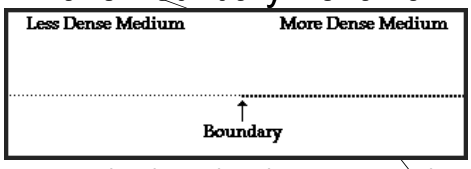
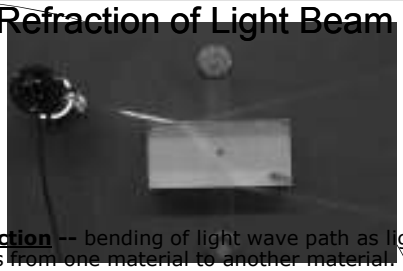
Refraction of Light

Wave Boundary Behavior



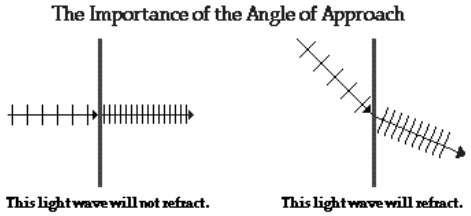
- wave speed and wavelength are greater in less dense medium
- wave frequency is not altered by crossing boundary
- reflected pulse is inverted when wave travels from less dense medium to more dense medium
- incident pulse amplitude is greater than reflected pulse amplitude

Refraction of Light Beam



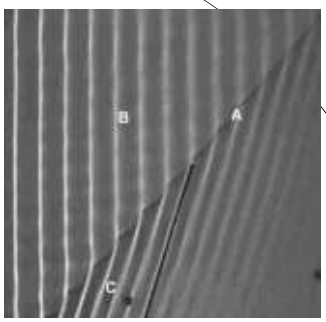
- **Refraction** -- bending of light wave path as light passes from one material to another material.
- Refraction occurs at the boundary and is caused by a change in the speed of the light wave upon crossing the boundary.
- Direction of bending depends upon whether light wave speeds up or slows down at the boundary.

Transmission Across a Boundary



- Wave speed & wavelength change
- When the wave approach is perpendicular to the boundary, its speed changes, but there is no bending of the path

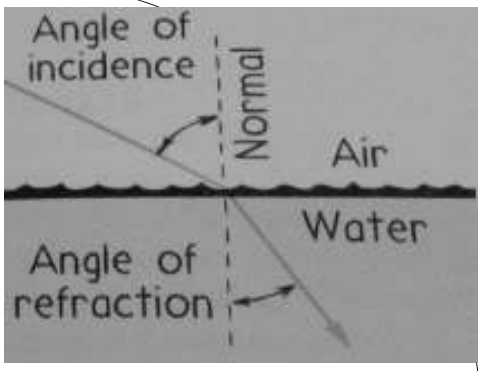
Refraction of Water Waves



Refraction Applets

- Applet by Philip Dukes, Brigham Young
- Applet by National High Magnetic Field Laboratory, Florida State University
- Applet by Fu-Kwung Hwang, National Taiwan Normal University

Ray Diagram



Optical Density

- Optical density -- tendency of the atoms of a material to hold on to absorbed energy from a photon in the form of vibrating electrons before reemitting it as a new photon
- The more optically dense a material is, the slower a wave will move through the material.

Index of Refraction

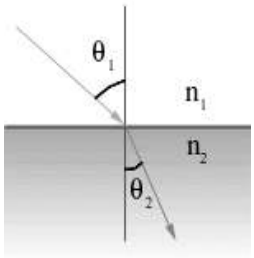
$$n = \frac{c}{v_{material}}$$

- Index of Refraction is a measure of optical density
- Represented by **n**
- The higher n is, the more optically dense the material and the slower light travels in the material

Indices of Refraction

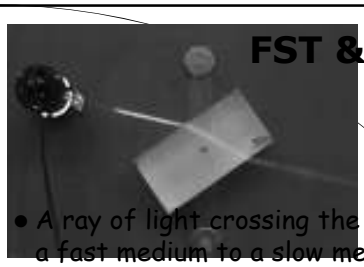
Material	Index of Refraction	
Vacuum	1.0000	<--lowest optical density
Air	1.0003	
Ice	1.31	
Water	1.333	
Ethyl Alcohol	1.36	
Plexiglas	1.51	
Crown Glass	1.52	
Light Flint Glass	1.58	
Dense Flint Glass	1.66	
Zircon	1.923	
Diamond	2.417	
Rutile	2.907	
Gallium phosphide	3.50	<--highest optical density

Law of Refraction
Snell's Law



$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

FST & SFA



- A ray of light crossing the boundary from a fast medium to a slow medium bends toward the normal. **(FST)**
- A ray of light crossing the boundary from a slow medium to a fast medium bends away from the normal. **(SFA)**

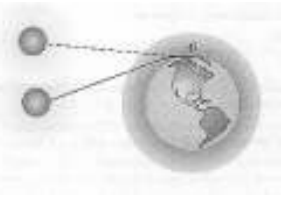
Apparent Depth

- Light exits into medium (air) of lower index of refraction, and turns left.

Spear-Fishing

- Spear-fishing is made more difficult by the bending of light.
- To spear the fish in the figure, one must aim at a spot *in front* of the apparent location of the fish.

Delayed Sunset

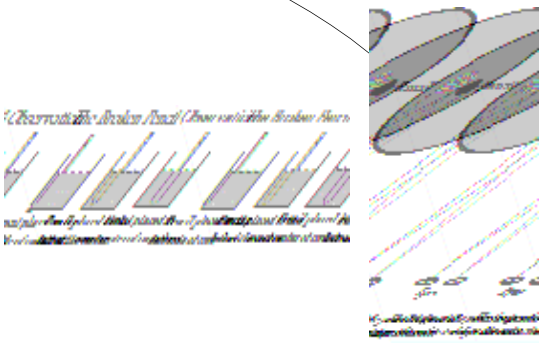


- The sun actually falls below below the horizon
- It "sets", a few seconds before we see it set.

Green Flash

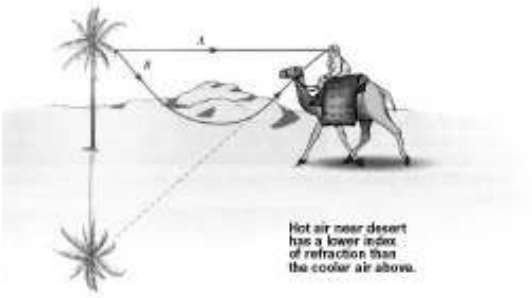
http://www.faqs.org/faqs/astronomy/faq/part3/section-13.html

Broken Pencil

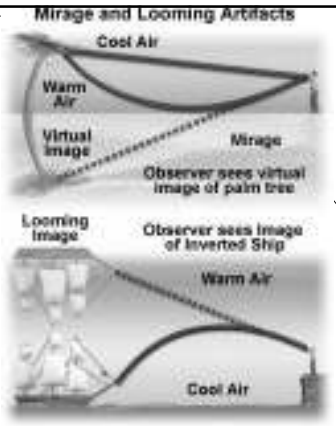


Water on the Road Mirage

Palm Tree Mirage



Mirage Near Dana – Home of Ernie Pyle



Fata Morgana

The fata morgana mirage is one that can occur only where there are alternating warm and cold layers of air near the ground or water surface. Instead of traveling straight through these layers, light is bent towards the colder, more optically dense, air.

Fata Morgana Explanation

The result can be a rather complicated light path and a strange image of a distant object. A fata morgana actually is a superposition of several images of one object. Typically one image is upright more or less above two inverted images that may be mingled together. The images may undergo rapid changes as the air layers move slightly up and down relative to the observer.

In Alaska the best chance of seeing the relatively rare fata morgana is in winter when temperature inversions develop in the larger valleys. When seeing a complex mountain image out across a valley or bay one can attempt to sort out in the mind the paths that the light rays must have taken.