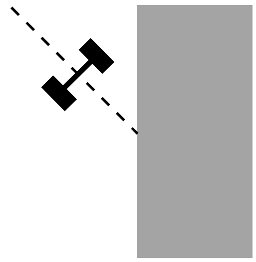
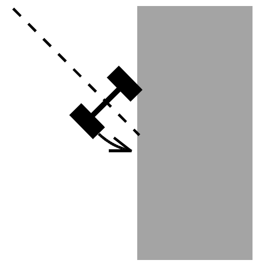
# PhyzGuide: Refraction Analogies

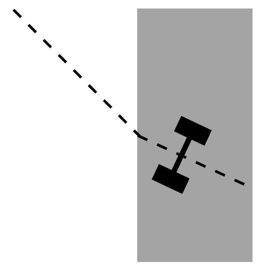
A pair of wheels rolls faster on concrete than on grass. If the pair were to roll straight from concrete to grass, it would simply slow down. But consider the situation shown to the right. A pair of wheels rolls from concrete to grass at an angle, and the path of the wheels is bent.



Consider a pair of wheels on an axle rolling along on concrete approaching a patch of grass obliquely (at an angle). The wheels travel quickly on concrete but slowly on the grass.



When the first wheel hits the grass, it slows down. The wheel on concrete continues rolling quickly. The result is that the axle turns to a new orientation.



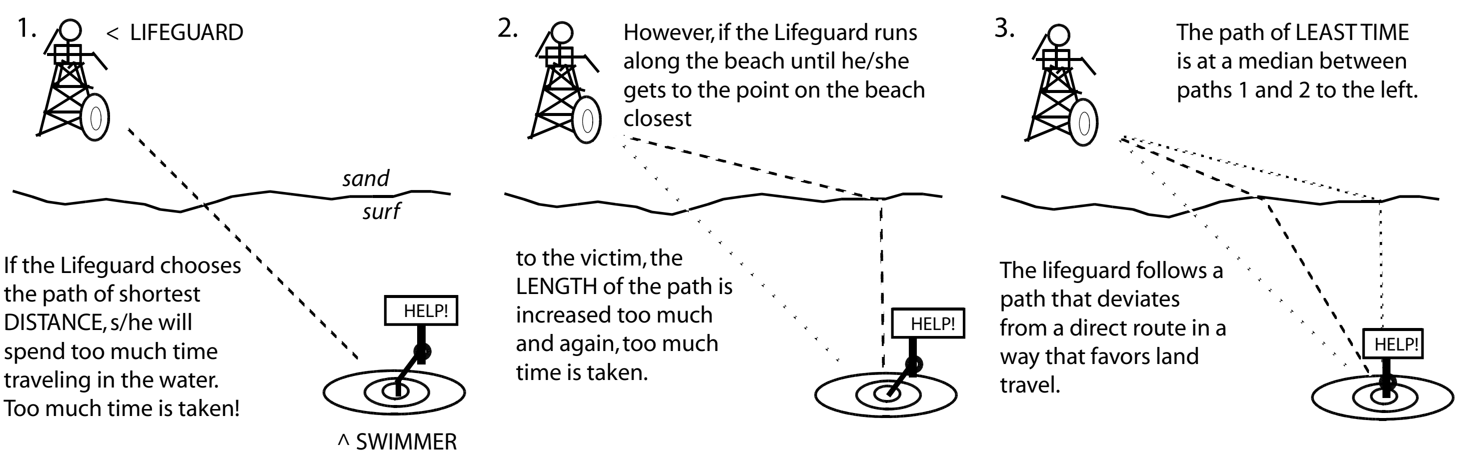
When the other wheel hits the grass, it slows down, too. The axle stops turning, the wheels roll along through the grass. Notice that the direction of rolling has changed.

Or consider the situation shown below. How can the lifeguard reach the swimmer in danger in the least time? As you can see, the path of *shortest distance* is not necessarily the path of *least time!*

When light passes through a vacuum, the oscillating electric and magnetic fields experience no "resistance" to their propagation. When light passes through a transparent solid, however, its propagation is slowed. This is because the incident fields must force the electrons in the solid to oscillate. If the electrons in the solid don't oscillate, the wave doesn't continue. The speed of the wave is slowed because the electrons in the solid have inertia, and resist being forced into oscillation.

Light passing obliquely from a light medium to a dense medium boundary will undergo a change in direction in addition to being slowed down, just like the wheels. In getting from point A to point B, light follows the shortest path in *time,* not in distance. This is known as **the principle of least time.**

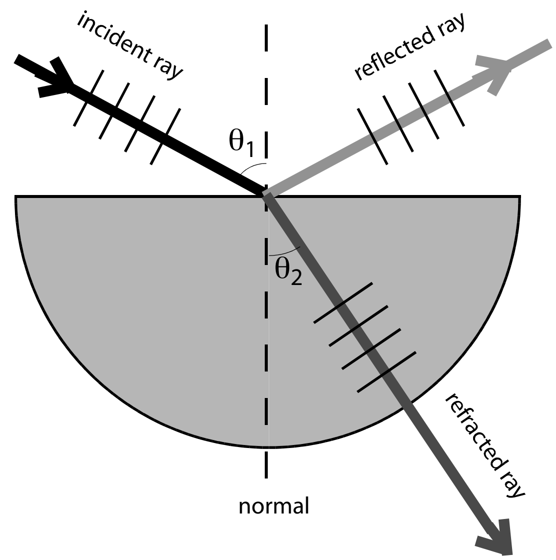
*How can the lifeguard get to the drowning victim in the least amount of time?*
*S/he can run on sand faster than he/she can swim through the water.*



# PhyzGuide: Refraction Diagrams

## Index of refraction, Snell's law




Angle of refraction is related to angle of incidence by the index of refraction of a specific material.

**Index of refraction** is a unitless number that refers to refraction of a wave when the wave passes from medium 1 to medium 2.

Index of refraction, *n,* for various media can be found experimentally with an arrangement such as that shown to the right. A beam of light is incident at an angle $\theta_i$ on the surface of a semicircular dish of liquid. Some of the light is reflected, the rest is refracted at an angle $\theta_2$ into the material. Because of the shape of the dish, the refracted ray will hit the second boundary (liquid to air) at 90˚ and is therefore not refracted further, so $\theta_2$ can easily be measured.

The index of refraction of the liquid is given by **Snell's law** (after seventeenth-century Dutch astronomer Willebrord Snell).

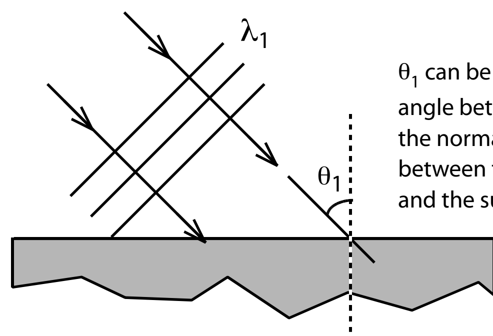
$$n = \sin\theta_1 / \sin\theta_2$$

Notice what happens to the wavelength λ of the wave as it is refracted. Two rays are shown to the right. The lines perpendicular to those rays represent wavefronts or wavecrests, so the distance between them is λ.

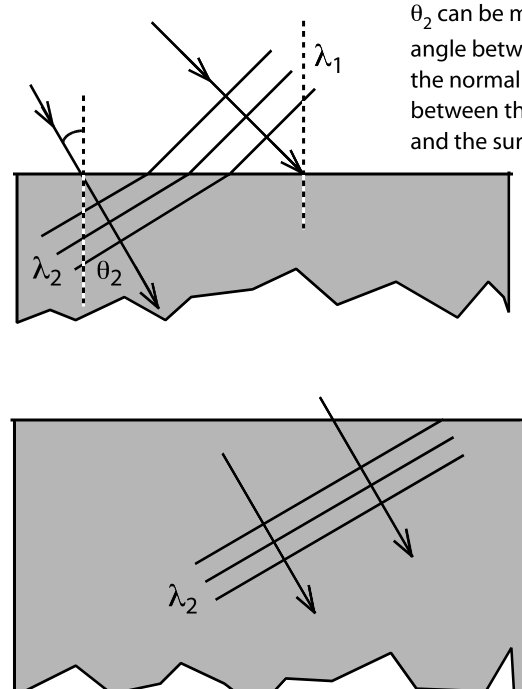
Because the waves travel more slowly in the second medium, $\lambda_2 < \lambda_1$. (Recall the conveyor belt analogy—if boxes go from a fast moving conveyor belt to a slow one, the distance between the boxes becomes smaller.)

The mathematical relation is

$$\lambda_1/\lambda_2 = v_1/v_2 = n_2/n_1$$




$\theta_1$ can be measured as the angle between the ray and the normal OR the angle between the wavefronts and the surface




$\theta_2$ can be measured as the angle between the ray and the normal OR the angle between the wavefronts and the surface