6.3.1: Refraction

A wave that changes speed as it crosses the boundary of between two materials will also change direction if it crosses the boundary at an angle other than perpendicular. This is because the part of the wavefront that gets to the boundary first, slows down first. The bending of a wave due to changes in speed as it crosses a boundary is called ***refraction***. As mentioned in the last chapter, light in air or a vacuum travels at $c = 3.0 \times 10^8\ \mathrm{m/s}$ but slows down when passing through glass. As shown in the diagram below, this will cause light to change direction a little. For a piece of glass with flat surfaces this isn't very noticeable unless the glass is very thick. But for a curved surface the light ends up leaving the glass going in a different direction and this is how lenses for glasses, telescopes, microscopes, binoculars, etc. are made.

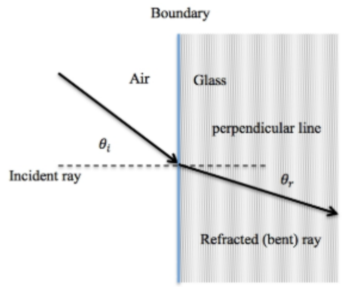

Figure 6.3.1.1

What about sound? Sound also undergoes refraction. Recall from the last chapter that wind can change the speed of air. In the following picture notice that Jill can hear Jack because the wind speeds up the upper edges of the sound, bending it back towards the ground. Jill can't hear Dana because the wind bends the sound upward.

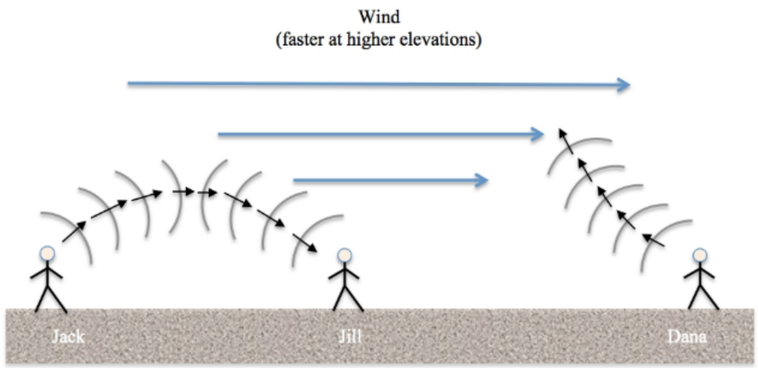

Figure 6.3.1.2

Likewise we know that the speed of sound depends on density which changes with temperature and humidity. In the following picture notice that Jill can hear Jack because the warmer temperature speeds up the upper edges of the sound, bending it back towards the ground. In the second picture there is a temperature inversion with warmer air trapped underneath cooler air. Jill sees but does not hear the lightning (this is sometimes called *heat lightning*, as shown in the second figure below).

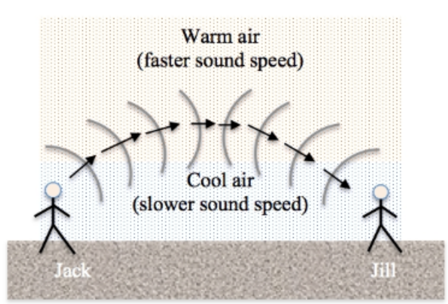

Figure 6.3.1.3

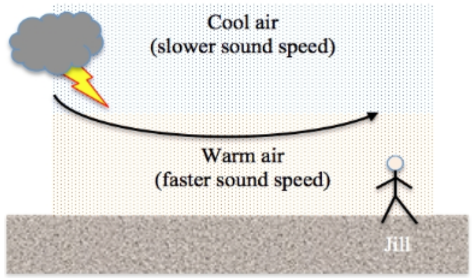

Figure 6.3.1.4

Video/audio examples:

- The broken straw illusion (due to refraction of light).
- Sound refraction example by Paul Hewitt.
- Explanation of ripple tank including Snell's law.
- Example of refraction in a swimming pool.
- Optical illusions due to the refraction of light.
- Snell's law tells you how much a light wave will bend when going from air to glass or vice versa.
- Refraction of sound in a balloon filled with Carbon Dioxide.
- Light going into glass ends up with a refracted angle that is smaller than the incident angle. Going the other way (glass to air) the light ends up with a larger refracted angle than the incident angle. In this case, what happens if the refracted angle tries to exceed 90 degrees? It reflects back into the glass, rather than passing into air. This is known as total internal reflection and is a consequence of Snell's law.
- An example of total internal reflection in a water stream. The same thing happens in a fiber optic cable; light stays inside the cable because of total internal reflection.
- Glass disappearing due to the index of refraction.
- Mini Lab on Ray Tracing.
