a predator does not recognize them, or they might hide the gut, which is opaque because of the food in it. The transparency achieved by some aquatic animals is not currently well understood but is surely due to minimizing the variations in the optical properties of the biological components so as to minimize the scattering of light. The variations that *are* present occur in distances that are smaller than a wavelength of light, and so light always scatters in a forward direction as if the variations were not present. A few animals are transparent for a simple reason—they can flatten themselves until the amount of scatter within them is almost imperceptible.

The Hawaiian bobtail squid hides itself by using unique proteins in stacks of platelets. Those platelets function as thin films that can reflect light, like a series of parallel soap films reflects light. What is curious about this squid is that the light is produced by bacteria in an organ on the squid's underside. When the squid is illuminated by, say, moonlight, it wants to avoid casting a shadow on the seafloor, which would reveal its presence. So, it alters the oxygen flow to the bacteria to provoke them into emitting light, and then the platelets reflect that light into the shadow region, eliminating the shadow.

### 6.91 • A road made crooked by refraction

If you sit in a window seat of a jet airplane, either over the wing or near the wing's trailing edge, watch as your view of a straight roadway slips past the leading edge. Often, the road section nearest the wing appears to become kinked (Fig. 6-34*a*). As more of the road seemingly slides beneath the wing, the kink travels along the road. What causes the kink?

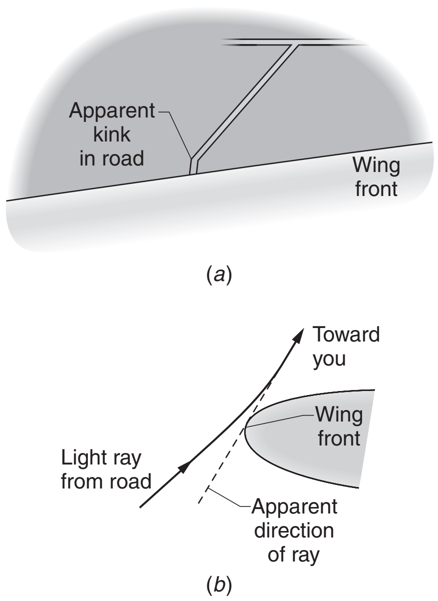


***Figure 6-34*** */ Item 6.91* (*a*) Your view of roadway. (*b*) Side view of a light ray passing the wing front.

**Answer** The light rays coming from most of your road view travel along a straight line, and you see the road's true shape. However, the light from the section that you see quite near the wing's front edge must pass through air that varies greatly in density because of the intrusion of the wing into the air. The variation in density refracts (bends) the light rays upward (Fig. 6-34*b*). When you intercept them, they appear to have originated lower in your view than they actually did. The kink is the point separating the affected rays from the unaffected ones.

### 6.92 • Watering plants in sunlight

Some gardeners claim that you should not water the lawn or shrubbery when sunlight is bright because the drops on the blades and leaves can focus the light enough to burn those surfaces. Is the claim valid?

**Answer** No researcher has reported seeing damage to leaves in such a situation. Indeed, one researcher reports that the presence of water can actually cool a leaf. Calculations suggest that focusing and subsequent heating are significant only if the drop beads up on a leaf. On most plants, the water tends to spread (the water is said to *wet* the leaves). However, some plants, such as the lotus plant, have leaves with special microscopic structures that cause water to bead into nearly perfect spheres. Although such plants might be in danger of overheating in direct sunlight, those near-perfect spheres tend to just roll off the leaves.

The advice of watering at night instead of during sunlight does have merit in arid regions. Once the sun goes down, the water has a better chance of soaking into the ground than just evaporating.

### 6.93 • Starting a fire with ice

In Jules Verne's story *The Desert of Ice*, Captain Hatteras and a few loyal men were abandoned near the Arctic by a mutinous crew during an attempt to reach the North Pole. Although the abandoned men possessed wood for a fire, they lacked any sparking materials or other means by which to ignite the wood. Faced with a long trek over the ice field to reach another ship, the abandoned men knew that they would soon freeze to death. However, the ship's doctor hit upon a scheme by which ice could be made to ignite kindling. Can you guess how? Will such a technique actually work?

**Answer** According to the story, the doctor fashioned a convex lens from a clear section of ice (it lacked air bubbles normally trapped in ice during the freezing process). With a hatchet he chopped out the section and roughly shaped it. Then he smoothed it with his knife and the warmth from his fingers. As he held the ice lens in the bright sunlight, he adjusted its height so that the point of concentrated sunlight (the *focus*) was positioned on the kindling. Within seconds, the kindling ignited.

The idea for this scheme may have originated with William Scoresby, a noted British scientist who is remembered for his pioneering Arctic work. He once described how his roughly formed lenses of transparent ice could ignite wood, melt lead, and light a sailor's pipe. More recently, Matthew Wheeler of McBride in British Columbia told me how he took photographs with a camera using an ice lens instead of its normal lens.

You might also be able to start a fire with a lens in common eyeglasses. If the lens is designed for someone who is farsighted, it has a focus that can be positioned on kindling. However, if the lens is designed for someone who is nearsighted, the lens does not focus the rays. Thus, the fire-starting story in *The Lord of the Flies* is flawed: Piggy is very nearsighted, and Ralph could not have ignited wood with the eyeglasses as described.

### 6.94 • Diamonds

Why do diamonds sparkle? What produces their colors, and why are the colors more brilliant in a larger diamond? Why is a diamond dark if you look through its bottom surface at a small source of light? Why does grime on the bottom surface decrease the sparkle seen through the top surface?

**Answer** If a diamond is to sparkle with color, light entering the top surface must separate into colors and return through the top surface. Thus, when the light reaches the bottom surface, it should reflect entirely and not escape through that surface. To avoid that loss, the bottom surface is angled sharply to the light's direction of travel, which causes all the light to be reflected by the surface. The light is said to undergo *total internal reflection*. Thus, if you look up through the bottom surface, the view is dark. However, if the bottom surface is coated with oil or some other grime, some of the light can escape into the coating, decreasing the diamond's sparkle. So, to keep a diamond brilliant, clean *both* top and bottom surfaces.

One measure of how well a material can separate colors when illuminated with white light is the *index of refraction* assigned to the material. Diamond, with a high value of the index, separates colors much better than glass, with a low value. Thus, fake diamonds made of glass may sparkle if cut with many facets, but they lack the play of colors you see from a diamond. In principle, a large diamond is much more colorful than a smaller one because the longer travel distance across the diamond increases the color separation in the light.

### 6.95 • Opals

What produces the striking colors of an opal? The color production must be different from that in a diamond because the size of an opal does not determine the color separation. Also, the colors are different. If you rotate a diamond below a bright white light, you see a variation in color across the full visible spectrum. If you rotate an opal in that light, you see a narrow range of colors. What determines the difference between the colorless potch opal and the prized black opal?

**Answer** An opal is not a crystal but an amorphous silica with a small amount of water. The silica is in the form of tiny spheres (with diameters of about 100 nanometers) that are closely packed somewhat like oranges in a container. The spaces between the spheres contain air, water vapor, or liquid water. This arrangement of spheres and spaces forms an array in which the optical properties vary. When white light passes into opal, it undergoes diffraction (a type of scattering) by the array such that different colors are sent back out of the opal at different angles. The angle at which any particular color is diffracted depends on the periodic spacing of the array (the diameters of the spheres) and the angle of the incident light. If an opal moves while you examine it, you see points of different colors flashing on and off—this display is called the *fire* of the opal.

If the colors are brilliant and distinguishable, as in a black opal, they must each consist of only a narrow range of wavelengths. To produce such narrow ranges, the spheres must be nearly uniform in size so that the diffraction from any particular part of the opal is uniform. However, the best displays, with brilliant colors seen from any angle, occur in opals where the silica stacking varies in orientation and arrangements from region to region; the stacking is said to have *faults*. The beauty of a black opal with faults is enhanced by the presence of small particles (carbon, iron oxide, or titanium oxide) that absorb the undiffracted light, providing a dark background to the colorful light you intercept and making that light more perceptible. In potch opal the range in the sizes of the spheres is wide and the colors are not brilliant. The range is smaller in white opals but still wide enough to yield a murky white *opalescence*.

### 6.96 • Alexandrite effect

The color of most gems is reasonably the same under sunlight and incandescent light, but certain gems, such as alexandrite and tanzanite, can undergo a remarkable shift in color—from blue-green in sunlight to yellow-red in incandescent light. When the first alexandrite gemstone was discovered in Russia's Ural Mountains in 1831, this color shift was named the *alexandrite effect* to honor Tsar Alexander II of Russia. What causes this color shift?

**Answer** A gem displaying the alexandrite effect transmits light well in the blue-green and red portions of the visible spectrum but not in the intermediate portion. Also, the transmission in the blue-green portion is better than in the red portion. When one of the gemstones is viewed in sunlight, which consists of the full visible spectrum, the transmission in the blue-green portion dominates what you see