

PHY 114 A General Physics II
11 AM-12:15 PM TR Olin 101

Plan for Lecture 20 (Chapter 36):
Optical properties of light

1. Images formed by thin lenses

2. Optical devices

a. Eyeglasses

b. Cameras, microscopes, telescopes

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14	03/20/2012	Induction and AC circuits	32.1-32.6	32.4, 32.20, 32.43	03/22/2012
15	03/22/2012	AC circuits	33.1-33.9	33.8, 33.24, 33.71	03/27/2012
16	03/27/2012	Electromagnetic waves	34.1-34.3	34.3, 34.10, 34.13	03/29/2012
17	03/29/2012	Electromagnetic waves	34.4-34.7	34.27, 34.46, 34.57	04/03/2012
18	04/03/2012	Ray optics Evening exam	35.1-35.8	35.20, 35.27, 35.35	04/10/2012
19	04/05/2012	Image formation Evening exam	36.1-36.4	36.8, 36.31, 36.42	04/10/2012
20	04/10/2012	Image formation	36.5-36.10	36.52, 36.54, 36.64	04/12/2012
21	04/12/2012	Wave interference	37.1-37.6		
22	04/17/2012	Diffraction	38.1-38.6		
23	04/19/2012	Quantum Physics	40.1-42.10		
24	04/24/2012	Molecules and solids	43.1-43.8		
25	04/26/2012	Nuclear reactions	45.1-45.4		
26	05/01/2012	Nuclear radiation	45.5-45.7		
	05/08/2012	Final exam 9 AM			

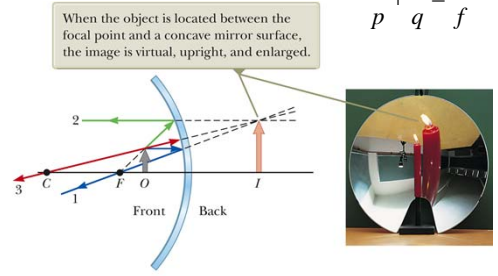

Note: HW 17 slightly altered

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Virtual image → **not** really there

When the object is located between the focal point and a concave mirror surface, the image is virtual, upright, and enlarged.

Mirror equation :

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$$



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Real image → really there

Mirror equation :

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$$

When the object is located so that the center of curvature lies between the object and a concave mirror surface, the image is real, inverted, and reduced in size.

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Summary of results for mirrors:

The mirror equation:

$$\frac{1}{p} + \frac{1}{i} = \frac{1}{f}$$

Magnification :

$$m = \frac{(\text{sign})h'}{h} = \frac{-i}{p}$$

+ signs for: p, f (concave mirror), i (real image), m (upright image)
 – signs for: f (convex mirror), i (virtual image), m (inverted image)

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Homework hint: (HW 16)

3. -0.333 points My Notes | SeePSE8 35

A laser beam is incident on a 45°–45°–90° prism perpendicular to one of its faces as shown in the figure below. The transmitted beam that exits the hypotenuse of the prism makes an angle of $\theta = 28.8^\circ$ with the direction of the incident beam. Find the index of refraction of the prism.

Basic principle: Snell's law

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

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Homework hint: (HW 17; note this problem is now optional)

4 -0.333 points My Notes Self-PEE 36 P03

A flint glass plate ($n = 1.66$) rests on the bottom of an aquarium tank. The plate is 7.00 cm thick (vertical dimension) and is covered with a layer of water ($n = 1.33$) 15.0 cm deep. Calculate the apparent thickness of the plate as viewed from straight above the water. (Assume nearly normal incidence.)

Basic principle: Snell's law For HW problem $R \rightarrow \infty$:

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

For small angles :

$$\frac{n_1}{p} + \frac{n_2}{q} = \frac{n_2 - n_1}{R}$$

$n_0=1$
 $n_1=1.33$
 $n_2=1.66$

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Image formation by refraction -- lenses

Thin lens equation

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$$

Front, or virtual, side p positive q negative

Back, or real, side p negative q positive

Incident light Refracted light

Converging or diverging lens

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Summary of thin lens configurations

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$$

When the object is in front of and outside the focal point of a converging lens, the image is real, inverted, and on the back side of the lens.

When the object is between the focal point and a converging lens, the image is virtual, upright, larger than the object, and on the front side of the lens.

When an object is anywhere in front of a diverging lens, the image is virtual, upright, smaller than the object, and on the front side of the lens.

Front Back Front Back Front Back

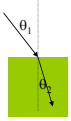
Lens makers' equation

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

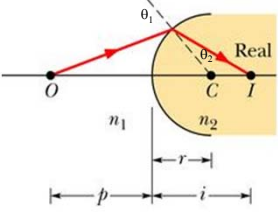
Biconvex Convex-concave Plano-convex Biconcave Convex-concave Plano-concave

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Basic physics of lenses:
 Snell's law: $n_1 \sin \theta_1 = n_2 \sin \theta_2$



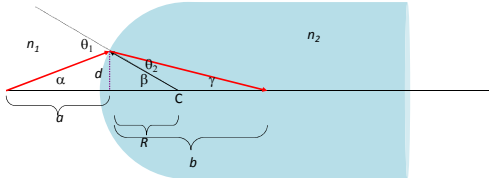
Refraction at a spherical surface:



Notation note:
 $q \leftrightarrow i$

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Refraction at a spherical surface



$\theta_1 = \alpha + \beta$
 $\theta_2 = \beta - \gamma$
 $n_1 \sin \theta_1 = n_2 \sin \theta_2 \Rightarrow n_1 \theta_1 \approx n_2 \theta_2$

$\tan \alpha = \frac{d}{a} \approx \alpha$ $\tan \beta = \frac{d}{R} \approx \beta$ $\tan \gamma = \frac{d}{b} \approx \gamma$

$\frac{n_1}{a} + \frac{n_2}{b} = \frac{n_2 - n_1}{R}$

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Refraction at a spherical surface – continued

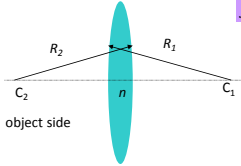
$\frac{n_1}{a} + \frac{n_2}{b} = \frac{n_2 - n_1}{R}$

→ In the small angle approximation, result is *independent of angle*.

Application to 2 surfaces in thin lens geometry

→ “lens makers’ equation”

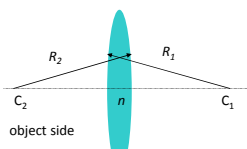
$\frac{1}{f} = (n - 1) \left(\frac{1}{R_1} - \frac{1}{R_2} \right)$



Sign convention:
 R_i is positive if it is convex relative to object and negative if it is concave relative to object.

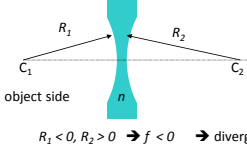
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Lens makers' equation – continued:

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


Sign convention:
 R_i is positive if it is convex relative to object and negative if it is concave relative to object.

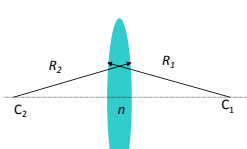
$R_1 > 0, R_2 < 0 \rightarrow f > 0 \rightarrow$ converging lens



$R_1 < 0, R_2 > 0 \rightarrow f < 0 \rightarrow$ diverging lens

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Lens makers' equation:

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


Sign convention:
 R_i is positive if it is convex relative to object and negative if it is concave relative to object.

Lens makers' equation can be proven using

- Snell's law: $n_1 \sin \theta_1 = n_2 \sin \theta_2$
- small angle approximation: $\sin \theta_i \approx \tan \theta_i \approx \theta_i$
- thin lens approximation: thickness $\ll f, p, i$

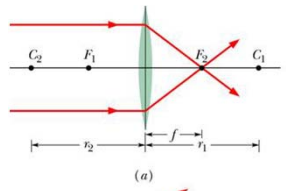
→ Lens equation:

$$\frac{1}{p} + \frac{1}{i} = \frac{1}{f}$$

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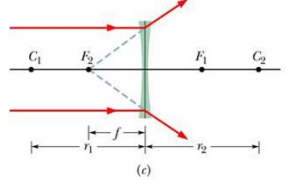
Example of thin lenses:

Converging lens: $f > 0$



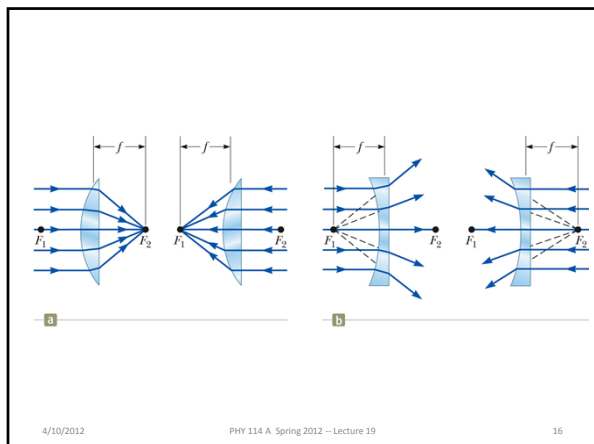
(a)

Diverging lens: $f < 0$



(c)

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Example: $\frac{1}{p} + \frac{1}{i} = \frac{1}{f}$

Forming a real image using a converging lens

This could represent, for example the lens system of a camera.

Example:
 $f = 2 \text{ cm}, p = 5 \text{ cm}$
 $\rightarrow i = 3.33 \text{ cm}$
 (real image)

$$\frac{1}{5} + \frac{1}{i} = \frac{1}{2}$$

$$\Rightarrow i = 3.333$$

$$M = \frac{-i}{p} = \frac{-3.33}{5} = -0.67$$

Thin lens equation: $\frac{1}{p} + \frac{1}{i} = \frac{1}{f}$ assuming sign convention:

Front	Back
p positive	p negative
q negative	q positive
Incident light \rightarrow	Refracted light \rightarrow

Example:
 $f = 2 \text{ cm}, p = 5 \text{ cm}$
 $\rightarrow i = 3.33 \text{ cm}$
 (real image)

Thin lens refraction -- continued

Example:
 $f = 2 \text{ cm}, p = 1.2 \text{ cm}$
 $\rightarrow i = -3 \text{ cm}$
 (virtual image)

$$M = \frac{-i}{p} = 2.5$$

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Thin lens refraction -- continued

Example:
 $f = -2 \text{ cm}, p = 4 \text{ cm}$
 $\rightarrow i = -1.333 \text{ cm}$
 (virtual image)

$$M = \frac{-i}{p} = 0.333$$

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Sherlock Holmes is apparently examining some evidence.
 Which ray diagram most closely describes this situation:

(A)

(B)

(C)


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a **b**

Which picture shows diverging corrective lenses? (A or B)

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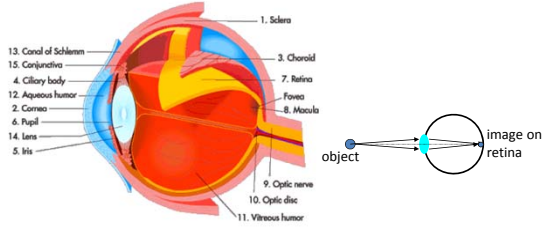


a **b**

Which corrective lens is appropriate for nearsighted person? (A or B)

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View of the eye from
<http://science.howstuffworks.com/eye1.htm>



13. Canal of Schlemm
15. Conjunctiva
4. Ciliary body
12. Aqueous humor
2. Cornea
6. Pupil
14. Lens
5. Iris

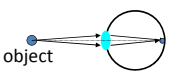
1. Sclera
3. Choroid
7. Retina
8. Macula
9. Optic nerve
10. Optic disc
11. Vitreous humor

object image on retina

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Vision problems and corrective lenses

Ideal vision:



Near sighted vision – problem with “Far point”

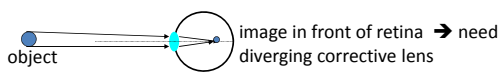


image in front of retina → need diverging corrective lens

Far sighted vision – problem with “Near point”


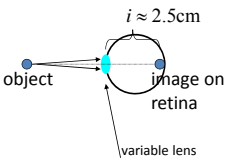


image in back of retina → need converging corrective lens

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More details about eye:



$i \approx 2.5\text{ cm}$

image on retina

variable lens

$$\frac{1}{p} + \frac{1}{i} = \frac{1}{f}$$

$$\frac{1}{25} + \frac{1}{2.5} = \frac{1}{f}$$

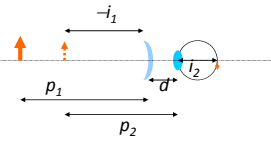
$$f = \frac{1}{\frac{1}{25} + \frac{1}{2.5}} = 2.27\text{ cm}$$

“near point” = closest point that the eye can focus
25 cm standard value
7-200 cm depending on person

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Refraction from two or more lenses

→ Successive use of lens equation



$$\frac{1}{p_1} + \frac{1}{i_1} = \frac{1}{f_1}$$

$$p_2 = -i_1 + d$$

$$\frac{1}{p_2} + \frac{1}{i_2} = \frac{1}{f_2}$$

Example:

$p_1 = 50\text{ cm}; f_1 = -25\text{ cm}; f_2 = 1.4\text{ cm}; d = 1.0\text{ cm}$

We find: $i_1 = -16.667\text{ cm}; i_2 = 1.52\text{ cm}$ Without the diverging lens: $i_2 = 1.44\text{ cm}$ (short of retina)

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Thin lens equation:

$$\frac{1}{p} + \frac{1}{i} = \frac{1}{f}$$

$f > 0; i > 0$

$f > 0; i < 0$

$f < 0; i < 0$

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Physics of the camera

aperture

shutter

real image on detector

Example: $f=50\text{mm} \rightarrow i=50\text{mm}$ for $p=\infty$
 $\rightarrow i=51.3\text{mm}$ for $p=2\text{m}$

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Compound microscope

The objective lens forms an image here.

The eyepiece lens forms an image here.

The three-objective turret allows the user to choose from several powers of magnification.

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Suppose you want to record an microscope image. Where would you place the camera?

- Where eye is
- Not at eye position

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Optics in the Hubble Space Telescope – two convex mirrors
http://hubblesite.org/the_telescope/nuts_and_bolts/optics/index.php

Light Path
 Incoming light travels down a tube fitted with baffles that keep out stray light. The light is collected by the concave (curved inward, like a bowl) primary mirror and reflected toward the smaller, convex (curved outward, like a dome) secondary mirror. The secondary mirror bounces the light back toward the primary mirror and through a hole in its center. The light is then focused on a small area called the focal plane, where it is picked up by the various science instruments.

Mirror surfaces are coated with 5×10^{-8} m Al and 3×10^{-8} m MgF_2 (early version had 10^{-6} curvature error which was subsequently corrected)

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When Hubble took this photograph of Mars in 1999, Mars was 87 million km (54 million miles) away, or more than 200 times the distance from Earth to the Moon.

The photo was made at the height of Martian summer in the northern hemisphere. The carbon dioxide (dry ice) portion of the north polar ice cap

STORMS ON MARS

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