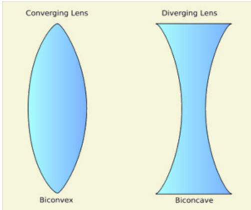
5.B.3 Lenses and Aberrations

Lens: A transparent material through which light refracts to enlarge, reduce, or focus images.

At least one surface is spherical.

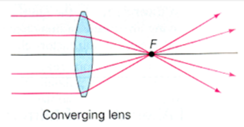
Biconvex lens has two convex surfaces:
Ex: magnifying glass. (Demo)

Biconcave lens has two concave surfaces.
(Demo: Look through both)

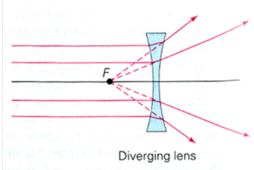


Convergence vs. Divergence

Convex lenses are converging: parallel rays meet at a focal point (f).
Conventions: f and radius are positive (see Res. 8).



Concave lenses are diverging: light rays scatter.
Conventions: f and r are negative.



Lens Factoids

Lenses form virtual & inverted real images (need screen - Demo with candle).

Looking at the object through the lens, you see a virtual image at the image distance (s_i).

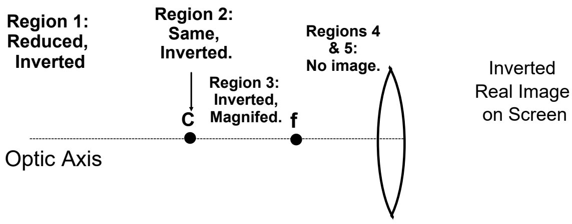
Magnification (same):

AP Equation		Non-AP Equation:
$\lvert M \rvert = \left\lvert \frac{h_i}{h_o} \right\rvert = \left\lvert \frac{s_i}{s_o} \right\rvert$	s_o = object distance s_i = image distance h_o = object height h_i = image height	$M = \frac{h_i}{h_o} = -\frac{s_i}{s_o}$

Converging Lens Regions: Real Image

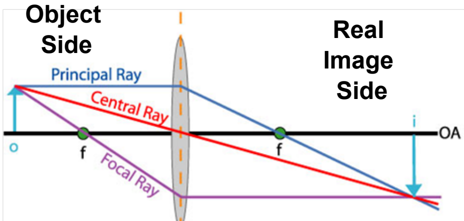
Regions:

1. $s_o > C$: reduced & inverted image.
2. $s_o = C$: real, inverted image same size.
3. $C > s_o > f$: real, inverted magnified image.
4. & 5: no real image.



Real Image Ray Diagram

Principal Ray: starts parallel to optic axis: then passes through focal point on image side.
Chief (Central) Ray: passes through **center of lens**.
Focal Ray: passes through focal point on the object side of a lens, and is parallel after passing through.



Converging Lens: Real Image

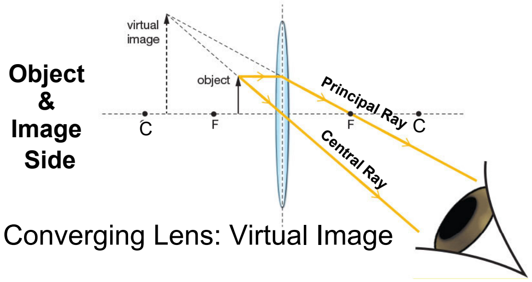
Converging Lens Regions:
Virtual, Upright, Magnified Image

For a magnifying glass to work, objects must be in Region 5. Beyond that, virtual images appear blurry if your eye is too close to the lens.

HOWEVER: when your eye is far enough away, distant objects appear upside down and reduced (Demo - Class looks through glass).

Virtual Image Ray Diagram

Principal Ray: starts parallel to optic axis: then passes through focal point on eyeball side.
Chief (Central) Ray: passes through **center of lens.**



Thin Lens Equation

Called "thin" because if the lens were thicker, light would be laterally displaced to a large degree.

Same as 5.B.2:

$\frac{1}{s_i}+\frac{1}{s_o}=\frac{1}{f}$ AP Equation	s_i = image distance s_o = object distance f = focal length

Useful alternative forms (same):

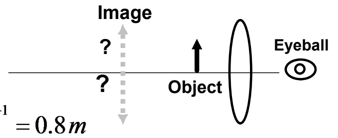
$$s_i = \frac{s_o f}{s_o - f} \qquad s_o = \frac{s_i f}{s_i - f}$$

1. Lens Example

An object 0.48 m in front of a converging lens makes a virtual image at 1.2 m.
What are the focal length and magnification?

Is the image upright or upside down?

s_o = 0.48 m s_i = -1.2 m.



$$f = \left(s_o^{-1} + s_i^{-1}\right)^{-1}$$

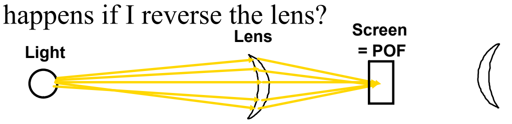
$$= \left(0.48m^{-1} + (-1.2m)^{-1}\right)^{-1} = 0.8m$$

$$M = -\frac{s_i}{s_o} = -\frac{-1.2m}{0.48m} = 2.5$$

Upright.

2. Lens Physics Democracy!

Some distance from the light, focused rays from this lens converge on a screen at a point of focus (POF).
What happens if I reverse the lens?



POF stays the same	POF goes away from lens	POF gets closer to lens

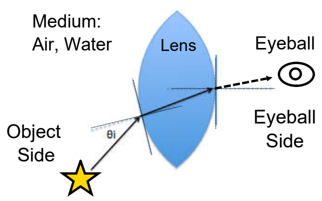
It stays the same! If you have glasses, look through them backwards - you should still see clearly.

3. Underwater Lens Democracy!

What happens to focal length (FL) for a submerged lens?

FL stays the same	FL goes away from lens	FL gets closer to lens

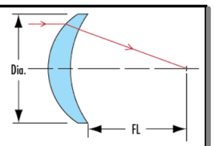
Focal length changes in different media: everything appears blurry if you open your eyes under water.

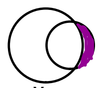


Lens Maker's Equation

Lenses can have different radii, but focal length is the same from both directions.

This equation accounts for this, AND adjusts for media other than air: water, oil, etc.





Venn Diagram

$\frac{1}{f}=\left(\frac{n}{n_m}-1\right)\left(\frac{1}{r_1}+\frac{1}{r_2}\right)$	n = index of lens n_m = index of medium r_1 = radius (object side) r_2 = radius (eyeball side)

4. Lens Maker's Example

A crown glass biconvex lens has radii of 13 cm and 22 cm. What are the focal lengths in air and water?

Conventions: both radii are positive.
n = 1.52 for crown glass, 1.33 for water.

Air:

$$\frac{1}{f}=\left(\frac{n}{n_m}-1\right)\left(\frac{1}{r_1}+\frac{1}{r_2}\right)$$

$$\frac{1}{f}=\left(\frac{1.52}{1.00}-1\right)\left(\frac{1}{13\,cm}+\frac{1}{22\,cm}\right)$$

$$=0.0636\,cm^{-1}$$

$$f=(0.0636)^{-1}=15.7\,cm$$

Water:

$$\frac{1}{f}=\left(\frac{n}{n_m}-1\right)\left(\frac{1}{r_1}+\frac{1}{r_2}\right)$$

$$\frac{1}{f}=\left(\frac{1.52}{1.33}-1\right)\left(\frac{1}{13\,cm}+\frac{1}{22\,cm}\right)$$

$$=0.0175\,cm^{-1}$$

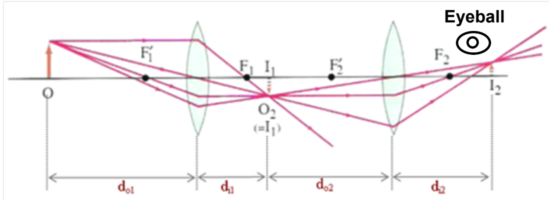
$$f=(0.0175)^{-1}=57.1\,cm$$

Way longer.

Combinations of Lenses

Optical instruments use lens combinations.

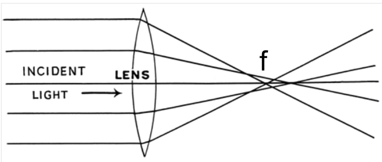
In a lens combination, the real image produced by the first lens is the object of the second (Res. 8).



Lens Aberrations

Spherical Aberration: Parallel rays passing through distant regions of a lens don't converge at f.

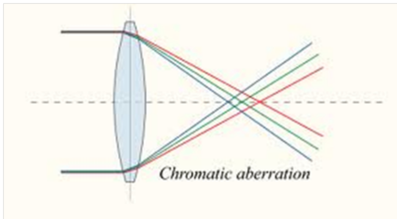
Minimized by reducing aperture through which light passes en route to the lens (card with hole demo).



Lens Aberrations

Chromatic Aberration: Different frequencies of light disperse as they pass through a lens.

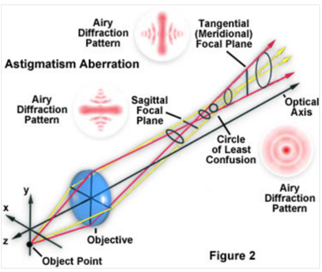
Minimized by passing light through materials with dissimilar dispersion properties in a compound lens.

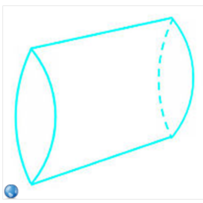


Lens Aberrations

Astigmatism: Caused by off-center light focusing at different, elliptical points, causing blurriness.

Minimized by using a cylindrical lens to correct.





Homework

5.B.3 Problems
Due Next Class.

Do Application Problems

Finish Unit 5.B Review Scan: Due ??