light touch

Olympic optics, or the world according to fish

BY MICHAEL E. KNOTTS

The Olympics are a big deal this summer,[1] and many Olympic events involve water: Swimming obviously, but also diving, rowing, synchronized swimming, canoeing, and kayaking, sailing, and, yes, water polo. Much of the action of water polo used to take place underwater, until the rules were changed.

This brings us to a great question to ask your children at the swimming pool this summer: What do you see underwater? Well, the answer is *not much,* unless you're a fish or you are wearing goggles. Why? Because your eyes are designed to operate in air, not water. The index of refraction of your cornea (1.376) is too close to that of water (1.33) to allow sufficient refraction to form an image on the retina.

What does a fish see? The short answer is, a fish sees everything—the whole 180° world, within a 97.5° cone. This is the meaning of "fish-eye view" (See Fig. 1). As the fish looks up, he sees a blue circle—the sky—fringed with a dark rim for the land. Beyond that rimmed circle is what looks like a perfect mirror, reflecting the underwater world back to the fish.

What's going on? Rays entering the water from the outside world are bent toward the vertical; the steeper the angle, the more they are bent. This wasn't always understood. An incorrect diagram from a book published in 1637 (See Fig. 2) shows the rays bent in a way that implies that light travels faster in water than in air. In fact, light travels about ¾ as fast in water (or, as we optics people would more often say, the index of refraction of water is about 4/3=1.33).

You can measure the (relative) speed of light in water pretty well with just your eyes.

- Get a tall glass; a graduated cylinder used for chemistry experiments would be perfect.
- Fill it with water and drop a penny in.
- Look at the submerged penny with both eyes at once and move your finger alongside the glass until it seems to be just as deep as the penny.
- Measure your finger's distance from the water surface and divide by the total depth of the water column. You should get about 0.75.

Congratulations! You have just measured the speed of light in water (relative to the speed in air) with a ruler; take the reciprocal, and you'll have the index of refraction. For some extra fun, repeat the same experiment with vegetable oil (n≈1.46–1.47) or glycerin (n=1.4746) and notice the difference. Objects underwater appear closer than they are; a swimming pool looks shallower than it really is. This is why it's hard to grab something underwater on the first snatch; you have to learn to allow for refraction.

Let's go back to the fish underwater. We'll imagine that he's a glowing fish and rays are coming from him. All the rays coming from him toward the surface can leave the water . . . until the angle from the vertical exceeds 48.75°. Then the rays are bent back into the water, as though by a perfect mirror (See Fig. 1).

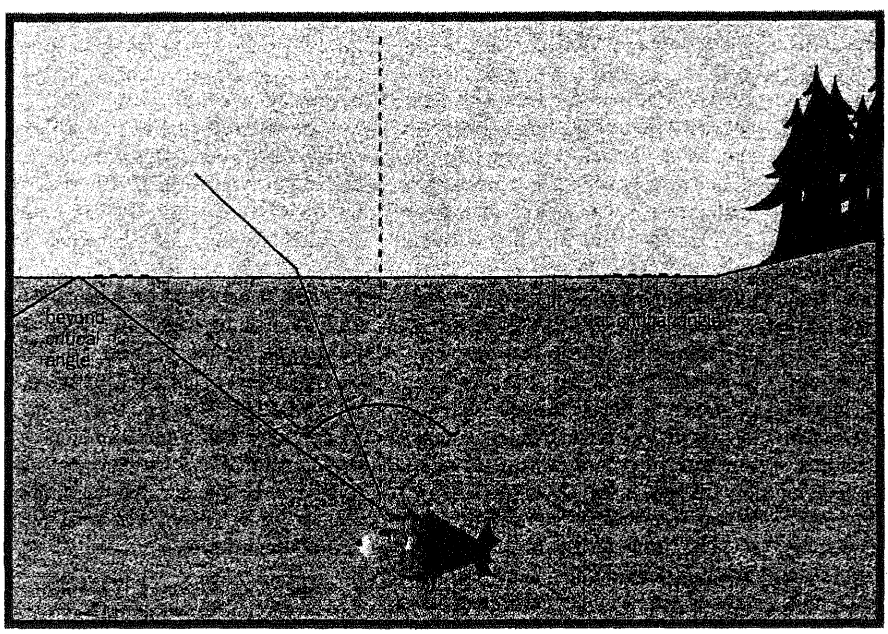

Figure 1. A fish's view of the world.

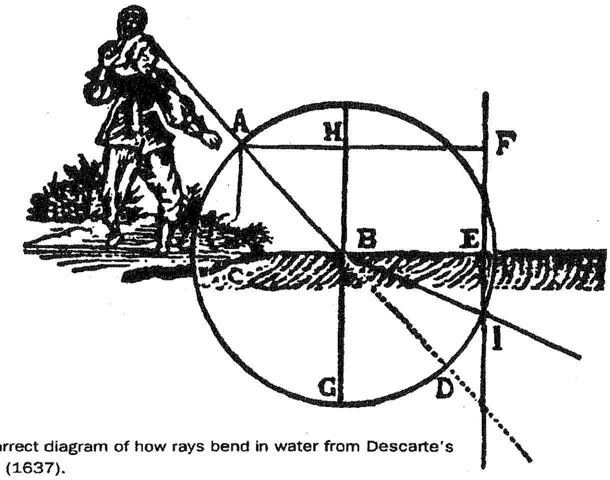

Figure 2. Incorrect diagram of how rays bend in water from Descarte's *La Dioptrique* (1637).

This is called total internal reflection—that is why there seems to be a mirror on the undersurface of the water, past the "fish-eye" circle of visibility. You can see this mirror without getting wet, just by looking at a glancing angle at the undersurface of water in a glass; the effect is "silvery." Put your finger in the water from above and see how it suddenly appears in the silver.

As for what you see underwater, cameras face challenges similar to those of swimmers without goggles. Underwater photography requires a camera with a lens optimized for immersion in water (such as the Nikonos, made by Nikon) or a lens inside a waterproof enclosure with a window.

During the Olympics, a special underwater camera attached to a track on the bottom of the pool will follow swimmers to provide video of the competition. For the diving venue, a camera will capture the action by sliding down a tall waterproof mast with a side window that extends from below the surface of the water to the height of the diving board 10 meters above.

This brings us to another question. How do divers, who surely wish to avoid a fate like birds who fly unknowingly into plate glass windows, know the location of the water's surface? The answer is scattering. In competition, a nozzle near the edge of the pool sprays water onto the surface near the diving area to roughen the water's surface. The diver can then see the random reflections off the surface. During practice, a sparger is used. This device consists of perforated strips on the bottom of the pool, through which compressed air is forced. The resulting stream of bubbles cushions the diver's landing and chops up the water enough to make it appear white.

So, armed with all of this information on eyeing aquatic events, enjoy the Olympics and a Saturday swim this summer. Don't forget your goggles.

Reference

1. The Georgia Institute of Technology is the home of the Center for Optical Science and Engineering, as well as the 1996 Centennial Olympic Games. The Olympic Village and several major venues (including swimming and diving competitions) are located on the campus.

Michael E. Knotts, OPN *contributing editor, is postdoctoral research fellow in the School of Physics, Georgia Tech, Atlanta, Ga.; ph281mk@prism.gatech.edu*