Effect of Index of Refraction on Rays Described by Snell’s Law

- Relates the angles of incident ray and refracted ray to two indices of refraction
- Ray angles measured from line perpendicular to interface
  - called the “surface normal"
  \[ n_1 \sin \theta_1 = n_2 \sin \theta_2 \]
  \[ \Rightarrow n_2 = \frac{n_1 \sin \theta_1}{\sin \theta_2} \]
  (complicated expression)

Angles in Snell’s Law

Snell’s Law for “Rare-to-Dense”

- Change in angle of ray after encountering interface between two media
  \[ n_1 \sin \theta_1 = n_2 \sin \theta_2 \]
  \[ \Rightarrow n_2 = \frac{n_1 \sin \theta_1}{\sin \theta_2} \]
Snell’s Law for “Rare-to-Dense”

- If the speed of light is slower in the second medium \((n_1 < n_2)\), then the angle of the refracted ray is smaller (i.e., the ray moves towards the surface normal)

\[
\frac{n_2}{n_1} = \frac{\sin \theta_1}{\sin \theta_2} > 1 \Rightarrow \frac{\theta_1}{\theta_2} > 1
\]

Snell’s Law for “Dense-to-Rare”

If \(n_1 > n_2\), then the ray angle increases (ray moves away from the surface normal)

Lenses

- Shapes of surfaces are selected to make light at particular locations slows down by specified amounts, which is equivalent to changing the angle of refraction by specific amounts
Ray Description of “Positive” Lens
- Redirect rays to a focus

Wave Description of “Positive” Lens
- Light at center of lens slows down more than light at edges

“Negative” Lenses
- Light at center of lens slows down less than light at edges
- Makes diverging waves diverge more or faster
“Negative” Lenses

Rays appear to diverge from point “behind” the lens, this is a “virtual image.”

“Negative” Lenses

Waves appear to “Diverge” from Image of Source Located “Behind” the Lens (“Virtual” Image)

“Focal Length” of a Lens

For an object at an “infinite” distance away, the distance from the lens to the image is the “focal length” \( f \)
Focal “Points” of a Lens

- Located one focal length distant from lens
  - “Object-space” focal point \( F \), aka “Front” focal point is “in front” of positive lens
  - “Image-space” focal point \( F' \), aka “Rear” focal point is “behind” positive lens

Word Definitions of Focal Points

- Light from an object at an infinite distance from the lens converges to the “image-space” focal point

Focal Length of Positive Lens

- Parallel rays from object located at infinite distance
Focal Length of Negative Lens

Parallel Rays from Object Located at Infinite Distance

F’

Imaging with Lenses

- Distance from Object to Lens is \( z_f \)
- Distance from Lens to Image is \( z_2 \)

- Relate \( f \) to \( z_f \) and \( z_2 \) through the *Imaging Equation*

Imaging with Positive Lens

- \( z_f \leq f \)
- \( z_2 \geq f \)
Imaging with Positive Lens

\[ z_1 = f \]

\[ z_2 = \infty \]

\[ z_1 < f \]

\[ z_2 > f \]

Image

Object