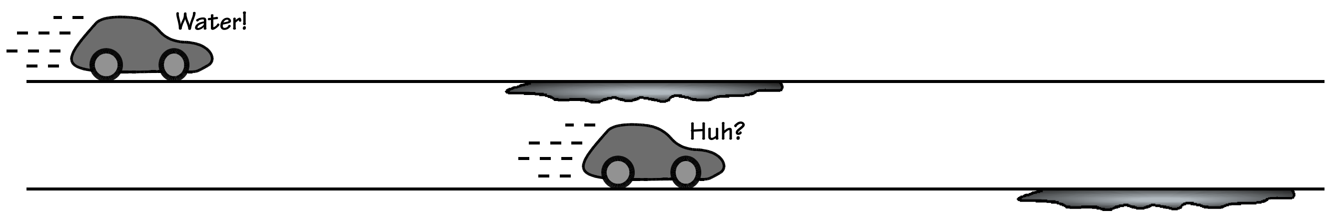
PhyzGuide: Atmospheric Refraction

SEEING A MIRAGE

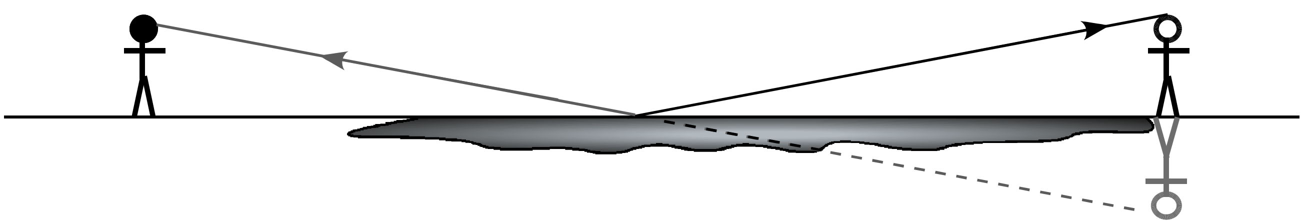
You're driving down the highway and you notice that there appears to be some water on the road ahead. But as you continue driving, you don't get any closer to the water. You're seeing a *mirage*.



The mirage appears to be a body of water that isn't really there. Is this because you're thirsty? Have you been driving too long? Could you take a picture of a mirage? The answers to these questions are no, maybe, and yes, respectively.

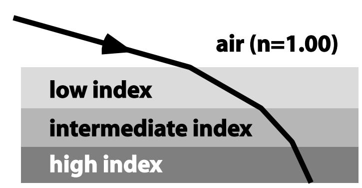
SEEING A REFLECTION FROM A PUDDLE, POND, OR LAKE

To understand the illusion of the mirage, we must first understand what happens when there really is a body of water on the road ahead. Have a friend stand beyond the far shore of a pond. What do you see?



You see your friend and—more importantly for us—a reflected image of your friend. It may be wavy if there are ripples on the water. You have done something like this enough times in your life to have learned that when you see this kind of reflected image, it is due to the presence of a body of water.

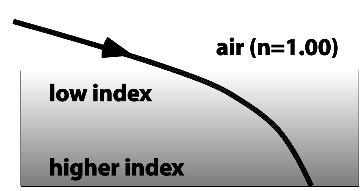
Hold that thought while we develop another part of our story.



GRADUAL REFRACTION

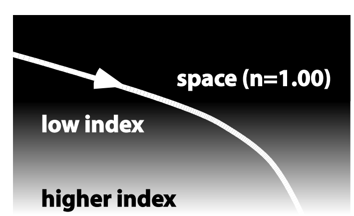
Suppose a beam of light were directed toward the layers of glass arranged as shown. Each time the beam passes from a lower- to a higher-index medium, its path is incrementally bent toward the normal.

Suppose there were a single piece of glass manufactured specifically to have an index of refraction that gradually changes from one surface to the other. A beam entering would curve toward the normal.



ATMOSPHERIC REFRACTION

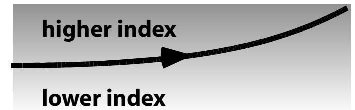
Air has a slightly higher index of refraction than does the vacuum of space. A beam of light that enters the atmosphere from space will bend slightly toward the normal. And as the beam passes into denser and denser layers of the atmosphere, it continues to bend in the direction of the higher index. The higher index corresponds to denser air.



MIRAGE CONDITIONS

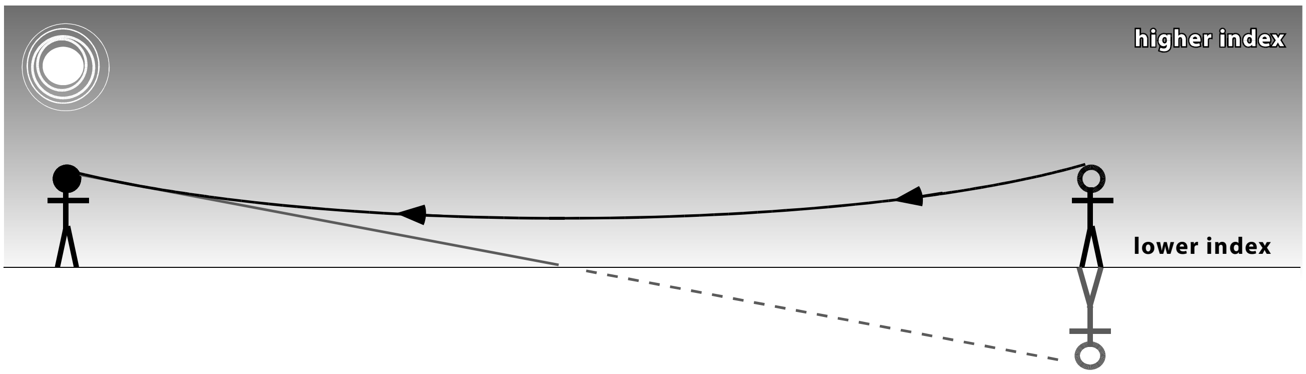
Next time you see a mirage, notice your surroundings. Especially the atmosphere. Notice that it's hot out and you're on land. It's really hot. And it's sunny. Specifically, the land is hot because of the sun shining on it and its low specific heat. The air just above the land is hot due to conduction and convection. But at higher and higher altitudes, the air is cooler and cooler.

FORMATION OF THE MIRAGE



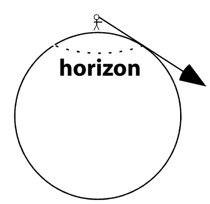
Cooler air is denser air. Denser air has a higher index of refraction than less dense (warmer) air. So the gradual change in temperature with increasing altitude (called a temperature gradient) leads to a gradual change in the index of refraction. This leads to gradual upward refraction.

So suppose your friend is somewhere distant from you. Light emerging from your friend toward the ground is gradually refracted upward toward your eyes.

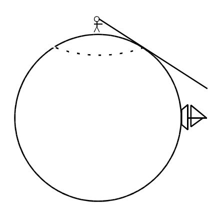


But your brain believes that light entering it has come along a straight line. Tracing that line straight back produces an image similar to the one produced when your friend is at the opposite shore of a pond or lake. The belief that the image is a reflection from a body of water is enhanced by rippling and shimmering that are the result of convection currents in the air (remember the hot, low density air is below cooler, higher density air).

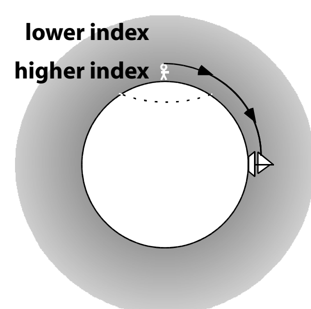
LOOMING



Usually, you cannot see anything beyond the horizon. What exactly *is* the horizon, you might ask. Suppose the Earth were a smooth sphere. For simplicity, suppose you're standing on "top" of the world as shown in the diagram to the right (diagram not to scale). Now draw a ray extending from your eye, tangent to the sphere. Now rotate that ray (imagine turning your head to look all around you). The circle described by points tangent to the ray from your eye is your horizon. (Notice *taller* people have more *distant* horizons.)



Anyway, objects beyond the horizon cannot be seen because the Earth gets in the way. However, it is sometimes possible to see objects beyond the horizon, thanks to gradual refraction in the atmosphere. Such image formation is called *looming*.



Looming typically occurs over large bodies of water. This allows for an unobstructed horizon and the kind of temperature gradient needed to bend the light correctly. Water's high specific heat keeps it cool even when exposed to radiant energy from the sun. Meanwhile, the air above warms up more quickly. Cooler, higher density, higher index of refraction air lies near the water while warmer, less dense, lower index air lies at higher altitudes. If the temperature gradient is just right, light will bend to follow the curvature of the Earth and allow observation of objects beyond the horizon.

