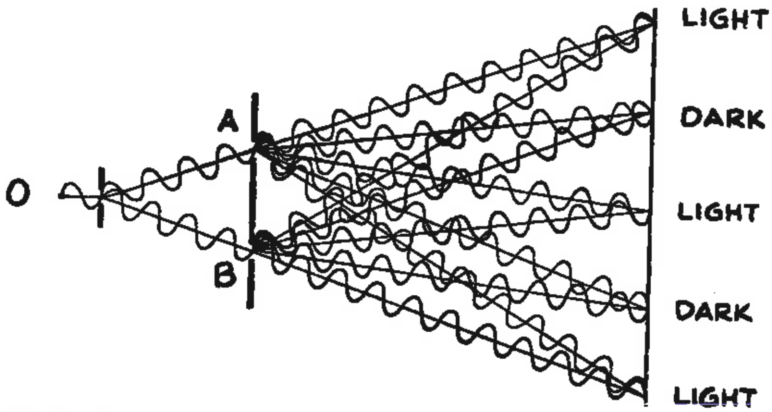


Fig. 31–15 Light from *O* passes through slits *A* and *B* and produces an interference pattern on the screen at the right.

▸ **Questions**

1. Why is it important that monochromatic (single-frequency) light be used in Young's interference experiment?
2. If the double slits were illuminated with monochromatic blue light, would the fringes be closer together or farther apart than those produced when monochromatic red light is used?

Interference patterns are not limited to double slits. A multitude of closely-spaced parallel slits makes up a **diffraction grating**. Many spectrometers use diffraction gratings rather than prisms to disperse light into colors. Whereas a prism separates the colors of light by refraction, a diffraction grating separates colors by interference. More common diffraction gratings are seen in reflective materials used in items such as costume jewelry and automobile bumper stickers. These materials are ruled with

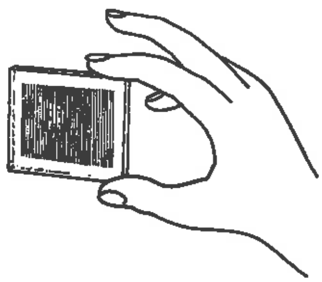


Fig. 31–16 A diffraction grating disperses light into colors by interference. It may be used in place of a prism in a spectrometer.

▸ **Answers**

1. If light of a variety of wavelengths were diffracted by the slits, dark fringes for one wavelength would be filled in with bright fringes for another, resulting in no distinct fringe pattern. This is similar to the person listening to the pair of speakers back in Chapter 26, Figure 26–14. If the path difference equals one-half wavelength for one frequency, it cannot also equal one-half wavelength for any other frequency. Different frequencies will "fill in" the fringes.
2. The wavelength of blue light is shorter than (nearly half) that of red light. Investigate the differences in the number of fringes for the water waves in Figure 31–12. The fringes of shorter wavelengths are closer together than those of longer wavelengths. So blue fringes would be closer together than red fringes.

tiny grooves that diffract light into a brilliant spectrum of colors. The pits on the reflective surface of digital audio laser discs not only provide high-fidelity music but diffract light spectacularly into its component colors.

31.5 Single-Color Interference from Thin Films

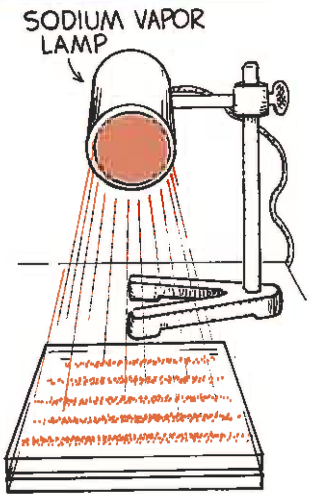


Fig. 31–17 Interference fringes can be produced when monochromatic light is reflected from two plates of glass.

Interference fringes can be produced by the reflection of light from two surfaces very close together. If you shine monochromatic light onto two plates of glass, one atop the other as shown in Figure 31–17, you'll see dark and bright bands.

The cause of these bands is the interference between the waves reflected from the glass on the top and bottom surfaces of the air space between the plates. This is shown in Figure 31–18. The light reflected from point *P* comes to the eye by two different paths. The light that hits the lower glass surface has slightly farther to go to reach your eye. If this extra distance results in light from the upper and lower reflections getting to your eye one-half wavelength out of phase, then destructive interference will occur and a dark region will be seen. Nearby, the path differences will not result in destructive interference, and a light region will be seen.

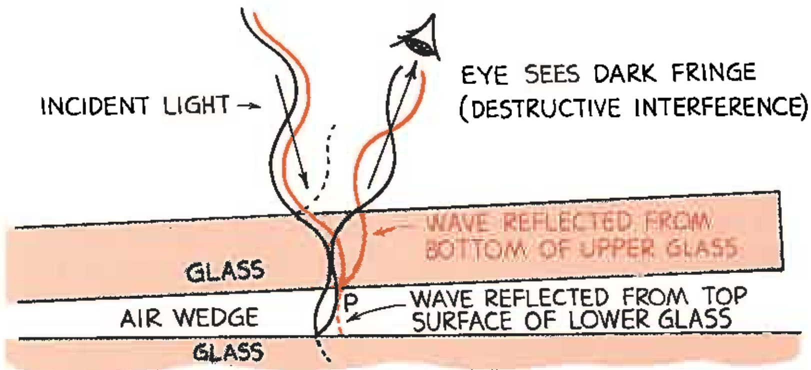


Fig. 31–18 Reflection from the upper and lower surfaces of a thin air space results in constructive and destructive interference.

A practical use of interference fringes is the testing of precision lenses. When a lens to be tested is placed on a perfectly flat piece of glass and illuminated from above with monochromatic light, light and dark fringes are seen (Figure 31–19). Irregular fringes indicate an irregular surface. When a lens is polished until smooth and concentric, the interference fringes will be concentric and regularly spaced.

a b c d

Fig. 31–19 The flatness or curvature of a surface can be tested by placing the surface on a very flat piece of glass and observing the interference pattern. (a) A rough surface; (b) a flat surface; (c) a poorly polished lens; (d) a precision lens.

31.6 Iridescence from Thin Films

Everyone who has seen soap bubbles or gasoline spilled on a wet street has noticed the beautiful spectrum of colors reflected from them. Some types of bird feathers have colors that seem to change hue as the bird moves. All these colors are produced by the interference of light waves of mixed frequencies in thin films, a phenomenon known as **iridescence**. Iridescence is illustrated in the color section found between pages 404 and 405.

A thin film, such as a soap bubble, has two closely spaced surfaces. Light that reflects from one surface may cancel light that reflects from the other surface. For example, the film may be just the right thickness in one place to cause the destructive interference of, say, blue light. If the film is illuminated with white light, then the light that reflects to your eye will have no blue in it. What happens when blue is taken away from white light? The answer is, the complementary color will appear. And for the cancellation of blue, that is yellow. So the soap bubble will appear yellow wherever blue is cancelled.

In a thicker part of the film, where green is cancelled, the bubble will appear magenta. The different colors correspond to the cancellations of their complementary colors by different thicknesses of the film.

Figure 31–20 illustrates interference for a thin layer of gasoline on a layer of water. Light reflects from both the upper gasoline-air surface and the lower gasoline-water surface. Suppose that the incident beam is monochromatic blue, as in the illustration. If the gasoline layer is just the right thickness to cause cancellation of light of that wavelength, then the gasoline surface appears dark to the eye. If the incident beam is white sunlight, on the other hand, then the gasoline surface appears yellow to the eye. This is because blue is subtracted from the white, leaving the complementary color, yellow.

The different colors you see in gasoline on a wet street, then, correspond to different thicknesses of the thin film. The colors provide a vivid "contour map" of microscopic differences in surface "elevations."

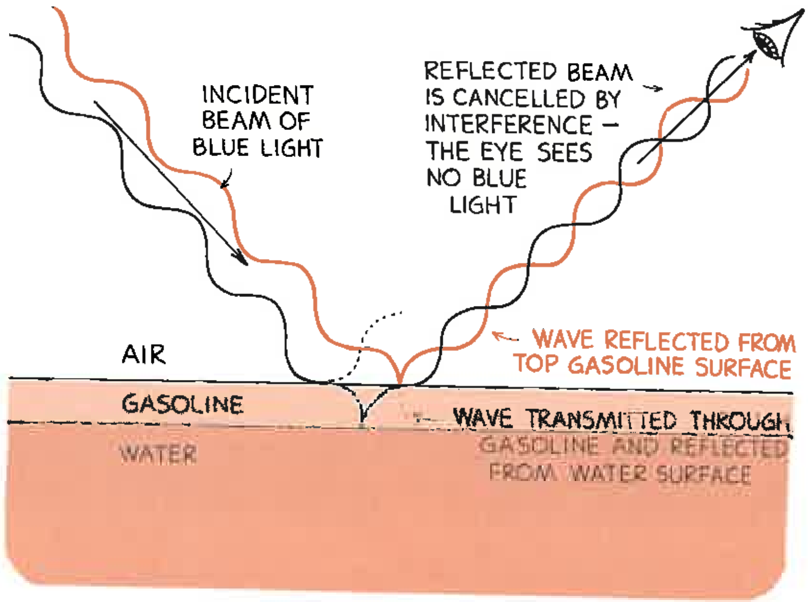


Fig. 31–20 The thin film of gasoline is just the right thickness so that monochromatic blue light reflected from the top surface of the gasoline is cancelled by light of the same wavelength reflected from the water.

▶ **Questions**

1. What color will appear to be reflected from a soap bubble in sunlight when its thickness is such that red light is canceled?
2. Many camera lenses have on their surfaces a thin clear coating that makes the lens appear bluish. What does this tell you about the thickness of the coating?

▶ **Answers**

1. You will see the color cyan, which is the complementary color of red.
2. The thickness of the coating is just right for producing the destructive interference of yellow light, since you see the complementary color, blue. For cancellation of yellow, part of a wave must reflect directly from the coating and part must continue through the coating material and reflect off the glass lens surface beneath, rejoining the directly-reflected light one-half (or an odd-number multiple of one-half) wavelength out of phase. (The purpose of the coating is to cancel yellow light that doubly reflects from inside the camera and arrives at the film out of focus.)

The beautiful colors reflected from some types of seashells are produced by interference of light from their thin transparent coatings. So are the sparkling colors from fractures within opals. Interference colors can even be seen in the thin film of detergent left when dishes are not properly rinsed.

Interference provides the principal method for measuring the wavelengths of light. Wavelengths of other regions of the electromagnetic spectrum are also measured with interference techniques. Extremely small distances (millionths of a centimeter) are measured with instruments called *interferometers*, which make use of the principle of interference. These instruments are sensitive enough to detect the displacement at the end of a long, several-centimeters-thick solid steel bar when you gently twist the other end with your hand. They are among the most accurate measuring instruments known.

The next two sections describe the laser and what is perhaps the most exciting illustration of interference—the *hologram*.

31.7 Laser Light

Light emitted by a common lamp is **incoherent**. That is, the light has many phases of vibration (as well as many frequencies). The light is as incoherent as the footsteps on an auditorium floor when a mob of people are chaotically rushing about. Incoherent light is chaotic. Interference within a beam of incoherent light is rampant, and a beam spreads out after a short distance, becoming wider and wider and less intense with increased distance.

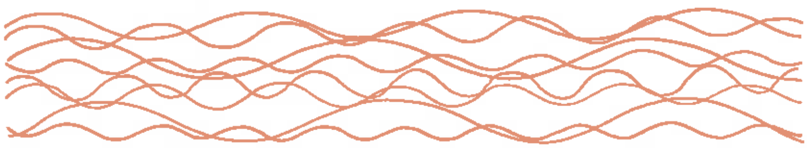


Fig. 31–21 Incoherent white light contains waves of many frequencies and wavelengths that are out of phase with each other.

Even if a beam is filtered so that it is monochromatic (has a single frequency), it is still incoherent, for the waves are out of phase and interfere with one another. The slightest differences in their directions results in a spreading with increased distance.

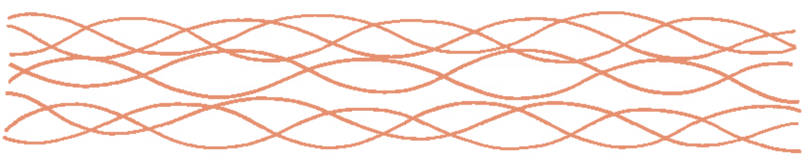


Fig. 31–22 Light of a single frequency and wavelength is still out of phase.

A beam of light that has the same frequency, phase, and direction is said to be **coherent**. There is no interference of waves within the beam. Only a beam of coherent light will not spread and diffuse.

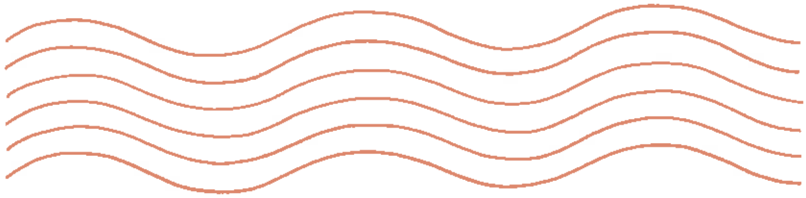


Fig. 31–23 Coherent light. All the waves are identical and in phase.

Coherent light is produced by a **laser** (whose name comes from light amplification by stimulated emission of radiation).* Within a laser, a light wave emitted from one atom stimulates the emission of light from a neighboring atom so that the crests of each wave coincide. These waves stimulate the emission of others in cascade fashion, and a beam of coherent light is produced. This is very different from the random emission of light from atoms in common sources.

Fig. 31–24 A helium-neon laser. A high voltage applied to a mixture of helium and neon gas energizes helium atoms to a prolonged energy state. Before the helium can emit light, it gives up its energy by collision with neon, which is boosted to an otherwise hard-to-come-by matched energy state. Light emitted by neon stimulates other energized neon atoms to emit matched-frequency light. The process cascades, and a coherent beam of light is produced.

* A word constructed from the initials of a phrase is called an *acronym*.

The laser is not a source of energy. It is simply a converter of energy, taking advantage of the process of stimulated emission to concentrate a certain fraction of the energy input (commonly 1 percent) into a thin beam of coherent light. Like all devices, a laser can put out no more energy than is put in.

Lasers come in many types and find broad applications in fields like the construction industry, communications, medicine, and energy research. Grocery store cash registers read product codes with laser light, and videodiscs use laser light as a type of optical "record needle." A most impressive product of laser light is the hologram.

Fig. 31–25 A product's code is read by laser light that reflects from the bar pattern and is converted to an electrical signal that is fed into a computer. The signal is high when light is reflected from the white spaces and low when reflected from a dark bar.

31.8 The Hologram

Holo- comes from the Greek word for "whole," and *gram* comes from the Greek for "message" or "information." A **hologram** is a three-dimensional version of a photograph that contains the whole message or entire picture in every portion of its surface. To the naked eye it appears to be an imageless piece of transparent film, but on its surface is a pattern of microscopic fringes. Light diffracted from these fringes produces an image that is extremely realistic.

A hologram is produced by the interference between two laser light beams on photographic film. The two beams are part of one beam. One part illuminates the object and is reflected from the object to the film. The second part, called the *reference beam*, is reflected from a mirror to the film (Figure 31–26). Interference between the reference beam and light reflected from the different points on the object produces a pattern of microscopic fringes on the film. Light from nearer parts of the object travel shorter paths than light from farther parts of the object. The different distances traveled will produce slightly different interference patterns with the reference beam. In this way information about the depth of an object is recorded.

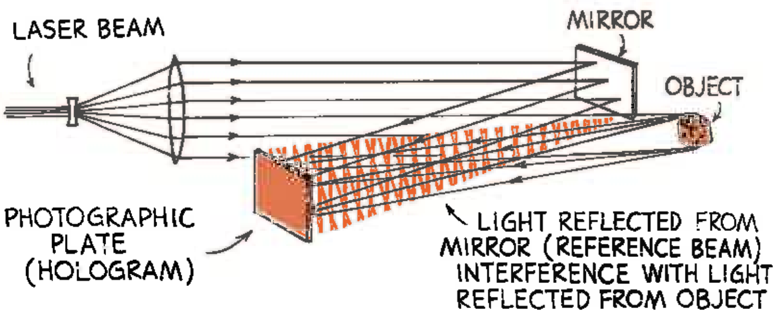


Fig. 31–26 A simplified arrangement for making a hologram. The laser light that exposes the photographic film is made up of two parts: one part is reflected from the object and one part is reflected from the mirror. The waves of these two parts interfere to produce microscopic fringes on the film. When developed, it is then a hologram.

When laser light (or, in some cases, white light) falls on a hologram, it is diffracted through the fringed pattern to produce wave fronts identical in form to the original wave fronts reflected by the object. The diffracted wave fronts produce the same effect as the original reflected wave fronts. You look through the hologram and see a realistic three-dimensional image as though you were viewing the original object through a window. Parallax is evident when you move your head to the side and see down the sides of the object, or when you lower your head and look underneath the object. Holographic pictures are extremely realistic.

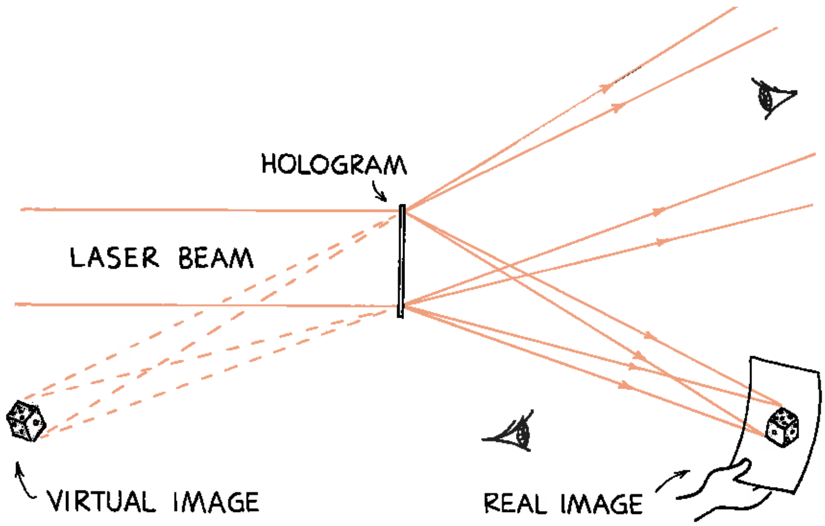


Fig. 31–27 When a hologram is illuminated with coherent light, the diverging diffracted light produces a three-dimensional *virtual* image that can be seen when looking *through* the hologram, like looking through a window. You refocus your eyes to see near and far parts of the image, just as you do when viewing a real object. Converging diffracted light produces a *real* image in front of the hologram, which can be projected on a screen. Since the image has depth, you cannot see near and far parts of the image in sharp focus for any single position on a flat screen.

Interestingly enough, if the hologram is made on film, you can cut it in half and still see the entire image. And you can cut one of the pieces in half again and again and see the entire image, just as you can put your eye to any part of a window to see outdoors. Every part of the hologram has received and recorded light from the entire object.

Even more interesting is holographic magnification. If holograms are made using short-wavelength light and viewed with light of a longer wavelength, the resulting image is magnified in the same proportion as the wavelengths. Holograms made with X rays would be magnified thousands of times when viewed with visible light and appropriate viewing arrangements. X-ray holograms have not been made as this book is being written. Technological growth is fast these days. Are X-ray holograms a reality as you are reading this?

Light is interesting—especially when it is diffracted through the interference fringes of that super-sophisticated diffraction grating, the hologram!

31 Chapter Review

Concept Summary

Diffraction of light is the bending of light by means other than reflection or refraction.

- Huygens' principle, which states that every point on a wave front acts like a point source of secondary wavelets, can be used to understand diffraction.
- Diffraction of light is visible when light passes through an opening comparable in size to the wavelength of the light.

Interference of light is the combining of single-frequency light from two parts of the same beam in a way such that crest overlaps crest or crest overlaps trough.

- The colors seen in soap bubbles or thin films of gasoline on water are due to destructive interference of different frequencies at different thicknesses.
- Holograms are three-dimensional pictures created through the interference of two parts of a laser beam.

Important Terms

coherent (31.7)
diffraction (31.2)
diffraction grating (31.4)
hologram (31.8)
Huygens' principle (31.1)
incoherent (31.7)
iridescence (31.6)
laser (31.7)
monochromatic (31.4)

Review Questions

1. What is Huygens' principle? (31.1)
2. a. Waves spread out when they pass through an opening. Does this spreading become more pronounced or less pronounced for narrower openings?
   b. What name is given to this spreading of waves? (31.1–31.2)
3. Does diffraction aid or hinder radio reception? (31.2)
4. Does diffraction aid or hinder the viewing of images in a microscope? (31.2)
5. Is it possible for a wave to be cancelled by another wave? Defend your answer. (31.3)
6. Does wave interference occur for waves in general, or does it occur only for light waves? Give examples to support your answer. (31.3–31.4)
7. What was Thomas Young's discovery? (31.4)
8. What is the cause of the fringes of light in Young's experiment? (31.4)
9. What is a diffraction grating? (31.4)
10. What is required for part of the light that reflects from a surface to be cancelled by another part reflected from a second surface? (31.5)
11. What is the cause of the bright and dark fringes visible in lenses that rest on flat plates of glass (as shown in Figure 31–19)? (31.5)
12. What is iridescence, and what phenomenon is it related to? (31.6)
13. If the thickness of a soap bubble is sufficient to cancel yellow by interference, what color will the bubble appear when illuminated by white light? (31.6)

14. Why is gasoline that is spilled on a wet surface so colorful? (31.6)

15. What is an interferometer, and on what physics principle is it based? (31.6)

16. How does light from a laser differ from light from an ordinary lamp? (31.7)

17. Is a laser capable of putting out more energy than is put in? (Would you have to know more about lasers to answer this question? Why not?) (31.7)

18. What is a hologram, and on what physics principle is it based? (31.8)

19. How does the image of a hologram differ from that of a common photograph? (31.8)

20. What would be the advantage of making holograms with X rays? (31.8)

Activities

1. Use a razor blade to cut a thin slit in a card and look at a light source through it. You can vary the size of the opening by bending the card slightly. Can you see diffraction fringes? Repeat with two closely spaced slits.

2. Make some slides for a slide projector by sticking crumpled cellophane onto pieces of slide-sized polarizing material. Also try strips of cellophane tape, overlapping at different angles. (Experiment with different brands of tape.) Project the slides onto a large screen or white wall and rotate a second, slightly larger piece of polarizing material in front of the projector lens in rhythm with your favorite music. You'll have your own light and sound show.

3. Do this one at your kitchen sink. Dip a dark-colored coffee cup (dark makes the best background for viewing interference colors) in dishwashing detergent and then hold it sideways and look at the reflected light from the soap film that covers its mouth. Swirling colors appear as the soap runs down to form a wedge that grows thicker at the bottom with time. The top becomes thinner, so thin that it appears black. This happens when the film is thinner than ¼ the wavelength of the shortest waves of visible light. The film soon becomes so thin that it pops.

Think and Explain

1. In our everyday environment, diffraction is much more evident for sound waves than for light waves. Why is this so?

2. Why do radio waves diffract around buildings while light waves do not?

3. Why are TV broadcasts in the VHF range more easily received in areas of marginal reception than broadcasts in the UHF range? (*Hint*: UHF has higher frequencies than VHF.)

4. Suppose a pair of loudspeakers a meter or so apart emit pure tones of the same frequency and loudness. When a listener walks past in a path parallel to the line that joins the loudspeakers, the sound is heard to alternate from loud to soft. What is going on?

5. In the preceding question, suggest a path along which the listener could walk so as not to hear alternate loud and soft sounds.

6. When monochromatic light illuminates a pair of thin slits, an interference pattern is produced on a wall behind. How will the distance between the fringes of the pattern for red light differ from that for blue light?

7. When Thomas Young performed his interference experiment, his monochromatic light passed through a single narrow opening before it reached the double openings. Explain how this procedure made the light coherent so that the interference fringes could be seen.

8. Seashells, butterfly wings, and the feathers

of some birds often change color as you look at them from different positions. Explain this phenomenon in terms of light interference.

9. If you notice the interference patterns of a thin film of oil or gasoline on water, you'll note that the colors form complete rings. How are these rings similar to the lines of equal elevation on a map that shows the contours of terrain?

10. Why are interference colors seen only for thin films and not for thick films, such as plates of glass, for example?