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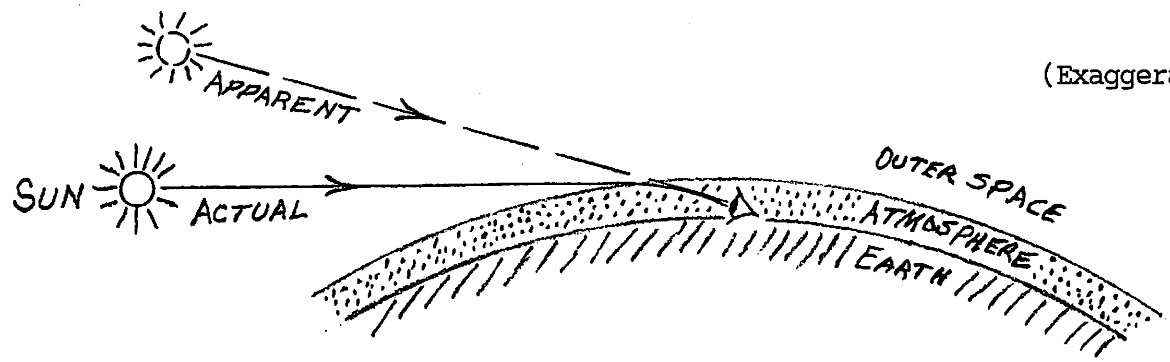
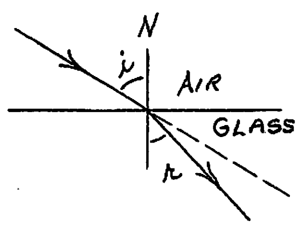
Atmospheric refraction - Sunrises and sunsets have enthralled people for thousands of years. Poets and artists have been interpreting them for centuries. However, one aspect of these phenomena has escaped most viewers, the part played by atmospheric refraction. Few observers realize that the sun on the rim of a hill (the horizon) is really below the rim out of direct sight; it only appears to be there. See the illustration below.



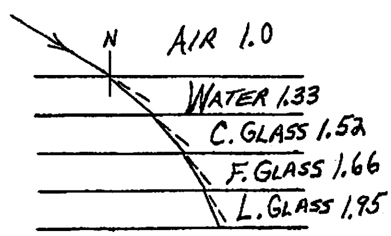
(Exaggerated.)

Refraction is the bending of light as it passes from one medium (air?) into another (glass, water. etc.?) at an angle other than 90° and when the optical densities of the two substances are different. See (a). Atmospheric refraction is the bending of light from outer space as it enters our more dense atmosphere. However, our atmosphere becomes even denser as the light penetrates deeper. Thus, the light continues to bend and to a higher degree. See (b). This means that light can bend (curve) over the horizon (rim) when the sun is still below it. This far-reaching result also means that we receive several additional minutes of sunlight on each end of the day. Neat! Just another of nature's endless wonders!

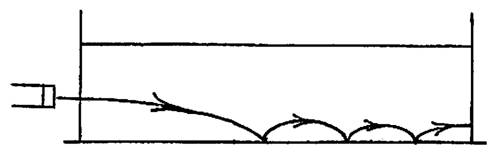
(a)



(b)



(c)



With some extra effort and a laser, you can simulate atmospheric refraction in the classroom; the experience is very rewarding. A liquid, a variable sugar solution, works well. You must establish continuous "layers" of different sugar concentrations that create a vertical gradient of indices of refraction similar to that in the earth's atmosphere.

Start with a clear, transparent tank similar to the one illustrated below. If such a tank is not available, one can be made out of clear Plexiglas and acrylic cement; details later. In a beaker, make up a concentrated sugar solution using 50 ml of warm water and 80 g of sugar. With vigorous stirring, dissolve the sugar at 40 - 45°C. Let it cool.

For final display, place the tank on something stable where it will not be moved again. Fill it to a depth of 3 cm with tap water a few degrees warmer than the sugar solution. Then add all of the sugar solution to the bottom of the tank by gently pouring it down a stirring rod to minimize mixing as the rod is slowly, gently moved once from one end of the tank to the other. Do not stir! You are creating a bottom layer of high density sugar that will "drift" upward after a few minutes to create the variable density that you want.

Line up a laser so that its beam enters the solution about 1 cm above the tank's bottom. In a darkened room, the simulation of atmospheric refraction should be clearly visible. A possible alternative for the bottom "layer" could be sugar cubes with uncertain results. You will learn that sugar in solution is a strong scatterer of light, making it excellent for showing laser beam paths.

For many, an even more interesting effect will be noted. After the first refraction occurs, the beam can be made to "bounce" several times. See (c). This demonstrates total internal reflection at the plastic-air interface of the outside surface of the clear plastic tank bottom and total internal refraction, the reverse deflection of the upward, reflected beam. By adjusting the height of the laser and its beam and changing the beam's angle of incidence with the tank and solution, the maximum effect can be achieved. Via further beam adjustments, additional interesting phenomena can be observed; have fun!

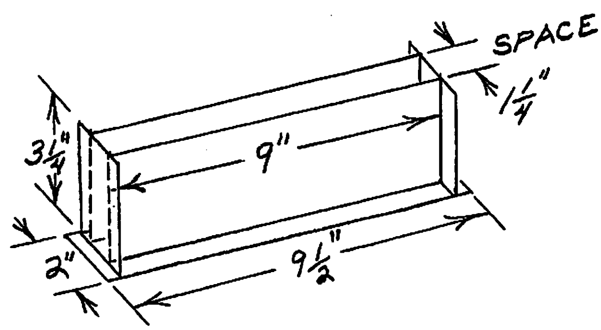
A couple of reminders. Once the gradient has been established it will remain stable for several days unless the tank is jiggled or the solution is stirred. When the demonstration has been completed and the beam is still passing through, stir the solution and watch the beam go straight. Now the resultant solution can easily be reused for other demos, like liquid lenses, prisms, and cylinders and other studies of refraction and internal reflection in liquids.

Final cleanup is easy. Use very warm water to thoroughly dissolve and rinse out the syrup. To avoid waterspots on the tank, immediately wipe all surfaces clean and dry with kleenex; do not rub!

Construction of the tank: Some experience with acrylic cement is needed. The design uses simple butt joints for the corners and requires five 1/8" thick acrylic rectangles and some acrylic cement. Lay out the sides (spacing) before cementing. The 1¼" inside spacing is necessary so your fingers and kleenex can wipe the inside of the tank clean and dry.

Warning: Cementing is tricky; use cement sparingly as excess can't be wiped off. Practice on some scraps before the final assembly. Also, the cement sets very fast.

Cement a long side onto the base first; set it square (90°). Follow by adding an end piece as square as possible. Continue with the remaining long side, remembering the 1¼" spacing. Cap on the final end piece. Test for leaks. Add more cement along the seams if necessary but don't over do it! Good luck!



1 base: 2" x 9½"

2 long sides: 3¼" x 9"

2 end pieces: 2" x 3¼"