Optics for the Fish

BY R. JOHN KOSHEL

Helping students understand physical phenomena can be rather difficult at times. Everyone sees optical effects in the real world—reflections in a car's rear-view mirror, scattering making the sky blue, diffraction of street lights through a window screen, and Moiré fringes in household curtains. Many of these effects go unnoticed and are hard to bring into the lecture hall. I have developed a series of experiments using a water-filled fish tank to display principles of optics such as refraction, reflection, scattering, and interference, as well as demonstrate a simple water-based system for optical communication.

What you need

The primary piece of equipment you'll need is a fish tank! For the experiments described, a small (5 gallon), rectangular shaped acrylic tank is recommended.[1] The only other major piece of equipment is a light source. Most of the experiments require a collimated beam of light; for this, I prefer an HeNe laser. Other laser sources can be used, but the HeNe laser is the cheapest solution barring diode lasers.[2] Additional equipment includes stands, catch buckets, milk or dye, sponges and rags, and, of course, water. You should also bring a sense of humor, since water can make for a wet experience.

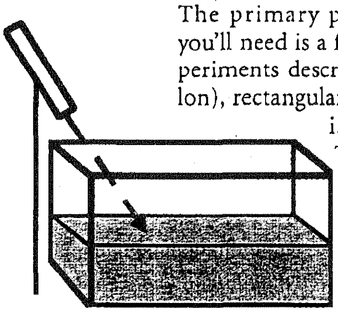

Figure 1. Layout for showing refraction.

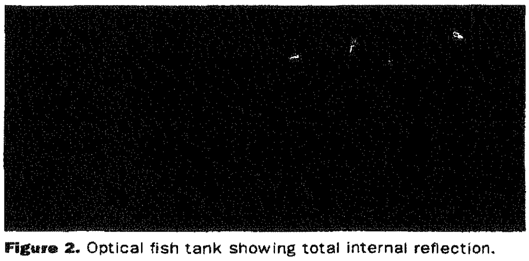

Figure 2. Optical fish tank showing total internal reflection.

I begin by telling the students that the laser beam is virtually monochromatic, or made up of "one color," and that it is directed, which means it propagates in one direction and is hard to see from angles away from its direction of propagation. I then caution them that looking into a laser is not a very good idea. Even though the HeNe laser is typically low power (*i.e.*, a maximum of 5.0 mW) the power is directed along a very narrow beam, unlike room lights that emit up to 100 W in all directions. For this reason, I caution everyone never to look into a laser beam, and always to be wary of stray reflections. In my experience, kids always want to look into the laser, no matter what I tell them.

Scattering

To show that the laser's beam is directed, it is useful to pat chalk dust-filled erasers together over the beam path with the room lights off. You'll get some oohs and ahhs as the students see that light is actually there. Explain that this mini-light show is due to the laser's light scattering off the chalk dust particles.

Next, position the laser so that it shines through the water-filled fish tank, from one end to the other. Ask your audience if they can see the beam. They should say no, but often there are impurities in the water that allow it to be viewed (especially for dark-adapted eyes).

To make the beam visible, add an impurity, such as milk or yellow food coloring, to the water. Be frugal with how much you add, since the milk or food coloring is a loss mechanism for the laser beam. I have discovered the hard way that a demo can be ruined if you add too much to the tank. A little milk goes a long way, and be wary of cream—a drop can sometimes be too much. Ask the audience why they can see the beam now. In your explanation, you may want to talk about the blue sky and Rayleigh scattering.

Refraction

Now place the laser on a stand so that it can be directed down toward the surface of the water at an angle to normal incidence (see Fig. 1). Ask the students if they can see that the laser beam changes directions at the surface of the water. Describe refraction to them, explaining that light takes the shortest path through any material, and discuss Snell's Law with more advanced students. To help motivate the students, it is useful to ask if they have ever noticed this phenomena. If there is no response, ask if they have looked at objects under water (*e.g.*, in the swimming pool) and misjudged the objects' location until they put their head underwater.

Reflection

For reflection, simply show that there is some light bouncing off the bottom of the fish tank. The angle at which the light is reflected with respect to the normal is the same angle as that with which it strikes. Of course, the light then hits the surface of the water and it refracts out of the water. You may be able to see another reflection coming off the surface of the water and heading back down into the tank. This effect will be maximized in the next step, total internal reflection.

Total internal reflection

Total internal reflection (TIR) occurs when light, originating in the medium of the greater index (in this case, water) hits the interface at an angle greater than the critical angle, which is about 48.8°.

Set up the system so that the laser is

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agement for students to develop the characteristics they need to meet the challenges of today and tomorrow.

Thus, IC emphasizes team activity and cooperative learning for both students and faculty. A joint approach to development, it fosters continuous improvement through feedback, assessment, and critiques of methods and outcomes.

References

1. B. Winkel and J. Froyd, "A new integrated first-year core curriculum in engineering, mathematics and science: A proposal," *Proceedings of the 1988 Frontiers in Education Conference* (Santa Barbara, Calif., October 1988).
2. See, for instance, Roedel *et al.*, "An integrated, project-based, introductory course in calculus, physics, english, and engineering," *Proceedings of the 1995 Frontiers in Education Conference* (Atlanta, Ga., Nov. 1995). Further articles can be found at www.osa.org.

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Light Touch

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angled downward once again, but this time it should hit below the water line through one end of the tank (see Fig. 2, page 50). You should be able to observe the laser beam bouncing up and down from the bottom of the tank to the surface. (It may help to place a mirror on the bottom of the tank.) The beam will ultimately emerge from the other end of the tank. The number of bounces the laser beam makes depends on the angle of the laser to the normal of the tank's end, the size of the tank, and the water level. If you enter the tank above the waterline, TIR does not occur.

TIR explains how optical fibers work. Many students have heard about optical fibers, but they have a hard time understanding what is involved with such devices. The optical fish tank provides a simple method of demonstrating rather removed devices like fibers.

Next month, we'll discuss optical fishtank systems, including the famous luminous fountain and an optical communication system using a water waveguide.

References

1. Glass tanks are cheaper, but they are heavier and more susceptible to breakage than acrylic. Next month's experiments require a tank with a hole, and it's also much easier to drill a hole in plastic than in glass. Larger tanks are harder to take on the road, and tanks with curved sides can alter the illuminating beam of light via refraction.
2. Diodes are difficult to use due to their broad divergence angle. They can be collimated, but this tends to be a more difficult, expensive, and less satisfactory alternative to a simple HeNe laser.

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Forensics and optics

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densities and different optical properties must be characterized. Lastly, consider the possibility of applying flow cytometry[15] to particle analysis. Complex mixtures of particles could flow past the microscope, with individual particles being characterized, and possibly sorted electronically, as they go.

Optical methods have a great potential to revolutionize forensic analysis of trace evidence over the next decade. This revolution will come from methods that will allow size, morphology, and optical properties to be simultaneously determined in a way that allows standardization among laboratories, efficient analyses, and the generation of databases that will assist interpretation.

References

1. D.A. Wilkinson and J.E. Watkin, "A comparison of the forensic light sources: Polilight, Luma-Lite and Spectrum 9000," J. Forensic Ident. **44**, 632–651 (1994). See also www.crimescope.com.
2. T.K. O'Brien, "Photonics uncovers possible clue to boy's killer," Photonics Spectra **31** (9), 18–19 (1997).
3. F.M. Hinant, "Nondestructive microscopical inspection of bulky art objects," Microscope **42,** 1–5 (1994).
4. Foster and Freeman Ltd. has produced four of the instruments referred to in this article: the ESDA, GRIM, VSC, and Fiber Finder. Their Web page is an excellent source of information and applications of these instruments: www.fosterfreeman.co.uk.
5. D.A. Stoney and P.M. Dougherty, "The microscope in forensic science," *More Chemistry and Crime*, S.M. Gerber and R. Saferstein, eds. (American Chemical Society, Washington, D.C., 1997), pp. 107–135.
6. W.C. McCrone, "Choice of analytical tool," Amer. Lab. **3** (4), 41–43 (1971).
7. Current information on Nanometrics products, including the Nanospec, can be found at www.nanometrics.com.
8. Current information on Zeiss products, including the MPM 800 Microscope Photometer can be found at www.zeiss.com.
9. J.A. Reffner and P.A. Martoglio, "Uniting microscopy and spectroscopy," *Practical Guide to Infrared Microspectroscopy*, H.J. Humecki, ed. (Marcel Dekker Inc., New York, N.Y. 1995), pp. 41–84.
10. A website devoted to information about these microscopes is www.*geocities.com/Cape Canaveral/3429/PV*.
11. W. Stocklein and R. Gobel, "Application of cathodoluminescence in paint analysis," Scanning Microscopy **6**, 669–678 (1992).
12. Two articles on firearms indentification databases are: T.M. Dees, "Automation of forensic ballistics," Law Enf. Tech. **March,** 44–47 (1994) and K.W. Strandberg "FBI 'Drugfire'," Law Enf. Tech. **April,** 50–51 (1994). Fingerprint computer systems information can be found at the AFIS subcommittee Web page of the International Association for Identification: www.iaibbs.org/afis.htm.
13. R. Oldenbourg and G. Mei, "New polarized light microscope with precision universal compensator," J. Microscopy **180,** 140–147 (1995).
14. S. Inoyé, "The centrifuge polarizing microscope," presented at the American Society of Clinical Biology Meeting, Washington, D.C., December 17, 1997. For an abstract see www.videomicroscopy.com/press%releases/centrfuge.htm.
15. *Optical Diagnostics of Biological Fluids and Advanced Techniques in Analytical Cytology*, A.V. Priezzhev *et al.*, eds., (SPIE, Bellingham, Wash., 1997).

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