Effect of Index of Refraction on *Rays* Described by Snell's Law

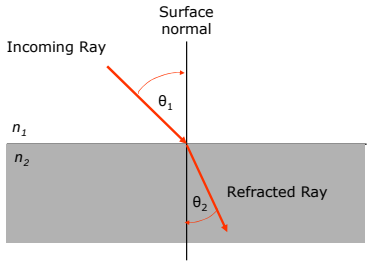
- Relates the angles of incident ray and refracted ray to two indices of refraction
- Ray angles measured from line perpendicular to interface
  - called the "surface normal"

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

$$\Rightarrow \frac{n_2}{n_1} = \frac{\sin\theta_1}{\sin\theta_2}$$

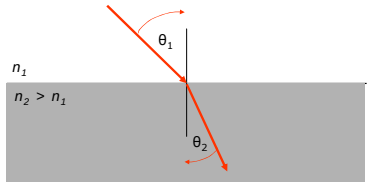
(complicated expression)

Angles in Snell's Law



Snell's Law for "Rare-to-Dense"

- Change in angle of ray after encountering interface between two media



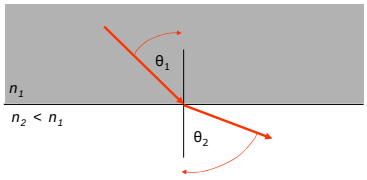
Snell's Law for "Rare-to-Dense"

- 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)

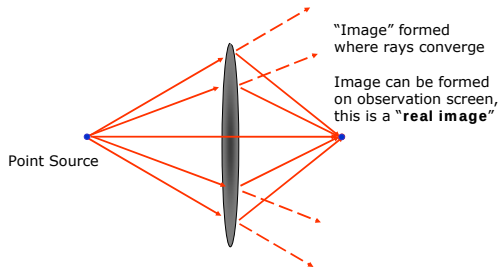


Lenses

- 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

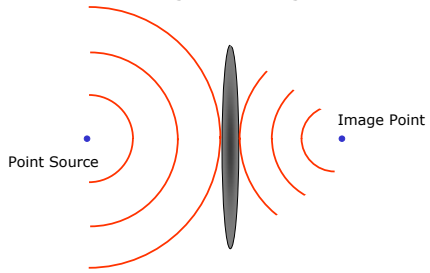
Ray Description of "Positive" Lens

- Redirect rays to a focus



Wave Description of "Positive" Lens

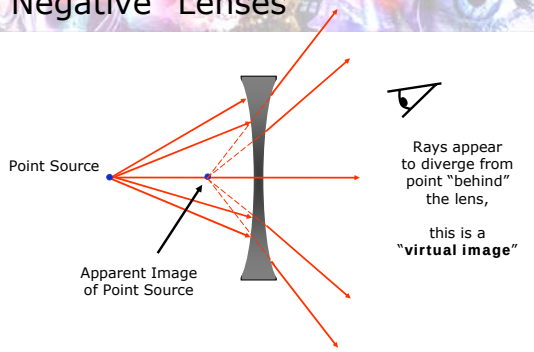
- Light at center of lens slows down more than light at edges



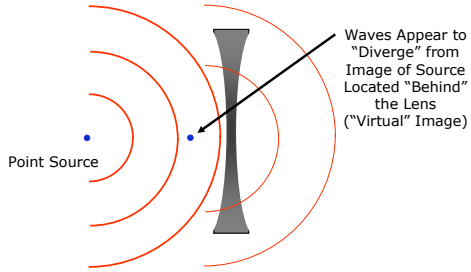
"Negative" Lenses

- Light at center of lens slows down *less* than light at edges
- Makes diverging waves diverge *more* or *faster*

"Negative" Lenses



"Negative" Lenses

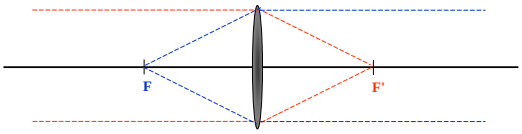


"Focal Length" of a Lens

- 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

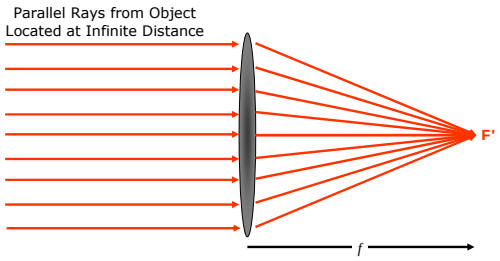
- Located one focal length distant from lens
  - "Object-space" focal point **F**, aka "Front" focal point is "in front" of positive lens
  - "Image-space" focal point **F′**, aka "Rear" focal point is "behind" positive lens



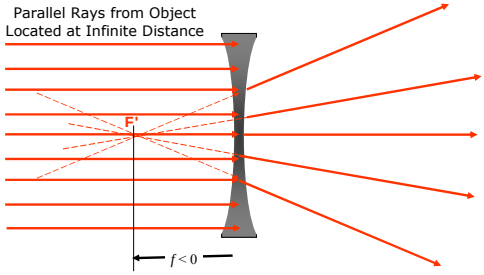
Word Definitions of Focal Points

- Light from an object at an infinite distance from the lens converges to the "image-space" focal point
- Light from a source located at the "object-space" focal point propagates to form an image an infinite distance from the lens

Focal Length of Positive Lens



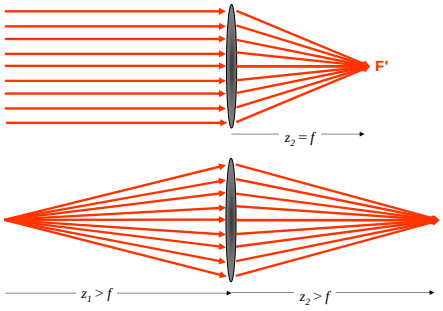
Focal Length of Negative Lens



Imaging with Lenses

- Distance from Object to Lens is z_1
- Distance from Lens to Image is z_2
- Relate f to z_1 and z_2 through the *Imaging Equation*

Imaging with Positive Lens



Imaging with Positive Lens