6.5.1: Dispersion Simulation

So far in this chapter and the previous one we have assumed that the speed of a wave does not depend on its frequency or wavelength. This is generally true; for example all the sounds of the instruments in an orchestra reach your ear at the same time, no matter what frequencies they are playing. However, it is the case that under some circumstances speed can depend on the frequency of the wave, a phenomenon known as ***dispersion***. For electrical signals in a cable this means the signal gradually deteriorates in quality because high frequency components travel at a different speed compared to lower frequency components. Different colors of light travel at slightly different speeds through glass (in other words the index of refraction depends on frequency) which is how a prism separates out the different frequencies of white light.

In the previous simulations on refraction we assumed that all wavelengths bend by the same amount. But with dispersion if we start with several different wavelengths (different colors) we expect there may be some situations in which the colors will separate. If the sides of the medium are parallel, each color unbends by the same amount that it bent going into the medium so all the colors are again going in the same direction. However if the sides are not parallel, such as a prism or lens, there will be a separation of color. This is in fact how a prism and water droplets separate colors and why good camera lenses (which compensate for this effect by using compound lenses) are expensive.

Dispersion occurs for all types of waves. For example, longer wavelength surface waves on the ocean travel faster than shorter wavelength waves. There is not much dispersion for sound waves in air but acoustic waves in solids do experience significant dispersion. The simulation below is for visible light passing through a prism. You can choose the color and see what the index is for that wavelength.

Simulation Questions:

1. Use the slider at the bottom of the simulation to try different wavelengths. Which visible wavelength is bent the most? Which the least? Note that the wavelength is given in nanometers (nm).
2. What would you see on the right if the source were a white light composed of all wavelengths?
3. The speed of light is $c = 3 \times 10^8\ \mathrm{m/s}$ and the index of refraction is $n = c/v$ where v is the speed in the medium. Using the index given in the simulation for the chosen wavelength, what are the maximum and minimum speeds for colors in the visible spectrum?
4. For one of the wavelengths use the protractor to measure the incident and refracted angles (as you did in the mirror simulation) for the exiting ray on the right. Calculate the index of the prism for that color using Snell's law. Don't forget that the angles are measured from a perpendicular to the surface (you will have to correct for the fact that the prism sides are slanted at 60 degrees). What is your answer? Do you get the index of refraction shown in the simulation for that color?