Sugar Water Mirage

The thin blanket of air that envelopes the Earth is rarefied at high altitudes and densifies with proximity to the surface. Thus the refractive index of the atmosphere increases in a continuous manner from unity in the vacuum of space to approximately n=1.000293 at sea level (λ=0.5893 μm). Everywhere the gradient of the refractive index points toward the Earth's center, and so light passing from the sun to an observer on Earth will take straight or curved paths depending on whether the light travels parallel or perpendicular to the index gradient. At high noon, the direct sunlight observed from the ground travels through the atmosphere along a straight trajectory. Direct sunlight reaching us at sunrise or sunset has taken a curved path, bending toward the high refractive index layers near the ground.

The curved ray trajectory at sunrise or sunset leads to a variety of interesting effects. For example, we can see direct sunlight when the sun is behind the Earth in the moments before sunrise and after sunset (see Fig. 1a). During a lunar eclipse, the moon is in the Earth's shadow, but some direct sunlight reaches the moon anyway. The reason is that some sunlight is bent around the Earth; in other words, the gradient-index atmosphere acts as a weak lens. Most blue light is scattered in the atmosphere, but some red light makes it through to pass through to the moon, and from there is scattered back to our eyes on Earth. Knowing the moon's approximate position in the sky, the dark adapted eye can find a very dim, dull red moon after the moon becomes fully eclipsed (see Fig. 1b). Perhaps a more familiar sight is the flattening of the sun's disk at sunrise or sunset. Again, the appearance is the result of curved ray paths along the Earth's atmosphere (see Fig. 1c).

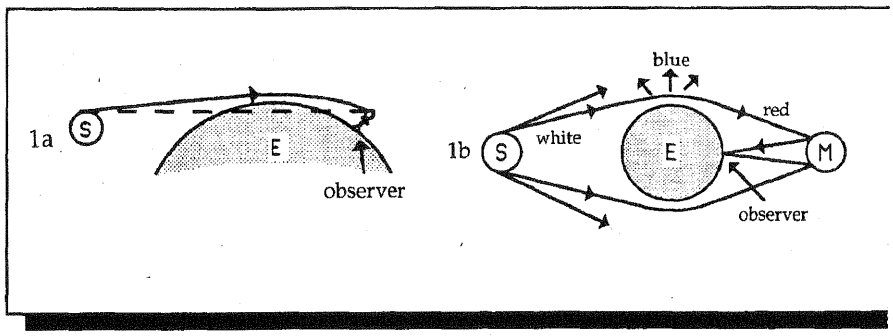

Figure 1. (a) An observer can see direct sunlight (solid line) even when a straight ray path (dashed line) is blocked; (b) during a lunar eclipse, some light is lensed around the Earth and dimly illuminates the moon; (c) the flattening of the sun's disk occurs when the sun is low in the sky. Light from point A is bent so as to appear to be coming from point B.

All of these effects are mirages because they arise from inhomogeneities in the atmosphere's refractive index. Mirages can also arise from local index inhomogeneities near the Earth's surface. Hot asphalt warms the air near a road surface and the refractive index decreases locally as the air becomes rarefied. Light passing through this region will bend away from the road to the cooler air above (see Fig. 2a). This is commonly seen on a still day after the sun has warmed a long stretch of road. There seem to be wet patches on the pavement; these arise from deflected skylight and are called "Inferior Mirage" images;[1] "Superior Mirage" images are usually seen over a cool ocean on a warm, still day. The result is inverted images that loom over the horizon (See Fig. 2b).

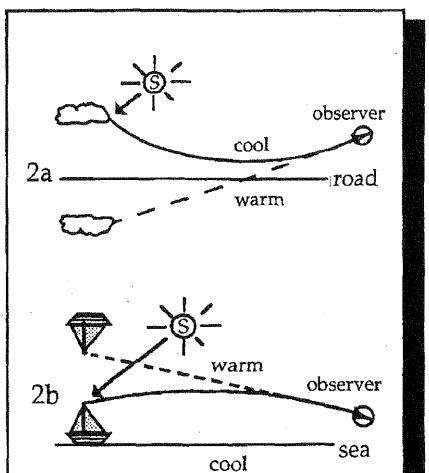

Figure 2. (a) Inferior Mirage: light bends away from the low refractive layer near the warm road surface and enters the eye at an angle so as to appear to have originated from below the road surface; (b) Superior Mirage: Light bends toward the cool air over the sea so the eye sees the image looming in the sky.

Mirage effects can be created with household materials. Place a clean fish tank in a quiet spot where it won't get jostled for a couple of days. Fill it half-way with tap water. Carefully pour one or two 16 oz. bottles of Karo syrup or 1-2 lbs. of granulated sugar into the tank, taking care so as to disturb the water as little as possible. Being heavier than water, the sweetener will settle at the bottom of the tank. However, the

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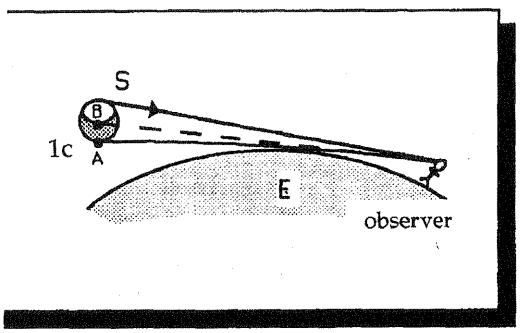

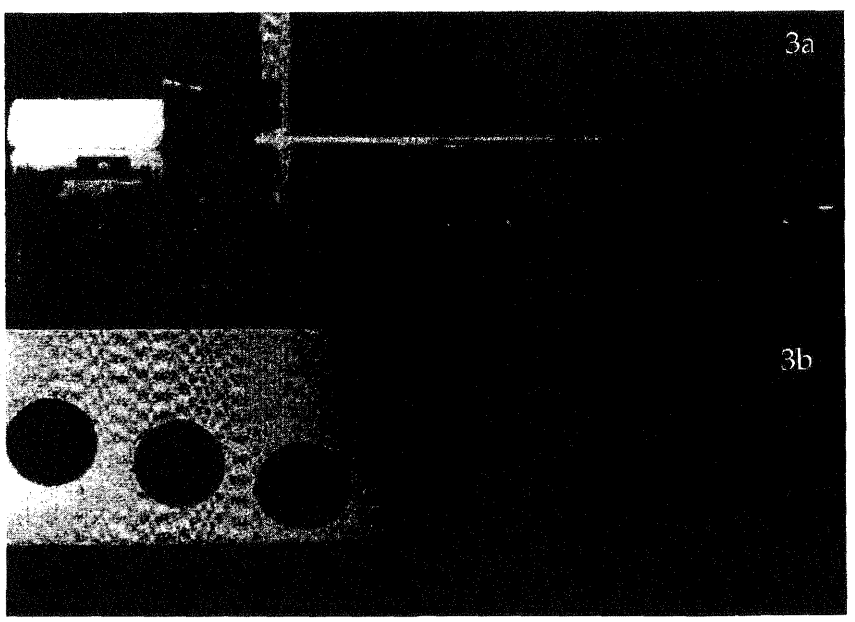

FIGURE 3. (a) COLLIMATED BEAM FROM A DIODE LASER BENDS INTO HIGH REFRACTIVE INDEX REGION OF SUGAR WATER IN FISH TANK. A SMALL FRACTION OF THE BEAM IS SENT THROUGH THE HOMOGENEOUS TANK WALL AS A REFERENCE FOR THE EYE; (b) SEVEN "DOTS" AS VIEWED THROUGH A FISHTANK FILLED WITH KARO SYRUP AND WATER. THE CIRCULAR DOTS APPEAR TO FLATTEN WHEN VIEWED THROUGH THE GRADIENT-INDEX REGION, MUCH LIKE THE SUN'S DISC FLATTENING NEAR THE HORIZON.

sweeteners are water-soluble and the dissolved sugar water will slowly diffuse upward. A gradient-index region near the bottom of the tank will be apparent after 8-24 hours.

A pencil beam pointed parallel to the index gradient travels in a straight line from the top to the bottom of the tank. A pencil beam pointed perpendicular to the index gradient will bend toward the high index region, in this case to the bottom of the tank. This is easily seen using a laser pointer or some other laser beam (see Fig. 3a). Viewing objects through the tank gives rise to distortions similar to those seen at sunrise and sunset (see Fig. 3b).

REFERENCES

1. M. Minneart, *The Nature of Light and Color in the Open Air*, Dover, 1954.