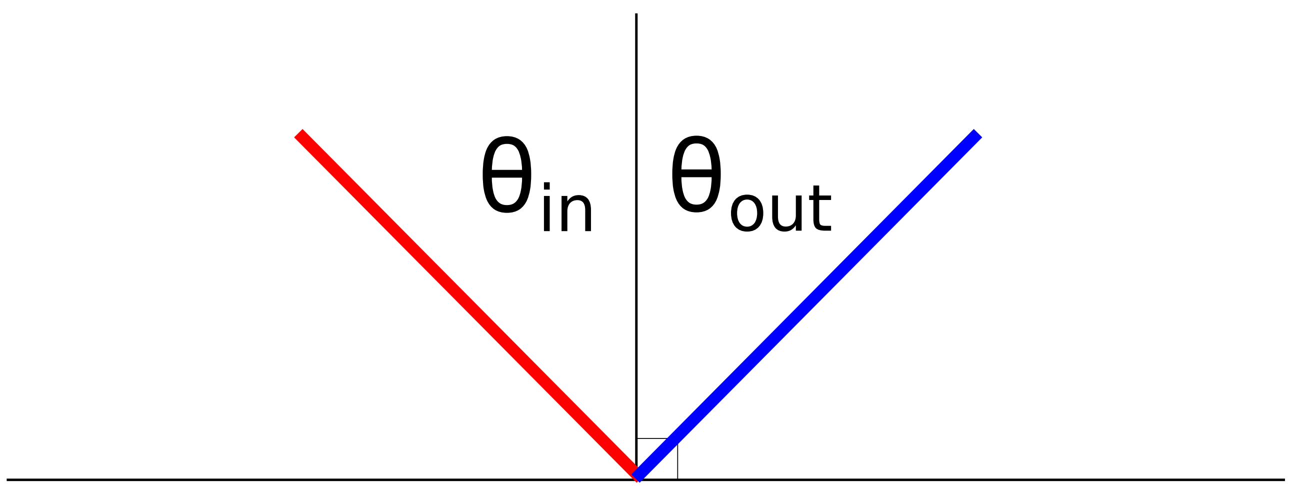
Geometric Optics

- Reflection
- Refraction - Snell's Law
- Mirrors and Lenses
  - Thin Lens Equation
  - Magnification
  - Lensmaker's Formula
- Other topics
  - Telescopes
  - Apertures

Reflection

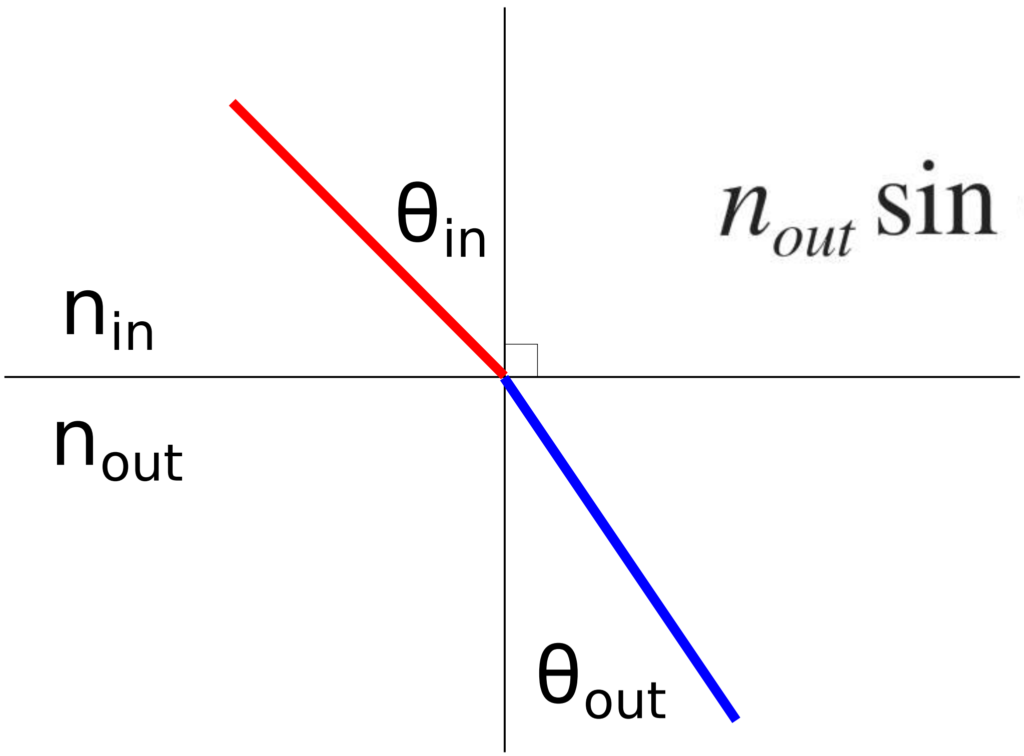
- Angle of incidence equals angle of reflection

$$\theta_{in} = \theta_{out}$$



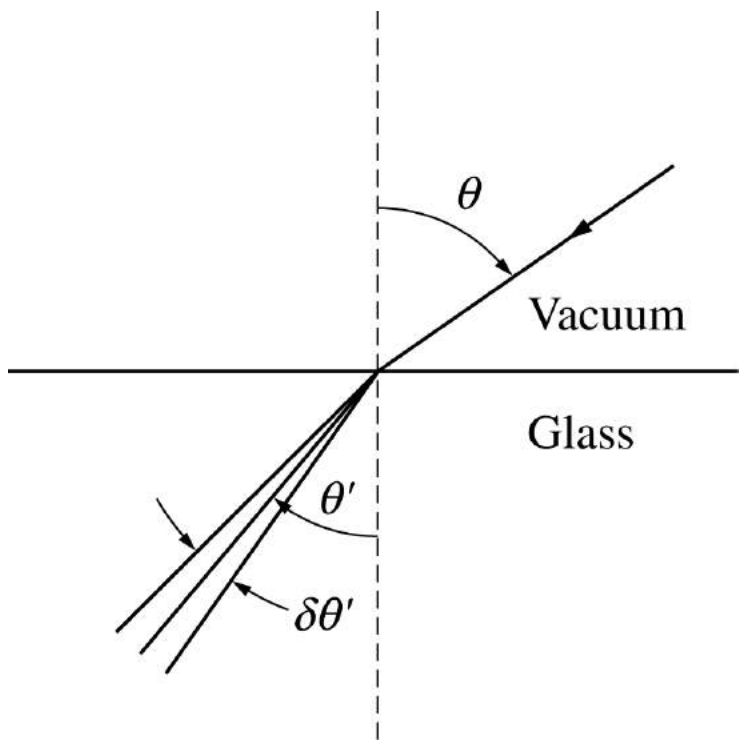
Snell's Law

- Relates angle of incidence to angle of refraction
  - *n* represents **refraction index** of material
  - Can change depending on light wavelength



$$n_{out} \sin(\theta_{out}) = n_{in} \sin(\theta_{in})$$

Snell's Law



97. A beam of light has a small wavelength spread $\delta\lambda$ about a central wavelength λ. The beam travels in vacuum until it enters a glass plate at an angle θ relative to the normal to the plate, as shown in the figure above. The index of refraction of the glass is given by $n(\lambda)$. The angular spread $\delta\theta'$ of the refracted beam is given by

(A) $\delta\theta' = \left| \frac{1}{n} \delta\lambda \right|$

(B) $\delta\theta' = \left| \frac{dn(\lambda)}{d\lambda} \delta\lambda \right|$

(C) $\delta\theta' = \left| \frac{1}{\lambda} \frac{d\lambda}{dn} \delta\lambda \right|$

(D) $\delta\theta' = \left| \frac{\sin\theta}{\sin\theta'} \frac{\delta\lambda}{\lambda} \right|$

(E) $\delta\theta' = \left| \frac{\tan\theta'}{n} \frac{dn(\lambda)}{d\lambda} \delta\lambda \right|$

Thin Lens Equation

- This is the only equation you need, provided you can interpret it correctly

$$\frac{1}{O}+\frac{1}{I}=\frac{1}{F}$$

- O = object distance from lens
- I = image distance from lens
- F = focal point distance from lens

Thin Lens – Getting Signs Right

$$\frac{1}{O} + \frac{1}{I} = \frac{1}{F}$$

- Sign conventions (why this is nontrivial)
  - A is where light **comes from**, B is where light **passes to**
  - Note side B is different for mirrors and lenses

$$O\begin{cases} >0 \;\; if \;\; on \;\; side \;\; A \\ <0 \;\; if \;\; on \;\; side \;\; B \end{cases} \qquad I,F\begin{cases} <0 \;\; if \;\; on \;\; side \;\; A \\ >0 \;\; if \;\; on \;\; side \;\; B \end{cases}$$

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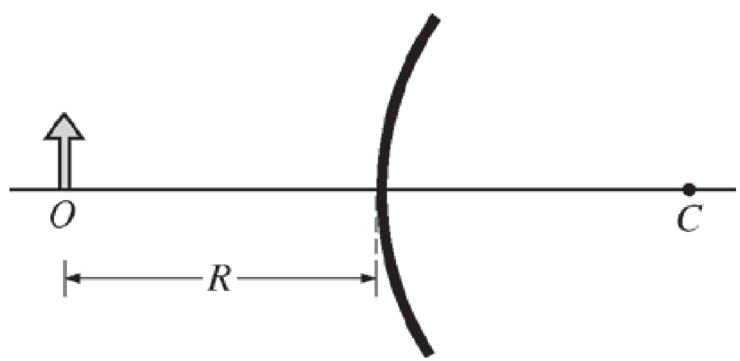
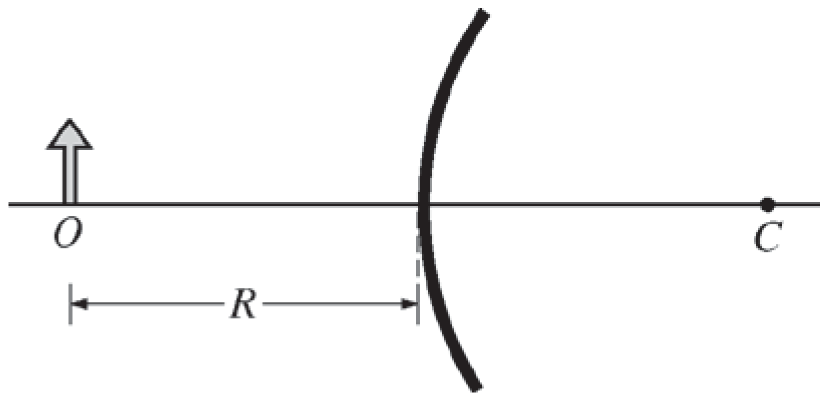
- Recommend picking on case to memorize
  - O > 0
  - F > 0
  - I = ?



Thin Lens Example



74. The figure above shows an object O placed at a distance R to the left of a convex spherical mirror that has a radius of curvature R. Point C is the center of curvature of the mirror. The image formed by the mirror is at

(A) infinity

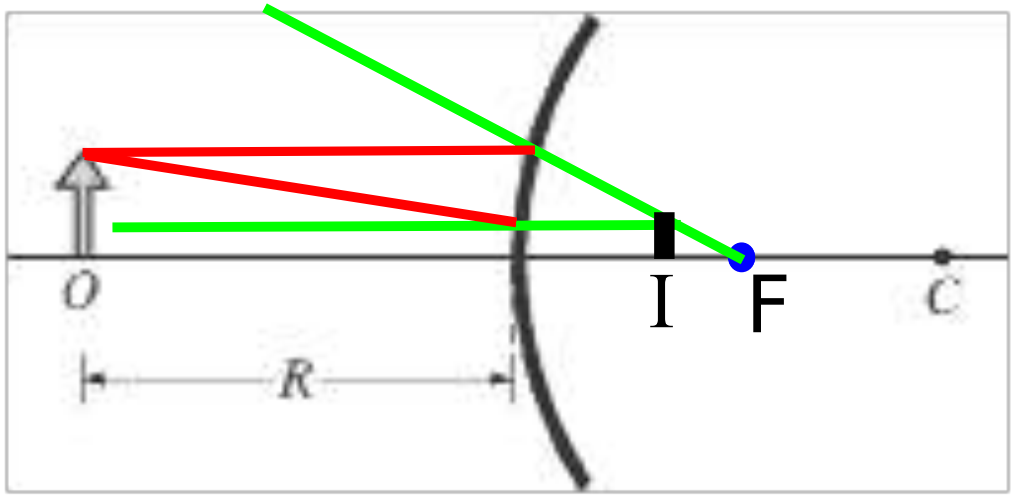
(B) a distance R to the left of the mirror and inverted

(C) a distance R to the right of the mirror and upright

(D) a distance $\frac{R}{3}$ to the left of the mirror and inverted

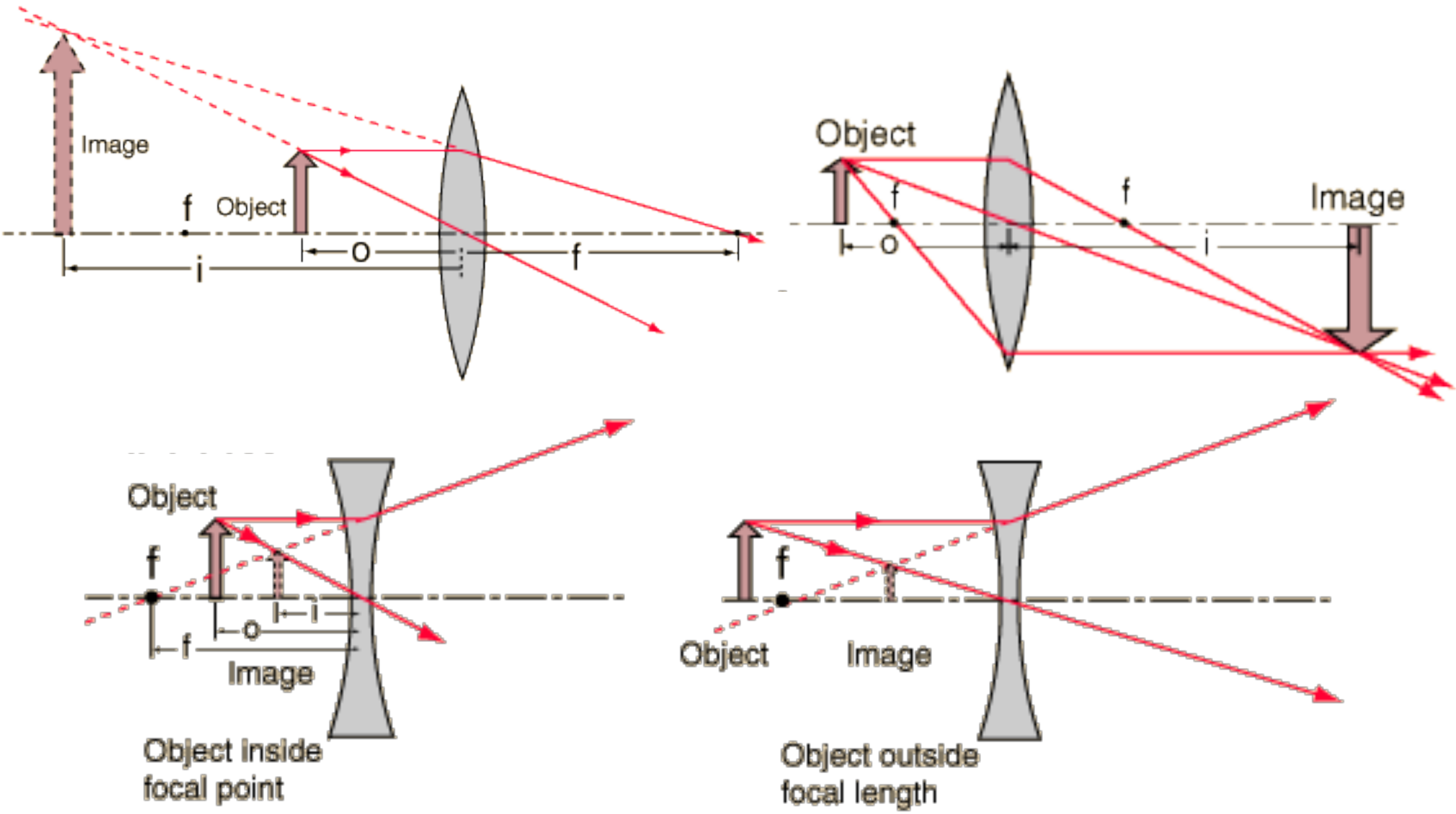
(E) a distance $\frac{R}{3}$ to the right of the mirror and upright

Thin Lens Example – Ray Diagram



- Draw rays to get qualitative sense of image
  - Rays from object to focus reflect parallel
  - Parallel rays from object reflect from focus
  - Rays from object to center reflect at equal angle
- Same deal for lenses, but with passing through

Example Ray Diagrams - Lenses



http://hyperphysics.phy-astr.gsu.edu/%E2%80%8Chbase/geoopt/raydiag.html

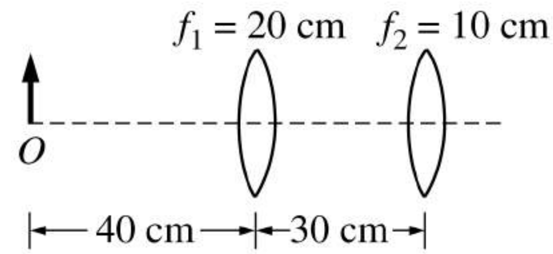
Magnification

- Magnification is image size relative to object
  - Image is “imaginary” if not in real space ($I < 0$)
  - Image is “real” if projected into real space

$$M \equiv \frac{-I}{O}$$

One more example: Multiple Lenses

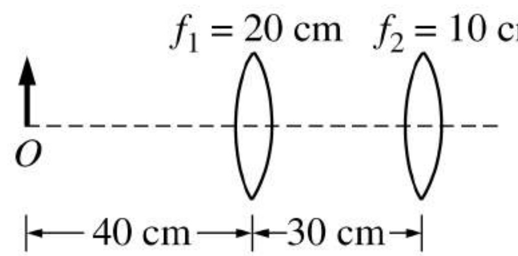
- Treat the image from the first lens as a virtual object
  - 1. Find the image from the first lens
  - 2. Use geometry to find O for the second lens
  - 3. Apply lens equation a second time



11. An object is located 40 centimeters from the first of two thin converging lenses of focal lengths 20 centimeters and 10 centimeters, respectively, as shown in the figure above. The lenses are separated by 30 centimeters. The final image formed by the two-lens system is located

(A) 5.0 cm to the right of the second lens
(B) 13.3 cm to the right of the second lens
(C) infinitely far to the right of the second lens
(D) 13.3 cm to the left of the second lens
(E) 100 cm to the left of the second lens

Multiple lenses



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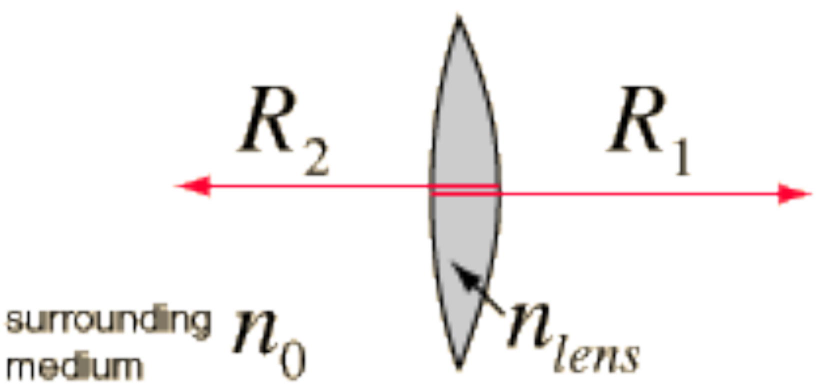
- First lens: O = 40 cm, F = 20 cm, I = ?
- Second lens: F = 10 cm, O = ?, I = ?

Lensmaker's formula

- Find the focal point, given the radii of the two faces of the lens

$$\frac{1}{f} = \left(\frac{n}{n_{out}}\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$



http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html

15. If the five lenses shown below are made of the same material, which lens has the shortest positive focal length?

Telescopes

- Telescope angular magnification
  - f_E: Focal length of eyepiece
  - f_O: Focal length of objective
  - Note: The two lenses share a focal point

$$M = \frac{f_o}{f_e}$$

22 A simple telescope consists of two convex lenses, the objective and the eyepiece, which have a common focal point P, as shown in the figure above. If the focal length of the objective is 1.0 meter and the angular magnification of the telescope is 10, what is the optical path length between objective and eyepiece?

(A) 0.1 m
(B) 0.9 m
(C) 1.0 m
(D) 1.1 m
(E) 10 m