Announcements 1/26/10

Handouts: PS2, tips for constructing ray diagrams

Share lenses (every other person), handle only by plastic holder

No additional reading for Thursday

Clarification on self-test problem

To draw accurate ray diagrams:

- Use a ruler so that lines are straight.
- Start by drawing the axis of the lens or mirror.
- Make diagrams big enough.
- For a lens, draw the midplane of the lens as well as the axis; rays change direction at the midplane.
- For a lens, be sure that the two focal points are at equal distances from the midplane of the lens.

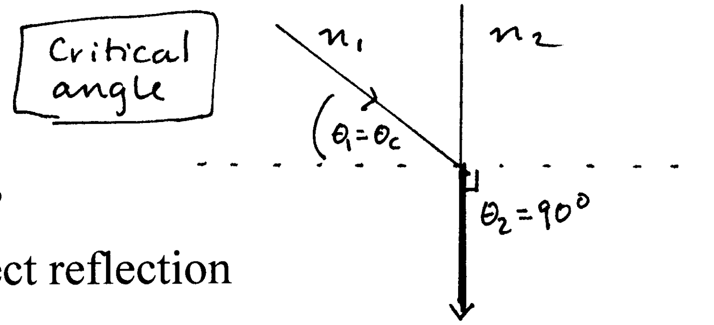
Otherwise ray diagrams can be misleading!

Key ideas from last time

Total internal reflection:

θ_c = value of θ_1 at which $\theta_2 = 90°$

If $\theta_1 > \theta_c$ no transmitted ray; perfect reflection



Curved mirrors

Converging (concave) mirrors reflect parallel rays to focal point

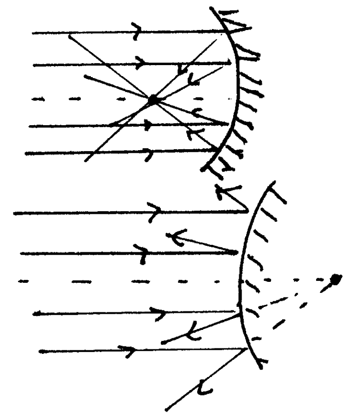
Diverging (convex) mirrors reflect parallel rays as if coming from a virtual focal point

To locate images formed by curved mirrors, construct principal rays

(1) Ray parallel to axis reflects through focal point

(2) Ray through focal point reflects parallel to axis

If mirror is diverging, "through focal point" means "on line through focal point"



Real image: light rays meet at image location

Virtual image: light rays appear to come from image location

J.J.
1/26/2010

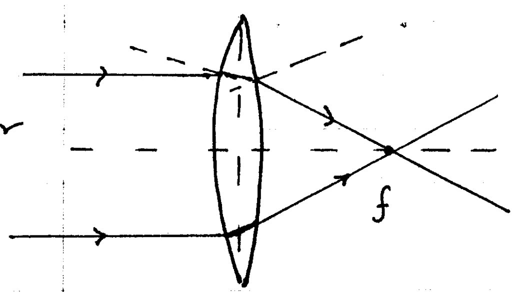
Forming images with lenses

Most important optical system to us: the human eye
Consists of a converging lens that forms images on the retina that can then be perceived by the brain
To understand how this works: today we will consider image formation with converging lenses

Lenses: focus light, and therefore form images, by refraction
Shape of lens designed so that rays ∥ to axis of lens all come to a point (focal point)

How does it work?
Two surfaces curve opposite ways; at each surface light bends down

Use big sketch for class

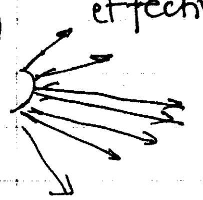


Surface curves symmetrically so that rays above & below axis bends opposite ways

Refraction actually happens at both surfaces, but in "thin lens" approx we draw rays as refracting only at the midplane

Save for p.3

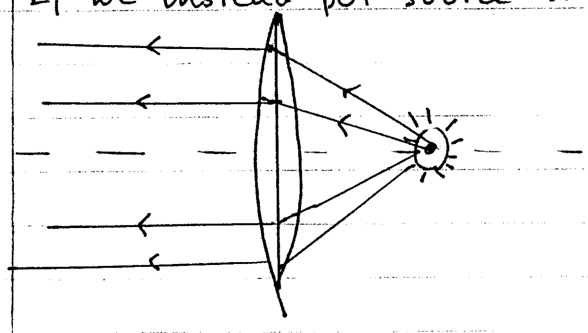
Magnifying glass (conv lens) focuses sun's rays to a point b/c very distant bright source produces rays that are effectively parallel: sunlight, starlight, even lights that are much farther away than the focal length f



~~Hand out~~

Earth

If we instead put source at focal point: rays come out $\parallel$ because same refraction occurs, just in reverse direction

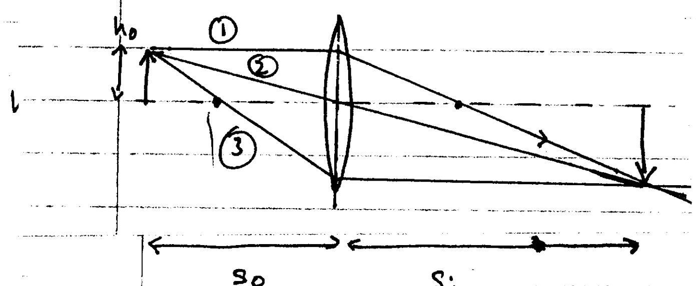


→ ~~[illegible]~~ Lenses have 2 focal points, one on each side

How do we locate

<u>Images with Lenses?</u> locate by drawing principal rays again

3 simple rays, choose 2 easiest



(1) Ray from object to lens $\parallel$ to axis ~~comes~~ refracts through f

(2) Ray through center is undeflected (Equivalent refractions on either side)

(3) Ray through f refracts $\parallel$

Handout: tips on drawing ray diagrams

11:40 CT Moving screen

What do we want to know about images?

(1) How big?

(2) Upright/inverted?

(3) Where is it?

(4) Real/virtual?

} Want quantitative description

Size: use similar $\triangle$ as w/pinhole $\Rightarrow \dfrac{|h_i|}{|s_i|} = \dfrac{|h_o|}{|s_o|} \Longrightarrow \dfrac{|h_i|}{|h_o|} = \dfrac{|s_i|}{|s_o|}$

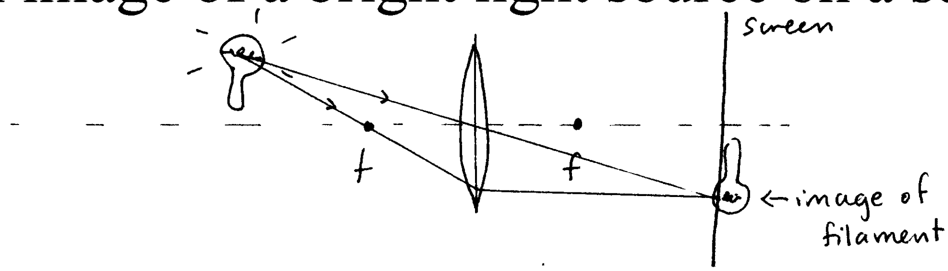
Why abs values? Want to use sign to tell us upright/inverted
(right side up) (upside down)

Choose h_o, h_i ⊕ if above axis, ⊖ if below

Choose s_o, s_i ⊕ if on opposite sides of lens

$$\Rightarrow \frac{h_i}{h_o} = -\frac{s_i}{s_o}$$ and define magnification $M \equiv \dfrac{h_i}{h_o}$

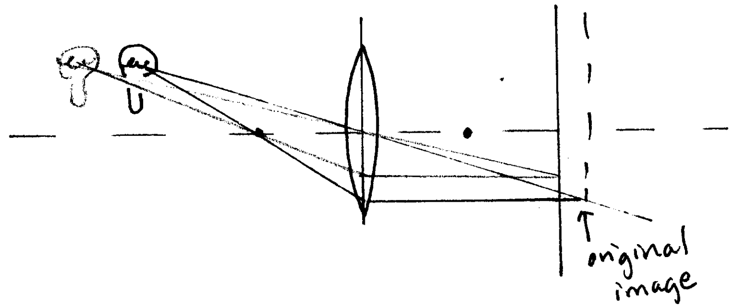
A converging lens is used in a projector to form an image of a bright light source on a screen.



If the screen is moved toward the lens, to keep the image in focus, the source should be moved

1. Closer to the lens.
2. Farther from the lens.
3. It doesn't need to be moved (the image will still be in focus on the screen).
4. Need more information to answer.

2: The source should be moved farther from the lens.



Can use triangles to find relnship between f, s_i, s_o:

$$\frac{1}{f} = \frac{1}{s_o} + \frac{1}{s_i}$$ "lens equation" with s_o, s_i, f all ⊕ in diagram

Signs:

h_o, h_i: ⊕ if above lens axis; ⊖ if below lens axis

s_o always ⊕

s_i ⊕ if on other side of lens from object

f ⊕ for converging lens

Earlier question (moving ~~object~~ screen): can we understand using lens eq?

$$\frac{1}{f} = \frac{1}{s_o} + \frac{1}{s_i}$$ ~~can be written~~ f fixed, so $\frac{1}{s_o} + \frac{1}{s_i}$ fixed
change $s_i \rightarrow s_o$ must change to compensate

Hand out lenses – tell everyone to try to form image of lights on paper

$\boxed{CT}$ If $s_o \gg f$, roughly where does the image form? (look at eq)

About at f: $\frac{1}{f} \approx \frac{1}{s_i}$ – Check this ($8\frac{1}{2}$" paper is 21 cm)

Distant objects form image close to focus

Understand in terms of rays:

rays from distant objects are nearly parallel

- Rays from very distant light source (sun, stars) are essentially parallel:

mag glass focuses sunlight at focal point

If an object is much farther away than the focal length of a converging lens, roughly where does the image form?

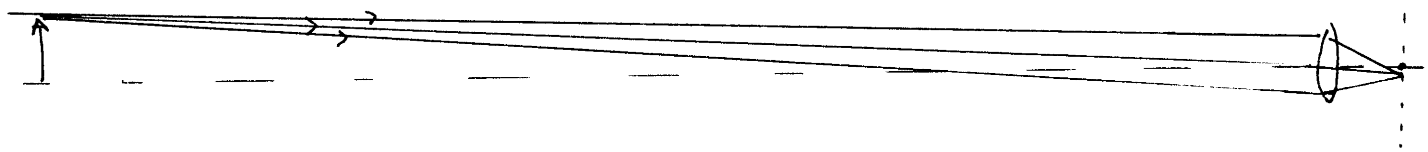
The image forms close to the focal point (slightly past it):

$$\frac{1}{f} - \frac{1}{s_o} = \frac{1}{s_i} \text{ and } \frac{1}{f} >> \frac{1}{s_o} \rightarrow \frac{1}{f} \approx \frac{1}{s_i}$$

8½" wide is 21 cm

Very distant object produces (nearly) parallel rays

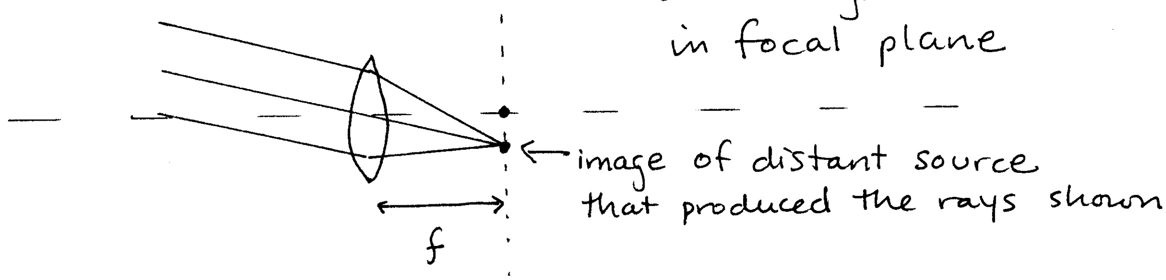
(sun, stars)



If those rays are at an angle to the lens axis, focus at a distance f but off-axis

How do you know where? Center ray is not deflected

Other rays meet center ray in focal plane



Human vision

Eye has converging lens at front and light-sensitive ~~at fixed distance from~~ retina at back
(show image) [Retina is like screen]
[We see objects when eye forms real image on retina]
(Light must strike retina to activate photoreceptors)

12:00 [CT] Image on retina: inverted or upright?
Inverted: your brain compensates!

Distance from lens to retina is fixed: to view objects at different distances, change f

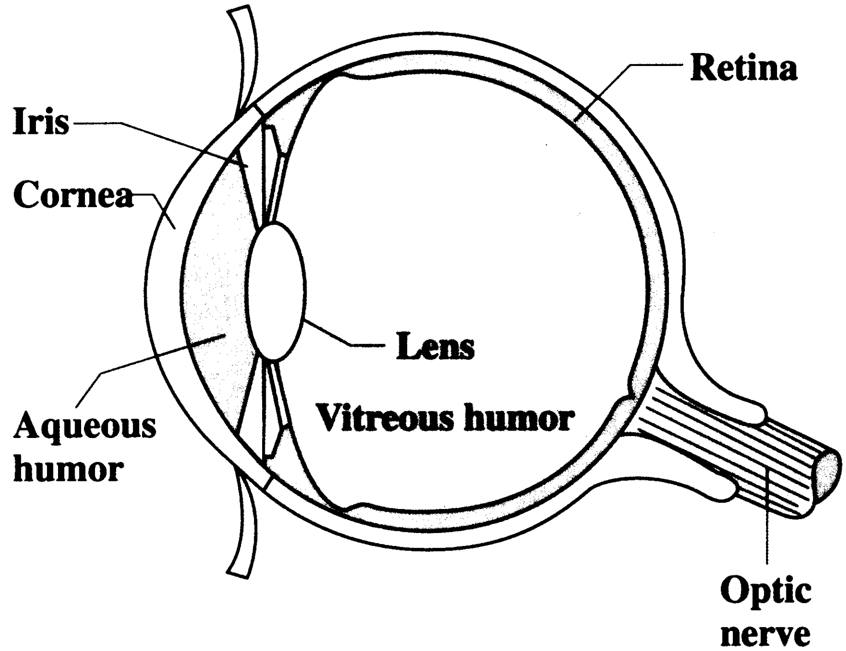
$$\boxed{\frac{1}{s_i} = \frac{1}{f} - \frac{1}{s_o}}$$

How change f?
cornea + lens combined do the focusing
cornea shape is fixed, but shape of lens can be adjusted with muscles

(Show image from Bruinsma)
⟹ we will treat ~~eye~~ cornea + lens together as a single lens of adjustable f ⟸

[Camera: adjust distance from lens to sensor or film, which changes both s_o and s_i
zoom lens: multipart lens, more parts to change f]

Example problem: look at bush
Retina is 23 mm from lens
What is f_{eye}? How big is the image?



Wolfson Fig. 31.27

Treat eye as having a single lens
(although cornea also does a lot of focusing)
We see objects when real image forms
on retina.

Is the image formed by your eye on your retina right side up or upside down?

1. Right side up
2. Upside down

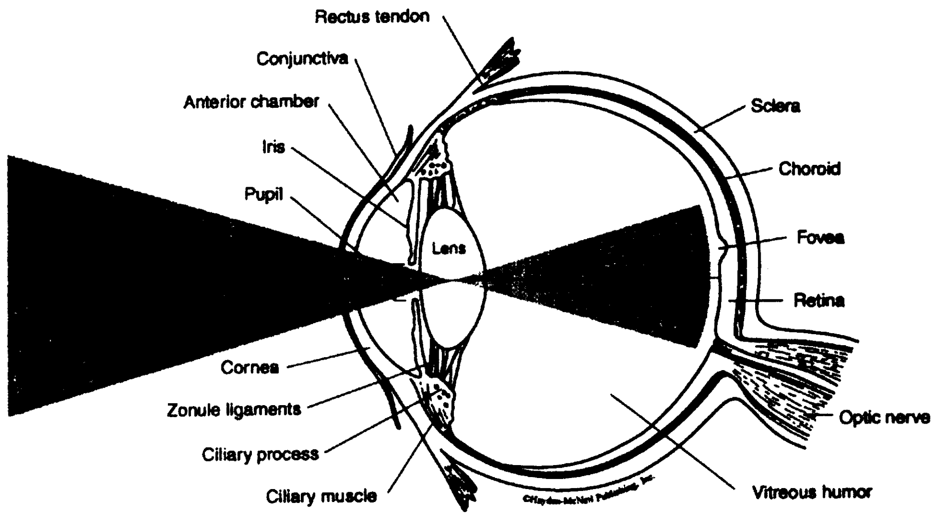
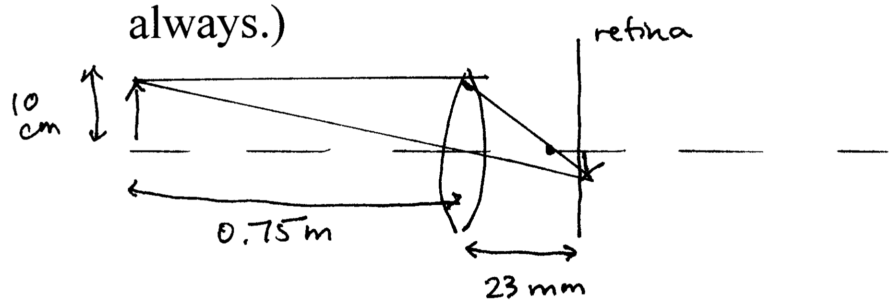


Figure 4.10

from Bruinsma

You are looking at a plant that is 10 cm tall and 0.75 m away from your face. Your retina is 23 mm from your eye's lens. What is the focal length of your eye's lens and how big is the image of the plant? (Treat the cornea and lens as a single lens as always.)

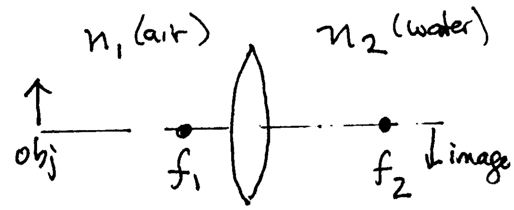


$$M = \frac{h_i}{h_o} = -\frac{s_i}{s_o} \Rightarrow h_i = -\frac{s_i}{s_o} h_o = -\left(\frac{2.3\times10^{-3}\,m}{0.75\,m}\right)(0.10\,m) = -3.1\,mm$$

Focal length: $\frac{1}{f} = \frac{1}{s_o} + \frac{1}{s_i}$

<u>BUT</u> lens surrounded by water (or other material) <u>changes</u> focal length

Lens at interface between water & air has two focal lengths $\frac{n_1}{f_1} = \frac{n_2}{f_2}$



Generalized lens eq

$$\frac{n_1}{f_1} = \frac{n_2}{f_2} = \frac{n_1}{s_o} + \frac{n_2}{s_i}$$

object is in n_1
image is in n_2

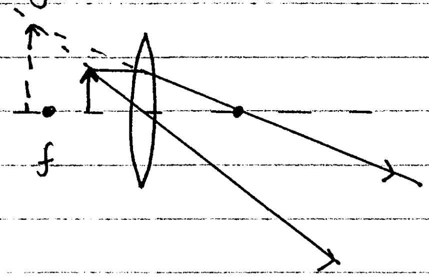
let's find f_2, $n_2 = 1.34$ (index of vitreous humor filling eye)

$$\frac{1.34}{f_2} = \frac{1.00}{0.75\,m} + \frac{1.34}{23\times10^{-3}} \Rightarrow f_2 = 22.9\,mm$$

Virtual images with convex lenses

[How are you used to using a lens? Mag glass - hold it close to page]

If object is inside focus: Look at rays



rays don't meet - instead spread out
can backtrack rays to ~~there~~ same side of lens as object - rays appear to come from that location

Virtual image

How use lens equation? Now we say $s_i < 0$ if image on same side of lens as object

Makes sense:

$$\frac{1}{f} = \frac{1}{s_o} + \frac{1}{s_i} \quad \text{can be written} \quad \frac{1}{s_i} = \frac{1}{f} - \frac{1}{s_o}$$

if $s_o < f$ then $1/f < 1/s_o$ and RHS is $-$

This is how we use convex lenses as magnifying glasses!

Image is upright: $M = -\frac{s_i}{s_o}$ is $+$ b/c s_i is $-$

Image is enlarged: $|s_i| > s_o$ (see from diagram)