Geometric Optics (II)
- Lenses
- Finding Images
  - graphically
  - numerically
- How to find focal point+
Snell’s Law

\[ n_1 \sin(\theta_1) = n_2 \sin(\theta_2) \]

That’s all of the physics – everything else is just geometry!
(just like with mirrors)
Two Different Types of Lenses

Converging Lens

Diverging Lens
Converging Lens: Consider the case where the shape of the lens is such that light rays parallel to the axis of the mirror are all “focused” to a common spot a distance $f$ behind the lens:
**Finding Image Graphically (2+ Principle Rays)**

1) Draw ray parallel to axis  
   refracted ray goes through focus

2) Draw ray through center  
   refracted ray is symmetric

3) Draw ray coming in through the focus  
   refracted parallel to axis

You now know the position of the same point on the image
\[ \frac{h_o}{h_i} = - \frac{S}{S'} \]

\[ \frac{h_o}{h_i} = - \frac{S' - f}{f} \]

\[ \frac{1}{f} = \frac{1}{S} + \frac{1}{S'} \]

Same as with mirrors!
Diverging Lens: Consider the case where the shape of the lens is such that light rays parallel to the axis of the lens all diverge but appear to come from a common spot a distance $f$ in front of the lens:

$1/f = 1/S + 1/S'$

Same formula except now $f < 0$
Example 27.1: The spider (again)

Our 2cm tall spider sits 50cm to the left of a double convex (converging) lens with a focal length of 20cm.

Where is the image of the spider formed?
Example 27.2: The spider (moving)

What if our spider moves to 15cm from the lens?

Where is the image of the spider formed?

What good does that do? We’ll see later.....
Calculating the focal length

\[ n_1 \sin \theta_1 = n_2 \sin \theta_2 \]

Small angle approx:
\[ n_1 \theta_1 \approx \theta_2 \]
\[ \alpha = \theta_2 - \theta_1 = (n-1) \theta_1 \]

\[ h/f = \tan \alpha = (n-1) \theta_1 \]

\[ \theta_1 \approx h/R \]

\[ 1/f = (n-1)1/R \]
Example 27.3: Double Convex Focal Length

What is the focal length of this double convex lens if $R_n = 0.75\text{m}$ and $R_f = 1.0\text{m}$? (n glass = 1.5)

$$
1/f = (n-1)(1/R_n - 1/R_f)
$$
Example 27.4: Diverging Focal Length

What is the focal length of this double convex lens if \(|R_n| = |R_f| = 1.0\text{m}\)? (n glass = 1.5)

\[
\frac{1}{f} = (n-1)\left(\frac{1}{R_n} - \frac{1}{R_f}\right)
\]
Example 27.5: Meniscus Focal Length

What is the focal length of this double convex lens if \(|R_f| = 1.0\text{m}\) and \(|R_n| = 0.75\text{m}\)? (n glass = 1.5)

\[
1/f = (n-1)(1/R_n - 1/R_f)
\]
Example 27.5: Meniscus Focal Length

We just found that if the light is coming from the left side, this meniscus lens is converging. What kind of lens would it be if the light were coming from the right?

A) Converging
B) Diverging
C) Neither (the lens doesn’t work if the light comes from the right.)
Example 27.6 (Magnifying glass)

A magnifying glass is used to read the fine print on a document. The focal length of the lens is 10mm.

At what distance from the lens must the document be placed in order to obtain an image magnified by a factor of 5 that is not inverted?

Conceptual Analysis

- Lens Equation: \( \frac{1}{s} + \frac{1}{s'} = \frac{1}{f} \)
- Magnification: \( M = -\frac{s'}{s} \)

Strategic Analysis

- Consider nature of image (real or virtual?) to determine relation between object position and focal point
- Use magnification to determine object position
Mirrors or Lenses, it’s the same formula:

\[
\frac{1}{s} + \frac{1}{s'} = \frac{1}{f} \quad M = -\frac{s'}{s}
\]

You just have to keep the signs straight.

**Mirrors:**

- \(S\): positive if object is “upstream” of mirror
- \(S'\): negative if image is “downstream” of mirror ★
- \(f\): positive if concave mirror

**Lenses:**

- \(S\): positive if object is “upstream” of lens
- \(S'\): positive if image is “downstream” of lens ★
- \(f\): positive if converging lens