Optics in the Fishtank

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Why is the sky blue? Why are sunsets red? How does light travel through optical fibers? To answer these questions and others, we brought out a secret weapon: the fishtank. Using a 10-gallon tank ($10) and an inexpensive laser pointer ($40) or a He-Ne laser, a flashlight, and a ruler, we can show many sophisticated effects ranging from waveguiding to Rayleigh scattering. The OSA student chapter at Northwestern University has performed these interactive demos at local high schools to encourage interest in optics.

Trapping light

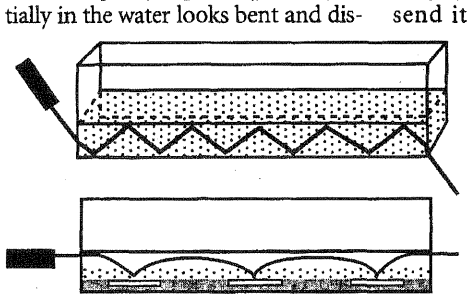
The tank should contain a couple of inches of water (minus the fish). By adding a few drops of milk to the water to enhance scattering, the beam will be readily visible if the room lights are low. If the laser source is polarized, rotate it to maximize the light (Rayleigh) scattered towards the sides. Best visibility occurs when the laser is vertically polarized. Reflection, refraction, and total internal reflection can be easily observed with this setup. By holding the laser pointer at various incident angles, we can show the beam entering the water, refracting, and exiting back into the air at the original angle. With this simple exercise, we choose a few angles and physically observe Snell's law: light bends differently as it enters or exits different media, illustrating why a pencil placed partially in the water looks bent and disconnected from the half in air.

Total internal reflection (TIR) is the effect responsible for waveguiding in optical fibers. By varying the angle of the beam inside the fishtank, we can observe TIR. As we approach the critical angle, the beam transmitted out of the water becomes almost parallel with the outer surface. At the critical angle the transmitted light disappears, and simultaneously the reflected beam in the tank grows noticeably stronger. The light trapped in the fishtank zigzags up and down and we have our macroscopic waveguide!

Making color

The scattering of sunlight by small particles in the atmosphere is known as Rayleigh scattering, a process in which higher frequencies (smaller wavelengths) are scattered more than lower frequencies. This mechanism is responsible for the blue sky and brilliant orange-red sunsets. By shining a bright white flashlight through the length of the tank, the higher frequencies (blue light) scatter more and the tank takes on a bluish hue, like the sky. Since the lower frequency (red) light is scattered less, the transmitted light at the far end of the tank is a reddish-orange color. In nature, this effect is best seen at sunset, when sunlight is traveling through the largest amount of atmosphere. This effect is also demonstrated quite well by placing a tall glass of water (with a few drops of milk) on an overhead projector The water in the glass appears blue and the projected image is orange.

Another exercise is to use a few lenses to expand the laser beam to a roughly 1-2 inch collimated beam and send it into the tank. By placing another lens in front of the beam, we can focus the beam inside the fishtank. This way, we can see the light converging to a bright spot and then diverging in the water. Other related experiments include measuring Brewster's angle and the critical angle from which the refractive index of the water can be calculated.



An illustration of TIR and waveguiding (above) and GRIN lensing (below)

Bending beams

The fishtank can also be used to demonstrate more ad-vanced concepts such as GRIN (GRaded INdex) lenses and waveguides. First, place five pounds of sugar evenly across the bottom of the empty fishtank. Then, gently add a few inches of water, taking care not to stir up the sugar on the bottom. As the sugar slowly dissolves from the bottom, a concentration gradient forms within a few hours giving rise to a graded index of refraction. As the gradient develops, a light beam traveling through the water parallel to the surface will start to bend toward the bottom. Initially, the effect is slight, but after a day or two the light will curve directly into the bottom. By placing a mirror at this point on the bottom of the tank, the light reflects upwards only to curve back down, effectively hopping across the bottom due to the GRIN lensing effect. The GRIN effect also causes an optical illusion when the tank is viewed from the side. The flat layer of undissolved sugar on the bottom of the tank appears as a curved hill. Its flatness, however, can be verified by measuring depth with a ruler.

The fishtank is an excellent tool for demonstrating fundamental concepts in optics. It has been well-received by high school students and teachers and has been incorporated into teaching labs at Northwestern. When not used to demonstrate the great technological impact of optics on our everyday lives, the fishtank can make a nice home for a couple of fish.

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