Lenses

Physics 2415 Lecture 33

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Today's Topics

- A bit more about mirrors…
- Refraction
- Lenses
- Ray tracing to locate image

Concave Mirror Focusing Sunlight

- This solar collector is really many small flat mirrors, but equivalent to a concave mirror focusing parallel rays to a point half way from the center of the mirror to its center of curvature.

First Military Use of Concave Mirror?

- **Archimedes** is said to have used mirrors to **burn up ships** attacking his city.

- Despite this picture, he probably used **many flat mirrors**, each held by a soldier.
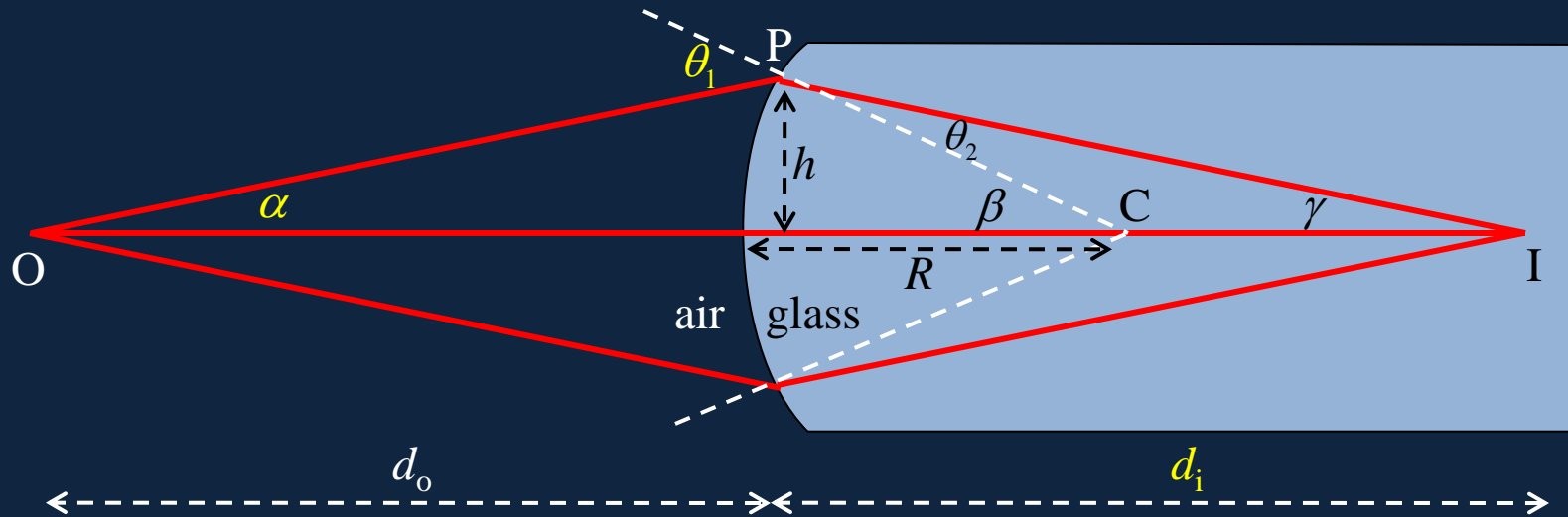
- Recent reenactments have shown this to be possible.

Don't sit by the pool for long at this hotel…

- *I'm sitting there in the chair and all of the sudden my hair and the top of my head are burning. I'm rubbing my head and it felt like a chemical burn. I couldn't imagine what it could be.*

- Local media, as well as some hotel staff and guests, have come to refer to the reflection as the "death ray," but MGM Resorts officials prefer to call it a "solar convergence phenomenon."
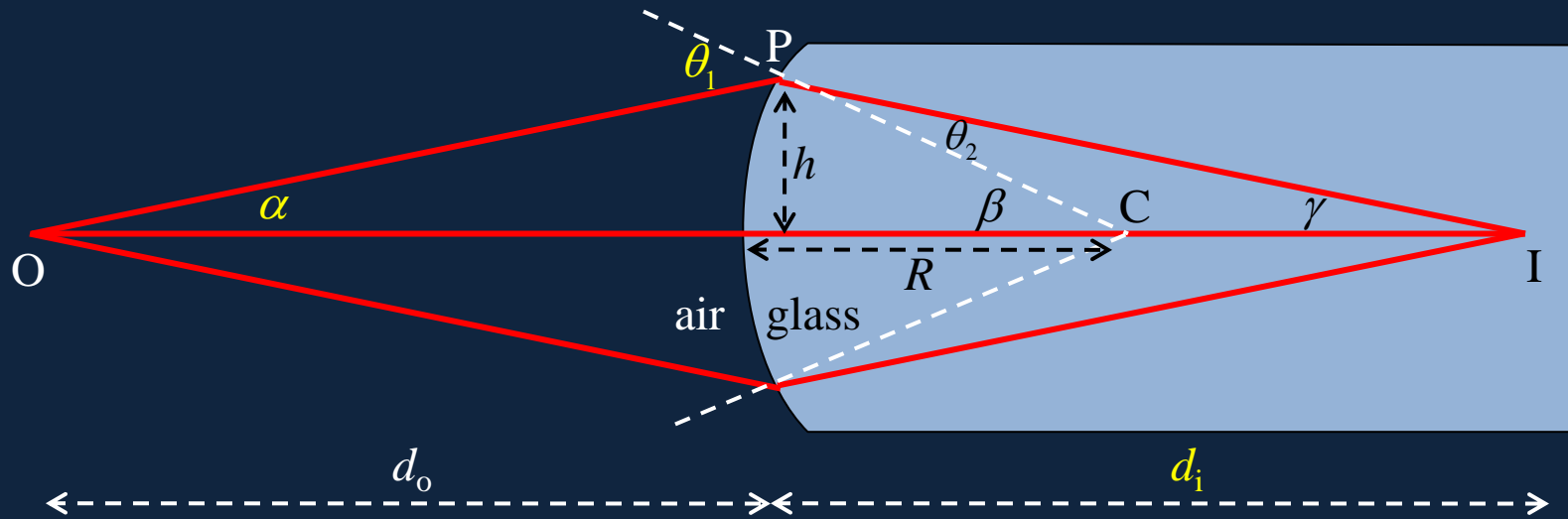
Refraction at a Spherical Surface

- Rays close to the axis ("paraxial") will focus to an image inside the glass:

- From $\theta_1 = n\theta_2 = \alpha + \beta = \alpha + \theta_2 + \gamma, \ h = d_o\alpha = R\beta = d_i\gamma$ we can show that $\dfrac{1}{d_o} + \dfrac{n}{d_i} = \dfrac{n-1}{R}$

Proof of formula

$$\theta_1 = n\theta_2 = \alpha + \beta = \alpha + \theta_2 + \gamma, \quad h = d_o\alpha = R\beta = d_i\gamma$$

$$\theta_1 = \alpha + \beta = \frac{h}{d_o} + \frac{h}{R}, \quad (n-1)\theta_2 = \alpha + \gamma = \frac{h}{d_o} + \frac{h}{d_i}$$

$$\theta_1 = n\theta_2 : \quad \frac{h}{d_o} + \frac{h}{R} = \left(\frac{n}{n-1}\right)\left(\frac{h}{d_o} + \frac{h}{d_i}\right) \quad \longrightarrow \quad \frac{1}{d_o} + \frac{n}{d_i} = \frac{n-1}{R}$$
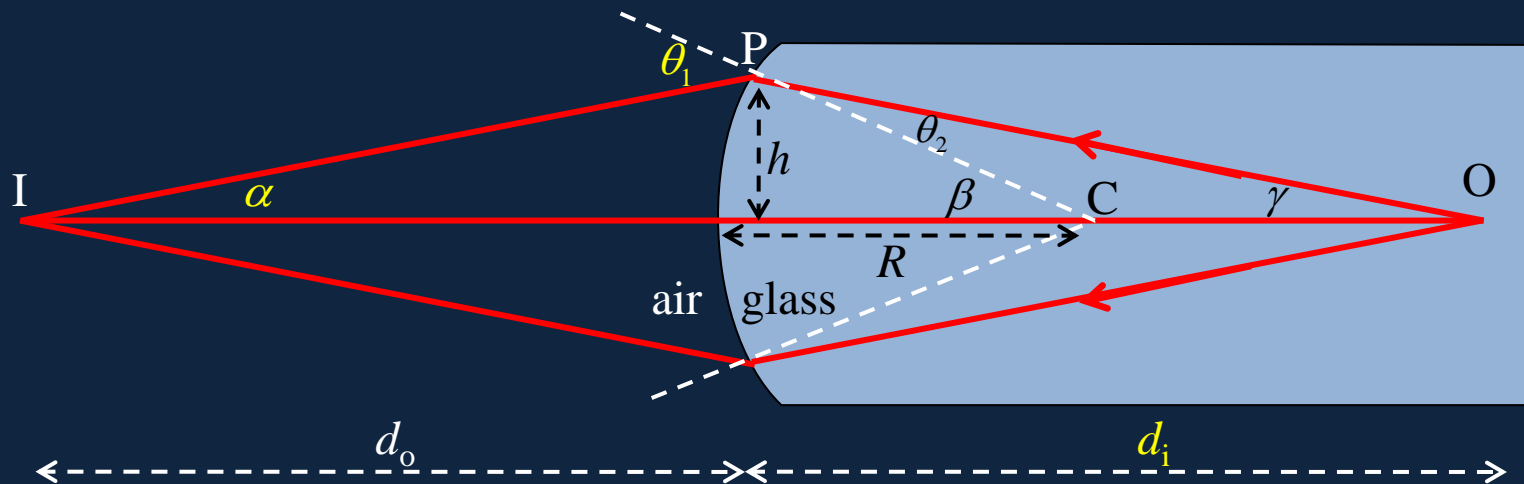
Clicker Question

- Is it possible for an object embedded in a solid glass sphere to have a real image outside the sphere?

A. Yes

B. No

Clicker Answer

- Is it possible for an object embedded in a solid glass sphere to have a real image outside the sphere?
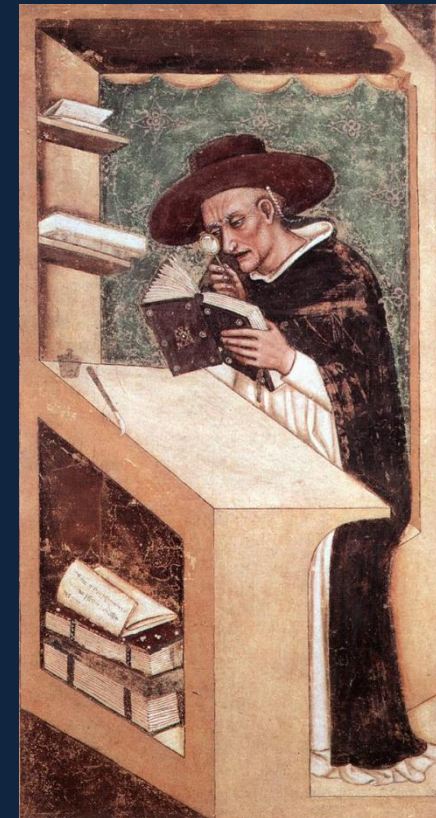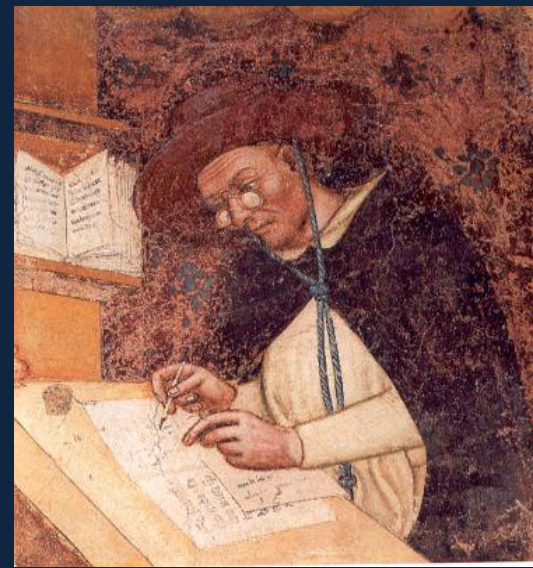
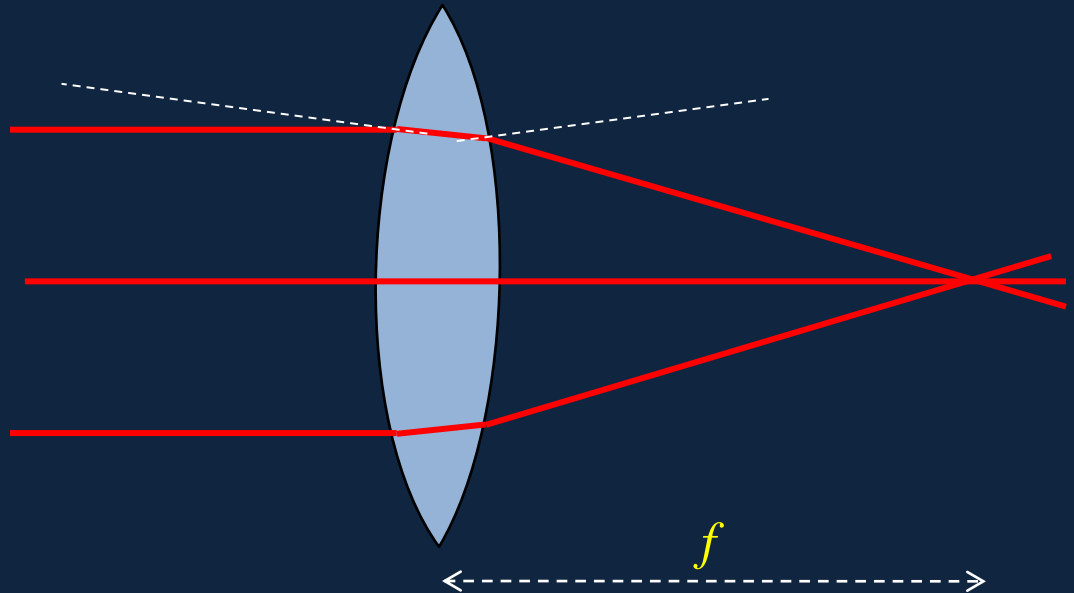A. Yes: just <u>reverse</u> the rays in the figure. ←

B. No

Lenses

- Although lenses were used much earlier as burning glasses, the first use for reading and writing was by monks in the 1200's, correcting farsightedness with convex lenses, and greatly extending their productive life—many worked on illuminated manuscripts.

- The first person to understand how glasses worked was Kepler. The inventor of <u>bifocals</u> was Benjamin Franklin.
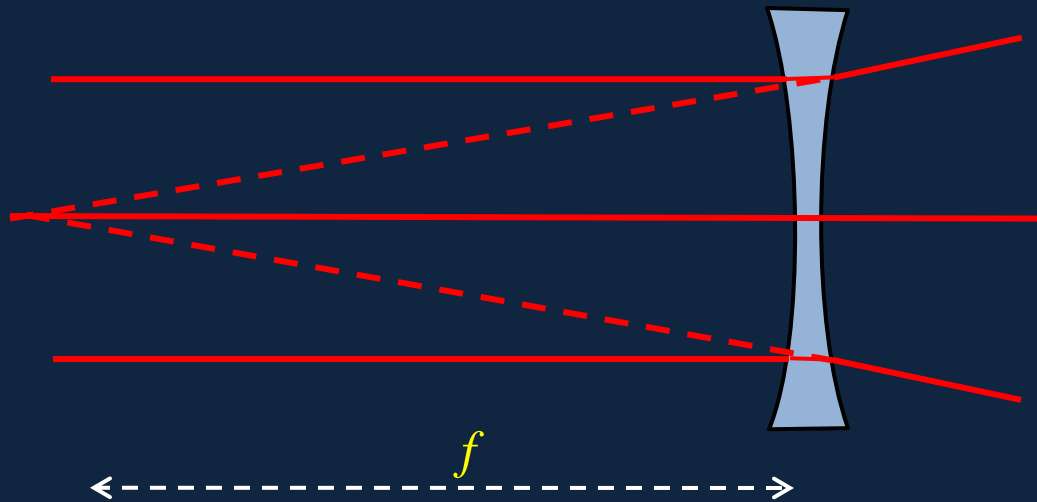
Ray Tracing for a Thin Convex Lens

- Here we consider only thin lenses (thin compared with radius of curvature of faces).

- This means that we can approximate: for example, we take the ray through the center of the lens to be unshifted (not quite true if it's at an angle).

- Parallel rays are brought to a focus at distance f :

Note that the refraction on entering the glass is towards the normal there, on going out of the glass away from the normal—but *both* refractions help focus the ray.

f

Thin Concave Lens

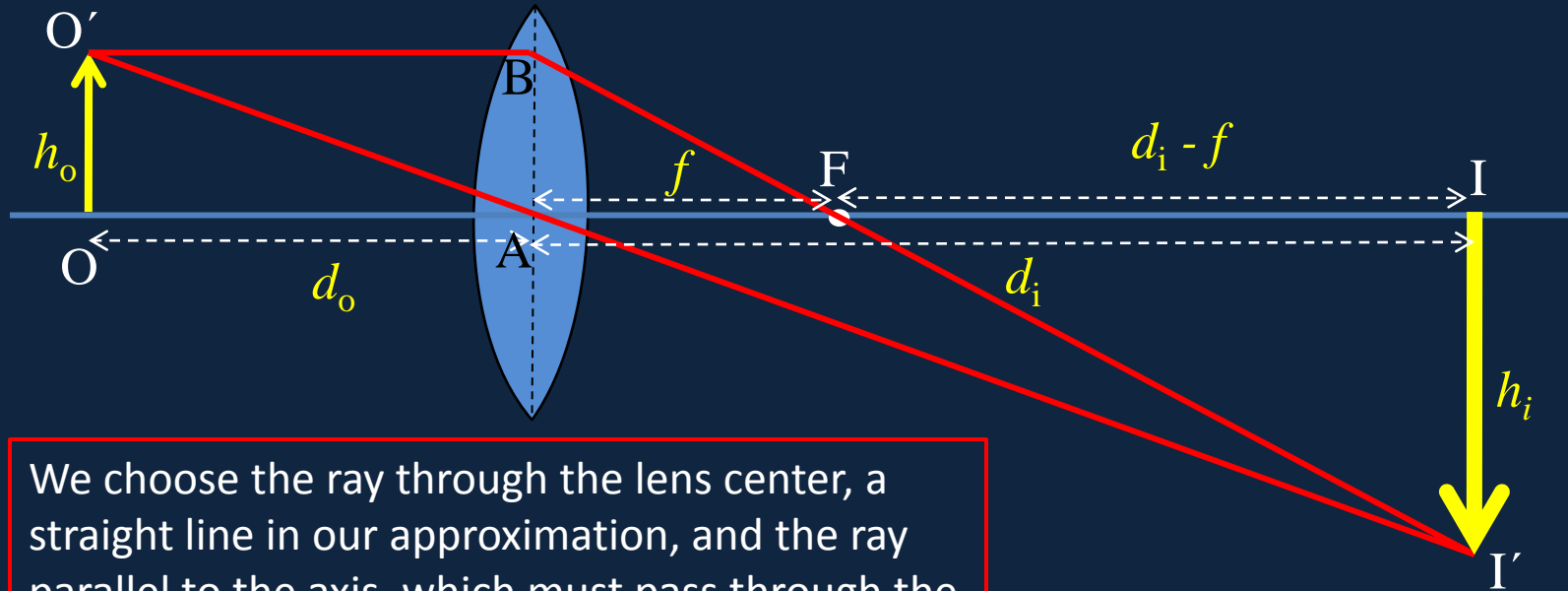- A concave (diverging) lens causes parallel ingoing rays to appear to come from a single point:

f

The optometrist measure of lens power is the diopter, the inverse of the focal length f in meters, negative for a diverging lens: if f above $=25$cm, the lens power $P = -4\mathrm{D}$

Image Location by Ray Tracing

- The rules we use for thin lenses:

1. We take the ray through the center of the lens to be undeflected and unshifted.

2. For a convex lens, rays passing through a focus on one side come out parallel on the other side.

3. For a concave lens, rays coming in parallel on one side are deflected so they apparently come from the focal point on that same side.

Ray Tracing for a Thin Convex Lens

O′

B

h_o

f F d_i - f   I

O   A

d_o d_i

h_i

I′

We choose the ray through the lens center, a straight line in our approximation, and the ray parallel to the axis, which must pass through the focus when deflected. They meet at the image.
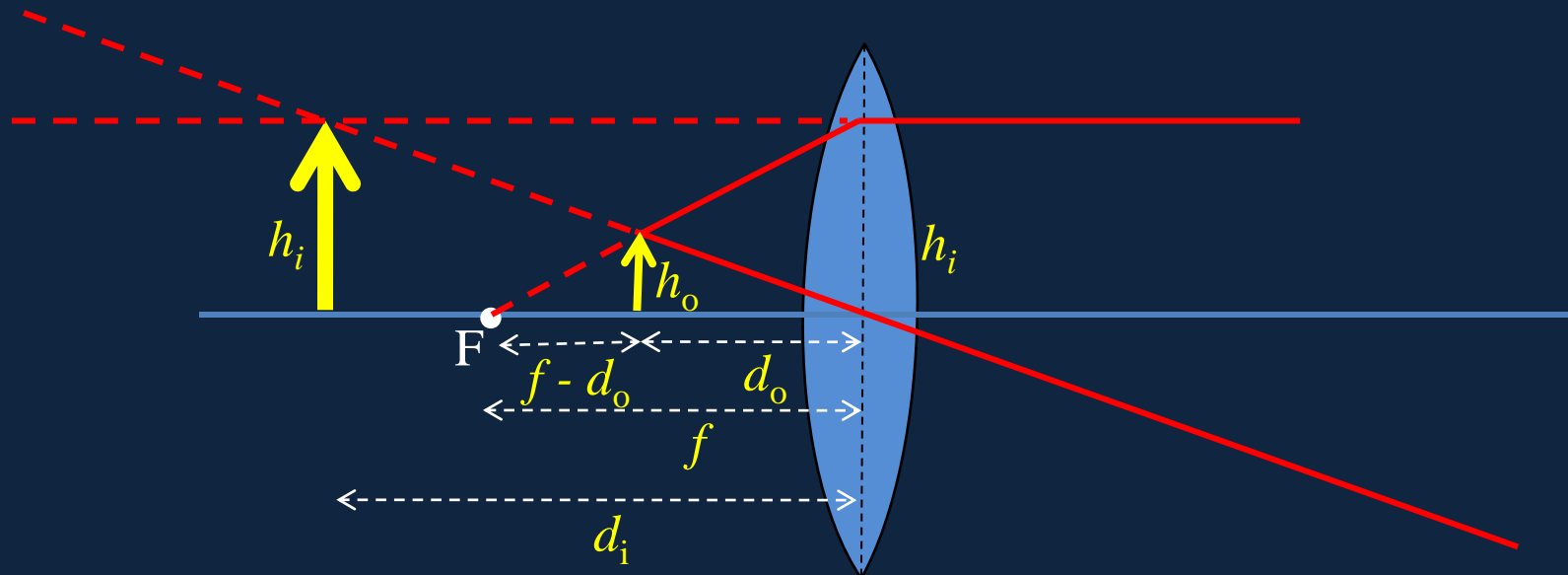
From the straight line through the center A $\; h_o / h_i = d_o / d_i$
from the line BFI′ $\; h_o / h_i = \mathrm{BA} / h_i = f / (d_i - f)$

This gives immediately:
$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

Convex Lens as Magnifying Glass

- The object is closer to the lens than the focal point F. To find the virtual image, we take one ray through the center (giving $h_i / h_o = d_i / d_o$) and one through the focus near the object ($h_i / h_o = f / (f - d_o)$), again $1/d_o + 1/d_i = 1/f$ but now the (virtual) image distance is taken <u>negative</u>.
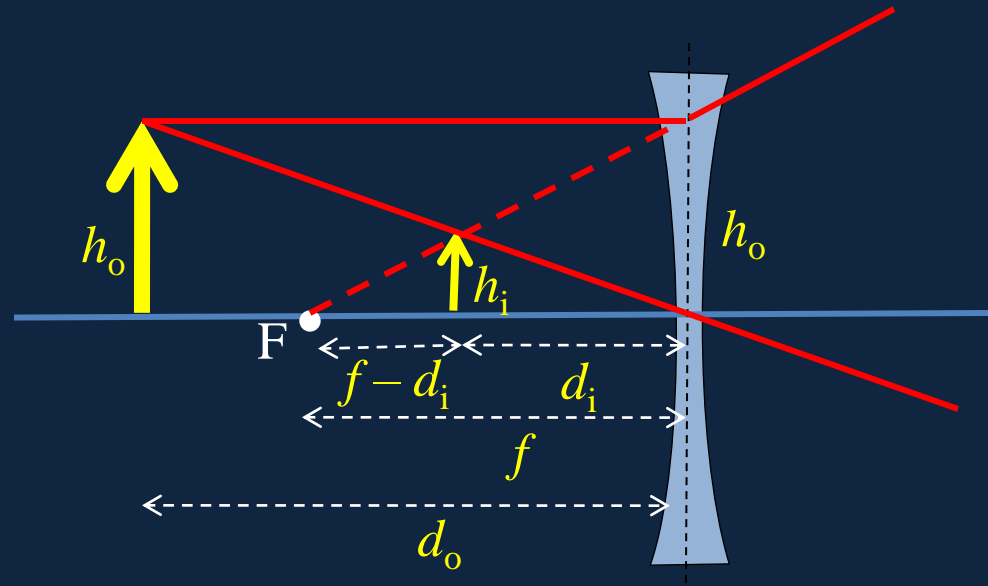
Diverging (Concave) Lens

- The same similar triangles arguments here give

$$\frac{h_o}{h_i} = \frac{d_o}{d_i} = \frac{f}{f - d_i}$$

from which

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

provided we now take both d_i and f as <u>negative!</u>

Formula Rules

- The formula

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

is valid for any thin lens.

- For a converging lens, f is positive, for a diverging lens f is negative.

- The object distance d_o is positive.

- The image distance d_i is positive for a real image, negative for a virtual image.

Note: the object distance d_o can be negative if the object is itself a virtual image created by another lens, such as a convex lens followed immediately by a concave lens.

Real Image Conditions

A concave lens (acting by itself, not in conjunction with other lenses) can form a real image if:

1) The object is closer than the focal length

2) The object is beyond the focal length

3) Never

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Just imagine

A convex lens produces an image of a large object. The top half of the lens is now covered. How does that affect the image?

1) The top half of the image goes away.

2) The bottom half of the image goes away.

3) The whole image is still there, but dimmer.

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