Physics 9 — Monday, October 8, 2018

- I found a way to run both Odeon and CATT-Acoustic on MacOS without a virtual machine! Stay tuned.
- For today, you read Giancoli ch10 (fluids)
- For Wednesday, read PTFP ch2 (atoms & heat)
- HW4 due Friday (Oct 12)
- If you'd like to do some extra-credit reading on Architectural Acoustics, you can read one or more chapters of a nicely illustrated (more drawings, less text) textbook I have (by Egan). For each chapter you read, you can collect extra credit by writing a few paragraphs (1–2 pages) to summarize what you learned from the chapter. Email me if you're interested.

"Blackboard optics"

- mirrors & rectangular block
- Converging & diverging lens
- Notice that paths that converge all take same time!
- Measure f for converging lens
- Ray tracing with laser: $d_o = 2f, \quad d_o = 3f, \quad d_o = \frac{3}{2}f$
- Big lens: $f \approx 40\ \mathrm{cm}$. Try $d_o = 2f$.

The usual mirror/lens equation still works!

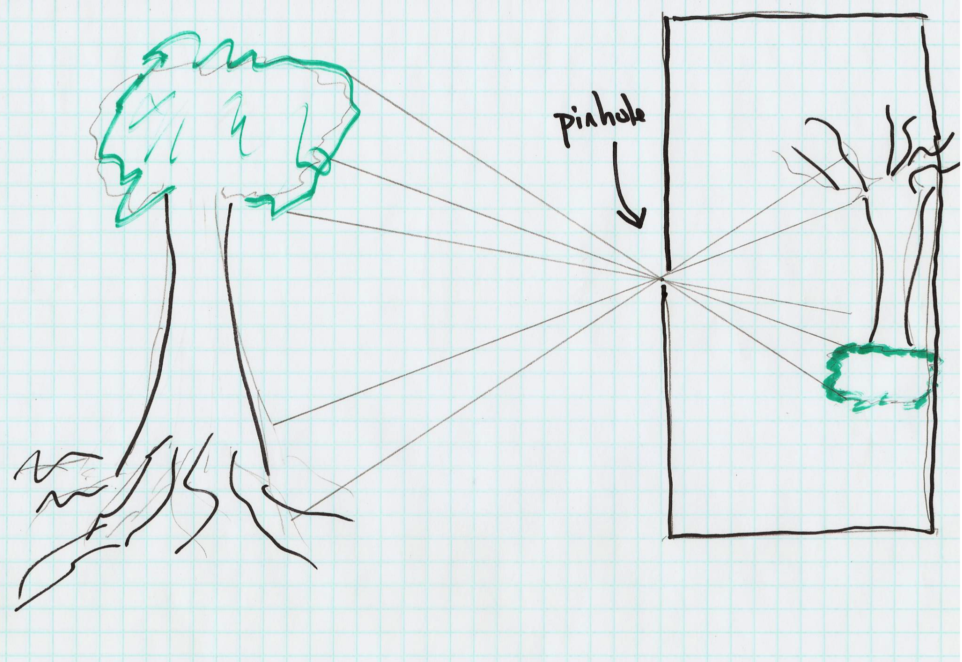
$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \qquad\qquad \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

Solve for d_i and h_i:

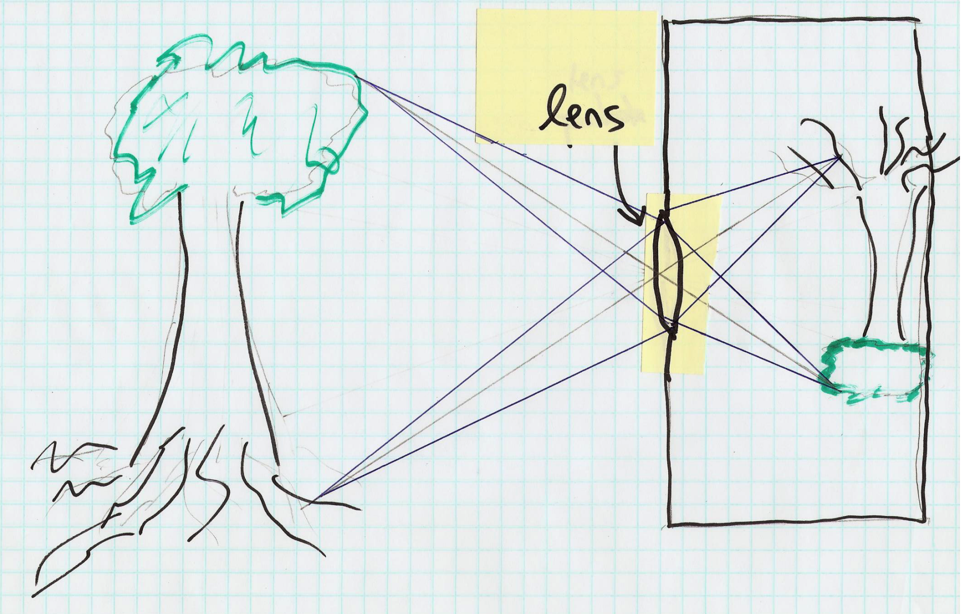
$$d_i = \frac{d_o f}{d_o - f} \qquad\qquad h_i = \frac{h_o f}{f - d_o}$$

But now $d_i > 0$ ("real image") means the **far side** of the lens!

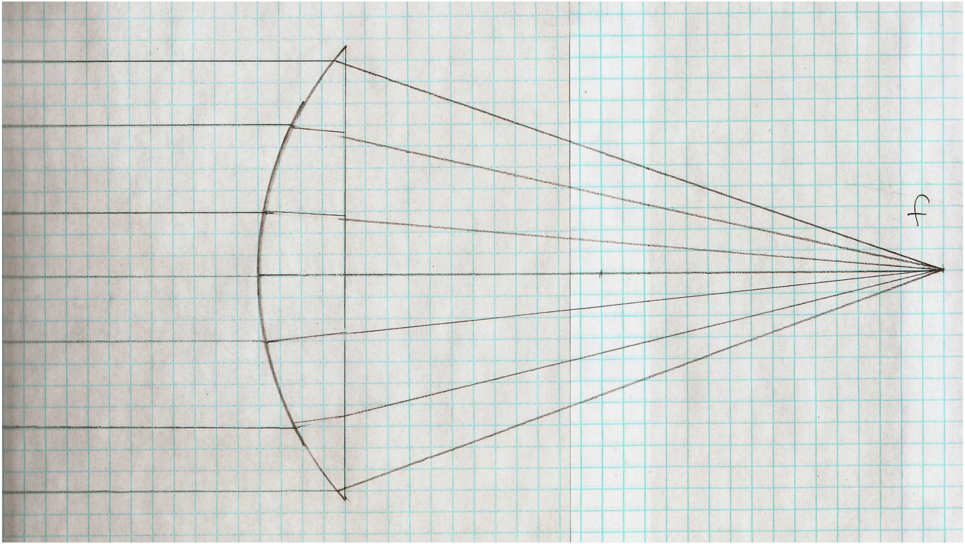
Pinhole camera



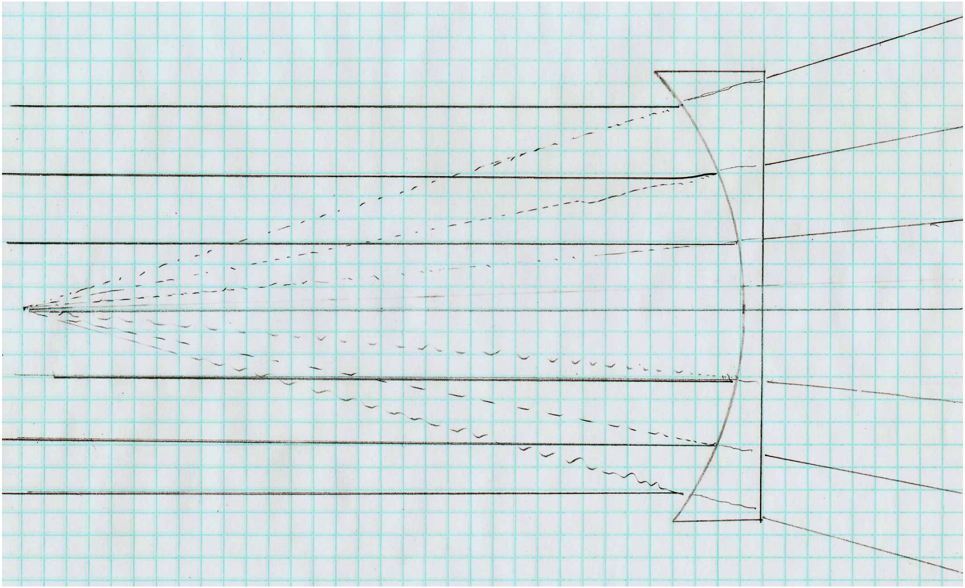
Pinhole $\rightarrow$ lens: collect *much* more light at each point on image. Light $\sim$ area $\sim \pi r^2$



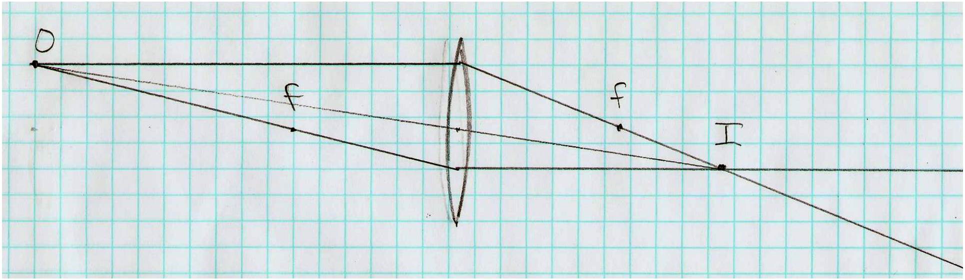
Converging lens: parallel rays focus on RHS ($f > 0$)



Diverging lens: parallel rays "focus" on LHS ($f < 0$)



The trick for finding the image point graphically: draw the easy-to-draw rays ("principal rays"), and see where they meet.



For thin converging lens, what comes in parallel to axis on LHS must pass through focus on RHS. What passes through focus on LHS must exit parallel to axis on RHS. What passes through the point at center of lens does not bend.

(There are analogous tricks for mirrors, thin diverging lenses, but thin converging lens is most useful case to remember.)

Lens/mirror equations:

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \qquad \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

Solve them for d_i and h_i:

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

Let's put an object a distance $d_o = 2f$ from a converging lens. (Light bulbs & big lens.)

At what distance d_i does the image appear?

(a) $-3f$ (b) $-2f$ (c) $-f$ (d) $-f/2$

(e) $f/2$ (f) f (g) $2f$ (h) $3f$

Lens/mirror equations:

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$\boxed{d_i = 2f}$. Which side of the lens is that? Is it real or virtual?

Lens/mirror equations:

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \qquad \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

Solve them for d_i and h_i:

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

Let's put an object a distance $d_o = 2f$ from a converging lens.
So $d_i = 2f$.

What is the "magnification" h_i/h_o of the image?

(a) $1/2$ (b) 1 (c) 2 (d) $-1/2$ (e) -1 (f) -2

Lens/mirror equations:

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \qquad \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

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Let's put an object a distance $d_o = 2f$ from a converging lens. So $d_i = 2f$.

What is the "magnification" h_i/h_o of the image?

(a) 1/2 (b) 1 (c) 2 (d) −1/2 (e) −1 (f) −2

$\boxed{h_i/h_o = -1}$. Is that upright or inverted? Enlarged? Reduced? Let's try it.

Lens/mirror equations:

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \qquad \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

Solve them for d_i, for d_o, and for h_i:

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

Now suppose we want to project an image of these two light bulbs onto the far wall, as if this were a movie projector. Do I move the bulbs closer to or farther from the lens?

Lens/mirror equations:

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \qquad \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

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Now suppose we want to project an image of these two light bulbs onto the far wall, as if this were a movie projector. Do I move the bulbs closer to or farther from the lens?

If the screen is at $d_i = 11f$ from the lens, how far d_o should the "film" be from the lens?

(a) $0.5f$ (b) $1.0f$ (c) $1.1f$ (d) $1.5f$ (e) $2f$

Lens/mirror equations:

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \qquad \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

Solve them for d_i, for d_o, and for h_i:

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

If the screen is "far, far away" ($d_i = \infty$), how far d_o should the "film" be from the lens?

(a) $0.5f$ (b) $1.0f$ (c) $1.1f$ (d) $1.5f$ (e) 0

Lens/mirror equations:

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \qquad\qquad \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

Solve them for d_i and h_i:

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

What happens if we place the object closer than f to the lens: $0 < d_o < f$? Where is the image now? For example, if $d_o = f/2$, then what is d_i ?

(a) $-0.5f$ (b) $0.5f$ (c) $-1.0f$ (d) $1.0f$ (e) 0

Lens/mirror equations:

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Which side of the lens is this? Is it real or virtual?

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(a) $-0.5f$ (b) $0.5f$ (c) $-1.0f$ (d) $1.0f$ (e) 0

Which side of the lens is this? Is it real or virtual?

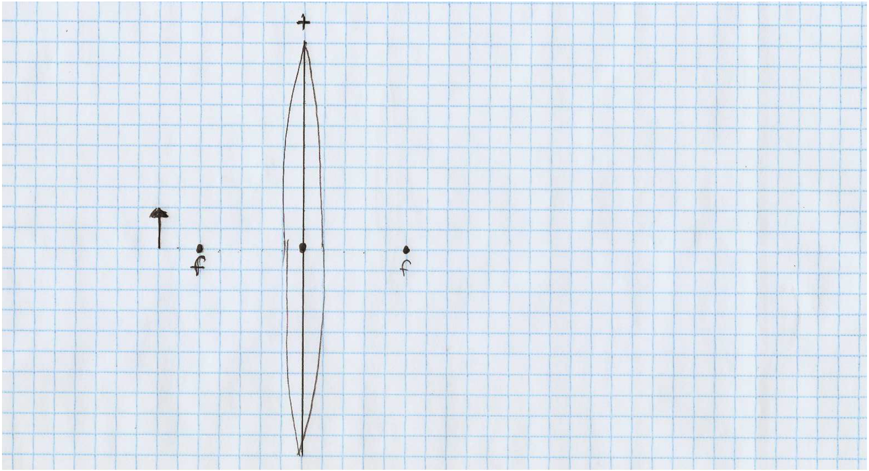
What is h_i/h_o ? Enlarged/reduced? Upright/inverted?

Solve lens/mirror equations for d_i and h_i:

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

You're using a magnifying glass of focal length f to read a telephone book. How far from the page should you hold the lens in order to see the print enlarged $3\times$?

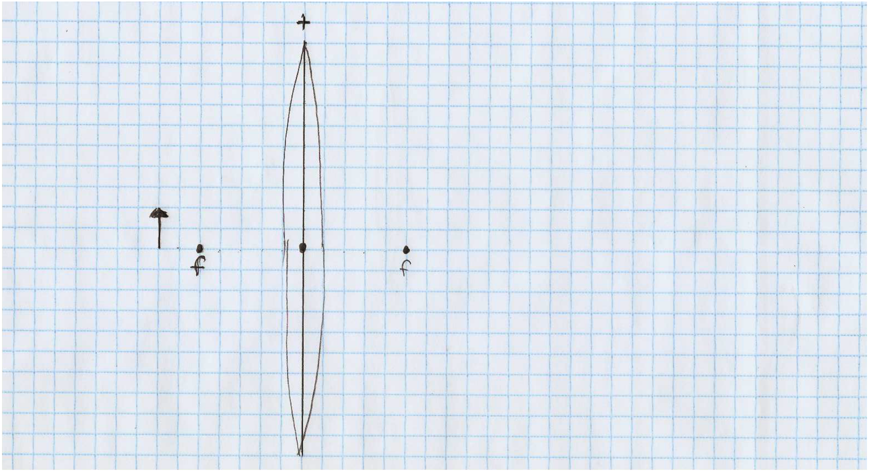
(a) f (b) $\frac{1}{2}f$ (c) $\frac{2}{3}f$ (d) $\frac{3}{4}f$



$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \quad , \quad \frac{h_i}{h_o} = -\frac{d_i}{d_o} \quad \Rightarrow \quad d_i = \frac{d_o f}{d_o - f} \quad , \quad \frac{h_i}{h_o} = \frac{f}{f - d_o}$$

For what values of d_o is the image inverted/upright? Real/virtual?

An object is placed 7 m to the left of a converging lens having focal length $f = 5$ m. Where does the image form?



Let's try the equations first this time.

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \quad , \quad \frac{h_i}{h_o} = -\frac{d_i}{d_o} \quad \Rightarrow \quad d_i = \frac{d_o f}{d_o - f} \quad , \quad h_i = \frac{h_o f}{f - d_o}$$

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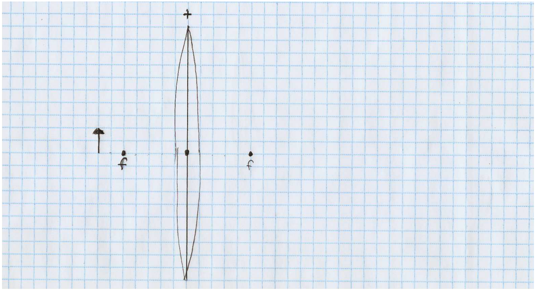


Object and image distances:

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

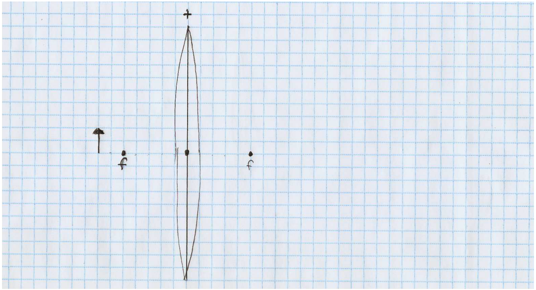
Magnification:

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

Image distance d_i is

(A) $+17.5$ m (B) -17.5 m (C) $+35$ m (D) -35 m (E) $+5$ m

An object is placed 7 m to the left of a converging lens having focal length $f = 5\ \mathrm{m}$. Where does the image form?



Object and image distances:

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

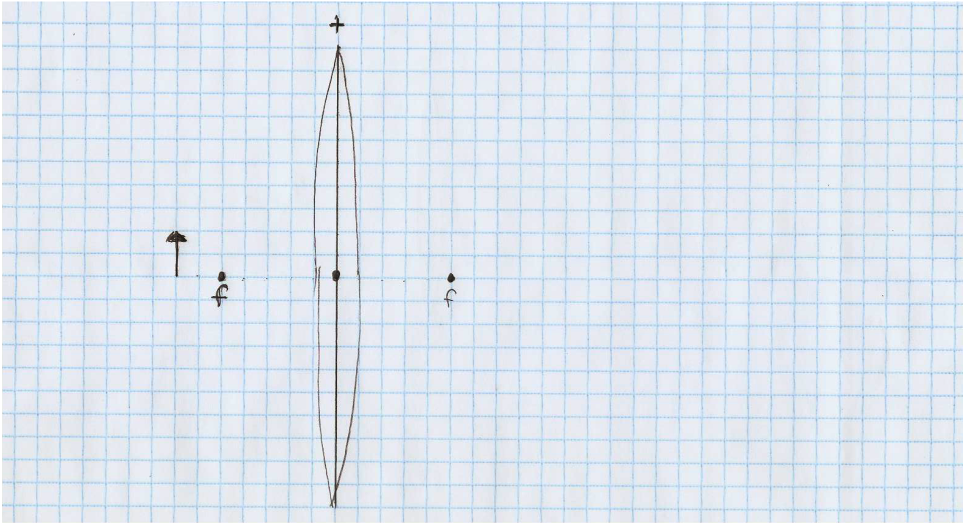
Magnification:

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

Magnification m is:

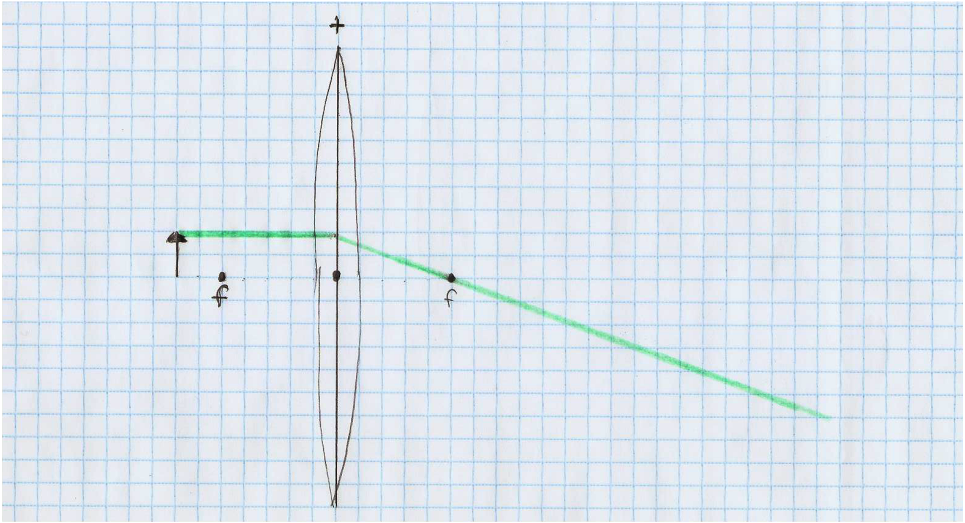
(A) $+0.4$ (B) -0.4 (C) $+2.5$ (D) -2.5 (E) $+5.0$

An object is placed 7 m to the left of a converging lens having $f = 5\ \mathrm{m}$. Where does the image form?



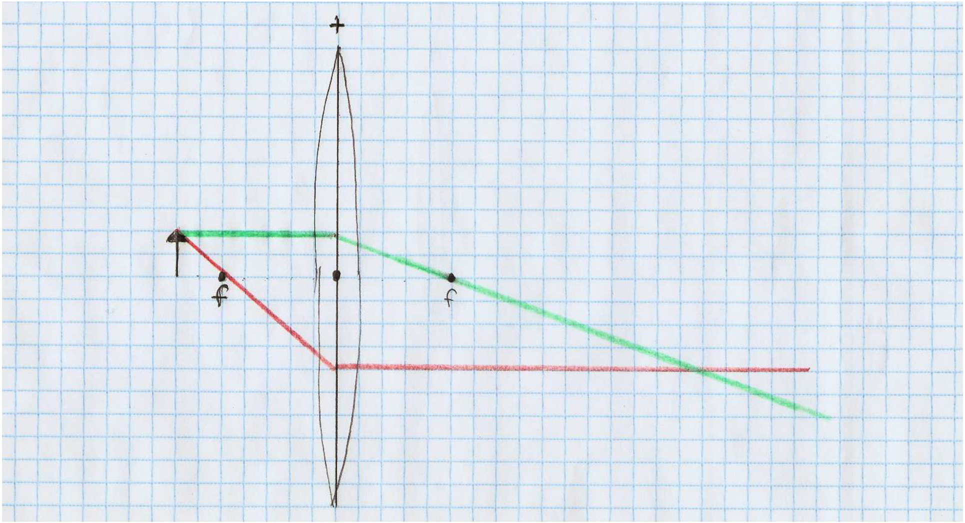
Where are the principal rays? Start with one that is horizontal on the left side of the lens.

An object is placed 7 m to the left of a converging lens having $f = 5\ \mathrm{m}$. Where does the image form?



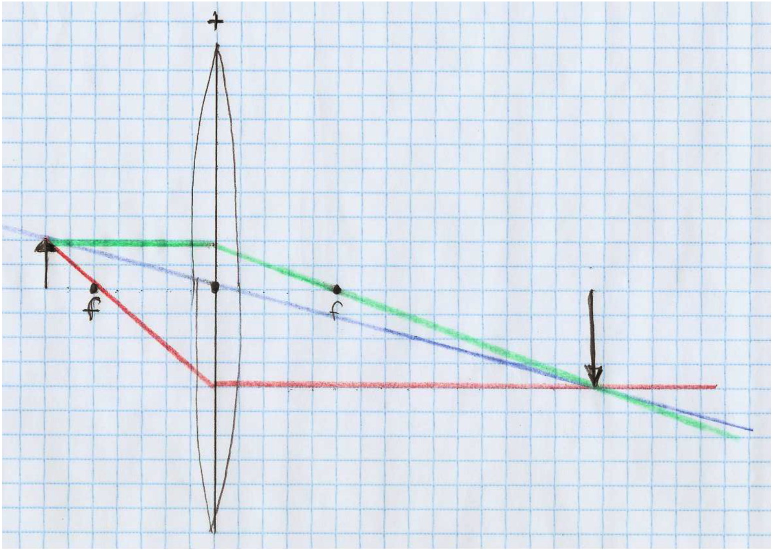
Next principal ray: passing through left focus.

An object is placed 7 m to the left of a converging lens having $f = 5$ m. Where does the image form?



Next principal ray: passing through center of (thin) lens.

An object is placed 7 m to the left of a converging lens having $f = 5$ m. Where does the image form?



Math gave $d_i = +17.5$ m, $m = -2.5$. The graph qualitatively agrees, but my thick colored pencils missed the mark slightly.

This may be helpful for the homework (from equations.pdf)

Lens & mirror summary (light always enters from LHS):

converging lens	$f > 0$	$d_i > 0$ is RHS	$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$
diverging lens	$f < 0$	$d_i > 0$ is RHS	$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$
converging mirror	$f > 0$	$d_i > 0$ is LHS	$f = R/2$
diverging mirror	$f < 0$	$d_i > 0$ is LHS	$f = -R/2$

Horizontal locations of object, image (beware of sign conventions!):

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

Magnification (image height / object height):

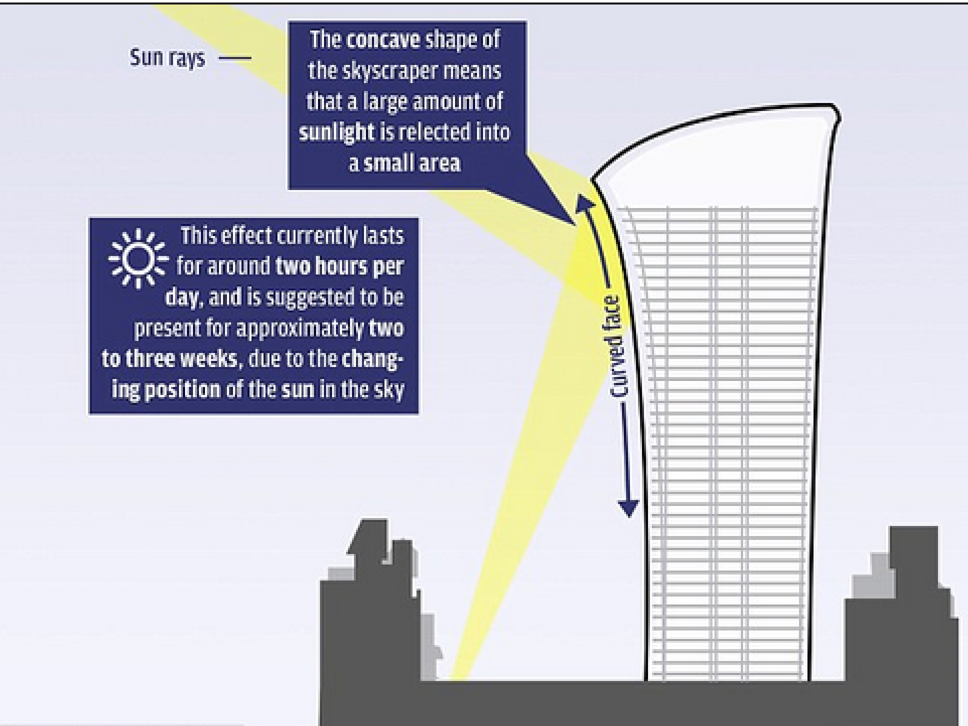
$$m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

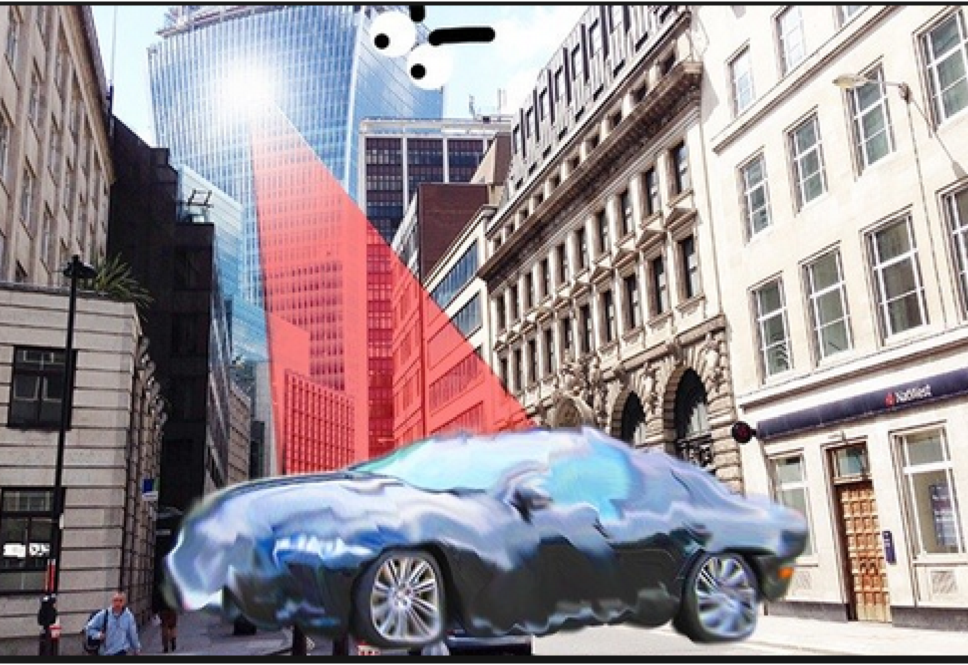
Lenses: $R_{1,2} > 0$ for "outie" (convex), < 0 for "innie" (concave).

Real image: $d_i > 0$. Virtual image: $d_i < 0$. Real image means light really goes there. Virtual: rays converge where light doesn't go.

Most of this course segment on optics has been largely for your liberal-arts education. But at least now you'll never forget that a concave building facade has the ability, like a converging mirror, to focus the sun's rays!

(You can search for "London walkie talkie building melts cars.")


Sun rays
The concave shape of the skyscraper means that a large amount of sunlight is relected into a small area
This effect currently lasts for around two hours per day, and is suggested to be present for approximately two to three weeks, due to the changing position of the sun in the sky
Curved face



Also, the next time you're grasping for a topic to discuss with the person next to you at a dinner party (the sort with very shiny silverware), you can pick up a soup spoon and point out that when you look at its back side, you always see an upright, reduced image of yourself, as if you were looking in a wide-angle mirror.

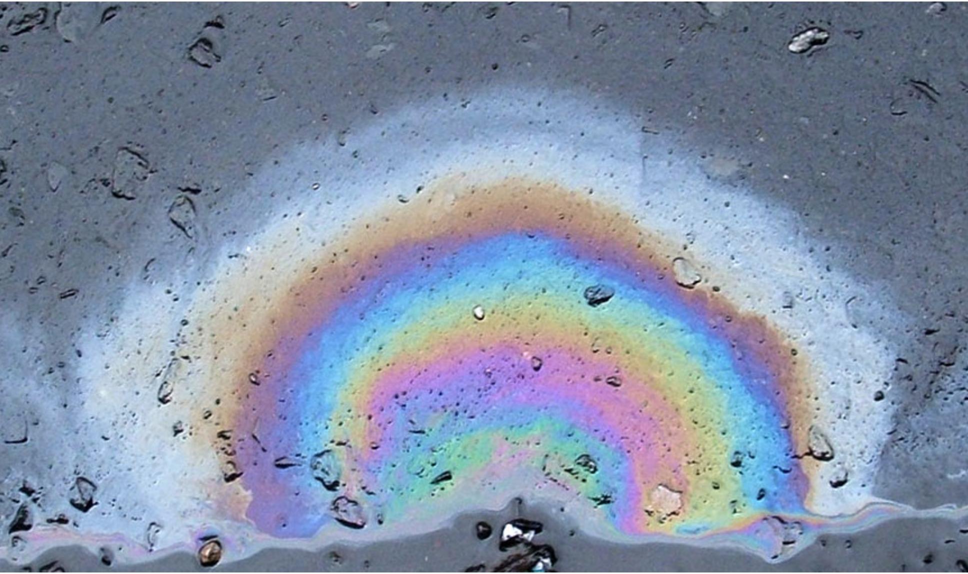
Then when you turn the spoon over and look way-up-close at its top side, you see an upright, enlarged image of yourself!

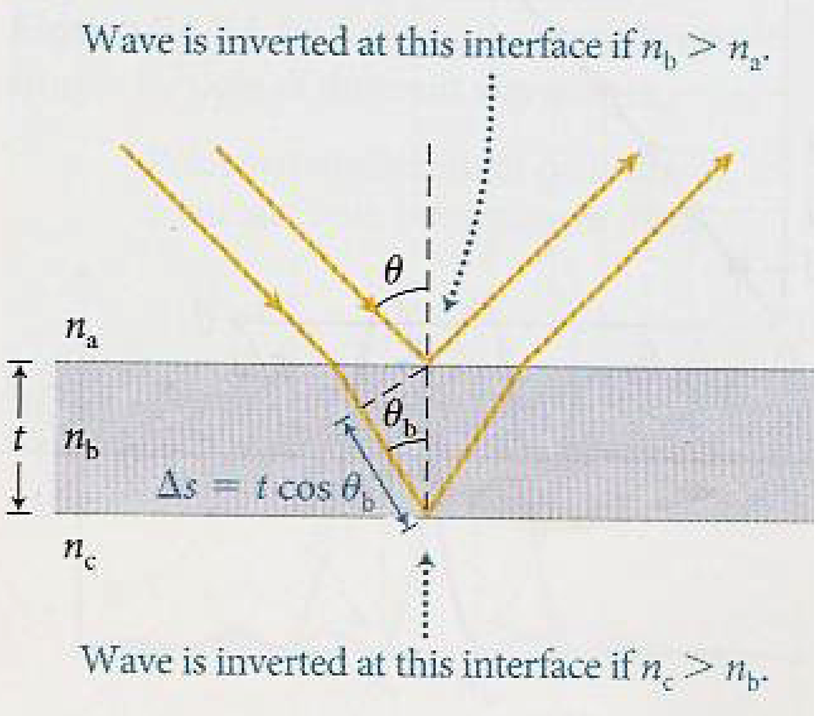
Finally, hold the spoon out at arm's length (still looking at the top side), and you're upside-down: an inverted, reduced image.

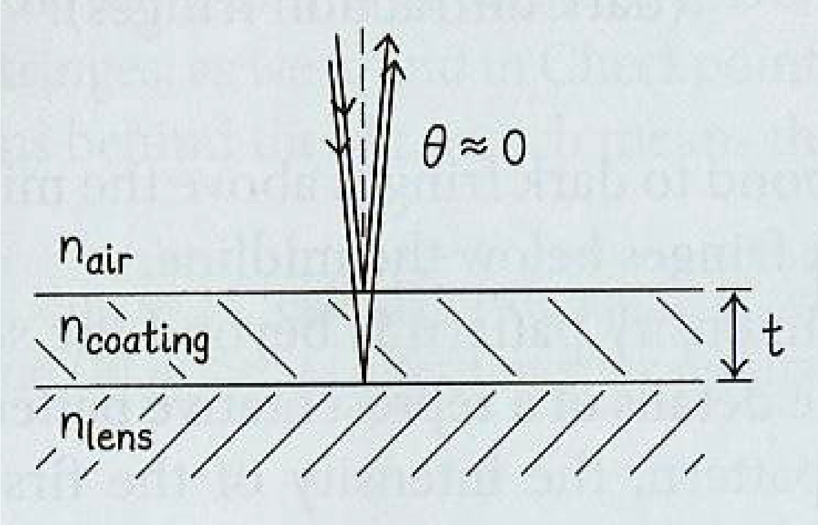
There is an intermediate distance ($f < d_o < 2f$) for which an inverted, enlarged image forms, but it forms behind your head, where your eyes can't focus, so at this intermediate range (looking at yourself), all you see is a blur.

Part of the fun of a liberal arts education is to be able to explain and analyze everyday things like this.

Why does this happen to oily pavement on a rainy day? Would this still happen if light were not a wave phenomenon?




Wave is inverted at this interface if $n_b > n_a$.
θ
n_a
θ_b
t
n_b
$\Delta s = t \cos \theta_b$
n_c
Wave is inverted at this interface if $n_c > n_b$.


$\theta \approx 0$
n_{air}
$n_{coating}$
n_{lens}
t

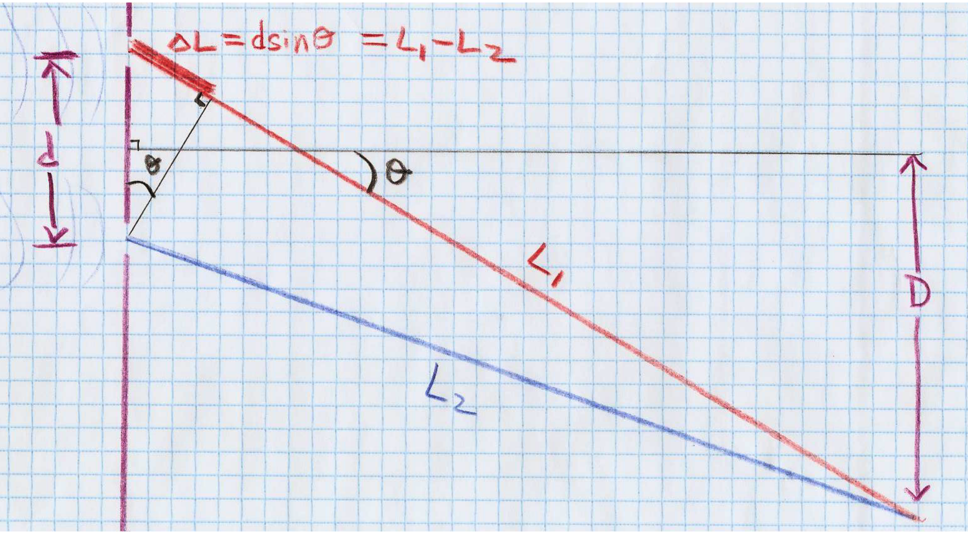
Speaking of the wave nature of light:

Let's measure the wavelength of green light and of red light (from my green and red laser pointers)!

Think about the demonstration (which doesn't work in this room, with its many reflective surfaces) that would have involved two separated speakers in the front of the room, playing exactly the same tone. In an anechoic room, you would have around the room and found spots where the sound was very loud and other spots where the sound was very quiet.

In what analogous way could we create a measurable interference pattern with the laser light?

How about sending the light from a laser through two narrow slits that are spaced several dozen wavelengths apart, then observing the interference pattern from far away?



d = distance between slits. D = distance between adjacent maxima at screen. L = path length from slit to screen.

$$\Delta L = L_1 - L_2 = (d)(\sin\theta) \approx (d)(D/L)$$

So adjacent maxima have $\Delta L = \lambda$: $\boxed{\lambda = dD/L}$

$D =$ distance between adjacent maxima (bright spots) on screen
$\lambda =$ wavelength of light
$d =$ distance between the two narrow slits in front of the laser
$L =$ distance from slits to screen (blackboard)

$$D = \left(\frac{\lambda}{d}\right) L \qquad \Rightarrow \qquad \boxed{\lambda = dD/L}$$

Before class, I estimated $L = 10.3\ \mathrm{m}$ from slits to blackboard. (We can measure more carefully now.)

The two slits are carefully machined to have $d = 0.125\ \mathrm{mm}$.

All that's left is for us to measure D on the blackboard. To get a better estimate of D, we'll count of 10 or 20 spots and divide by n.

We'll do this both for the green laser-pointer and for the red laser-pointer.

We got about 500 nm for green and about 600 nm for red. A much more careful measurement would have found $\lambda_{\text{green}} = 532$ nm and $\lambda_{\text{red}} = 650$ nm. But our measured values are pretty good (within about 10%).

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