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

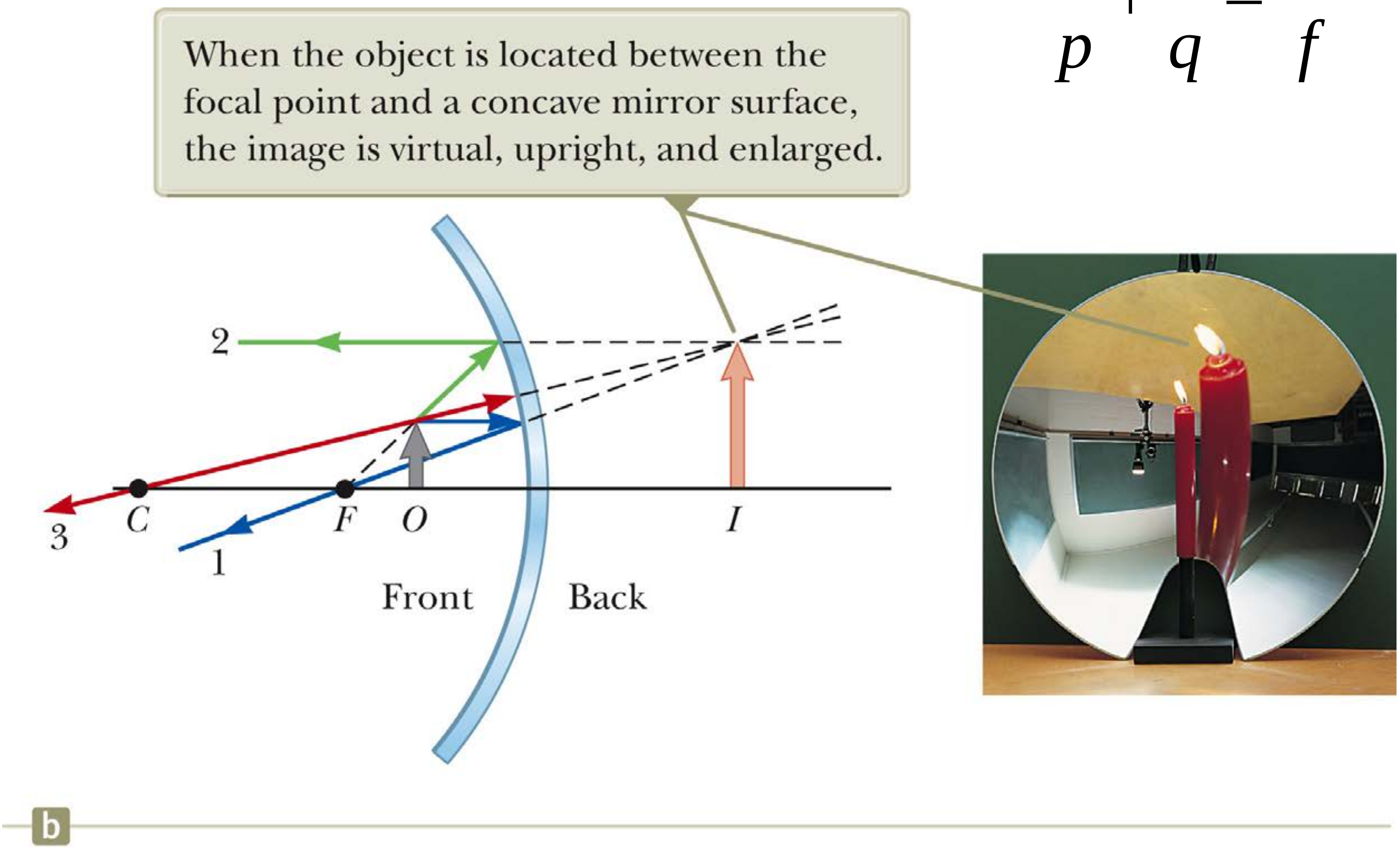
14	03/20/2012	Induction and AC circuits	32.1-32.6	32.4,32.20,32.43	03/22/2012
15	03/22/2012	AC circuits	33.1-33.9	33.8,33.24,33.71	03/27/2012
16	03/27/2012	Electromagnetic waves	34.1-34.3	34.3,34.10,34.13	03/29/2012
17	03/29/2012	Electromagnetic waves	34.4-34.7	34.22,34.46,34.57	04/03/2012
18	04/03/2012	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

Virtual image ➔ **not** really there

Mirror equation :

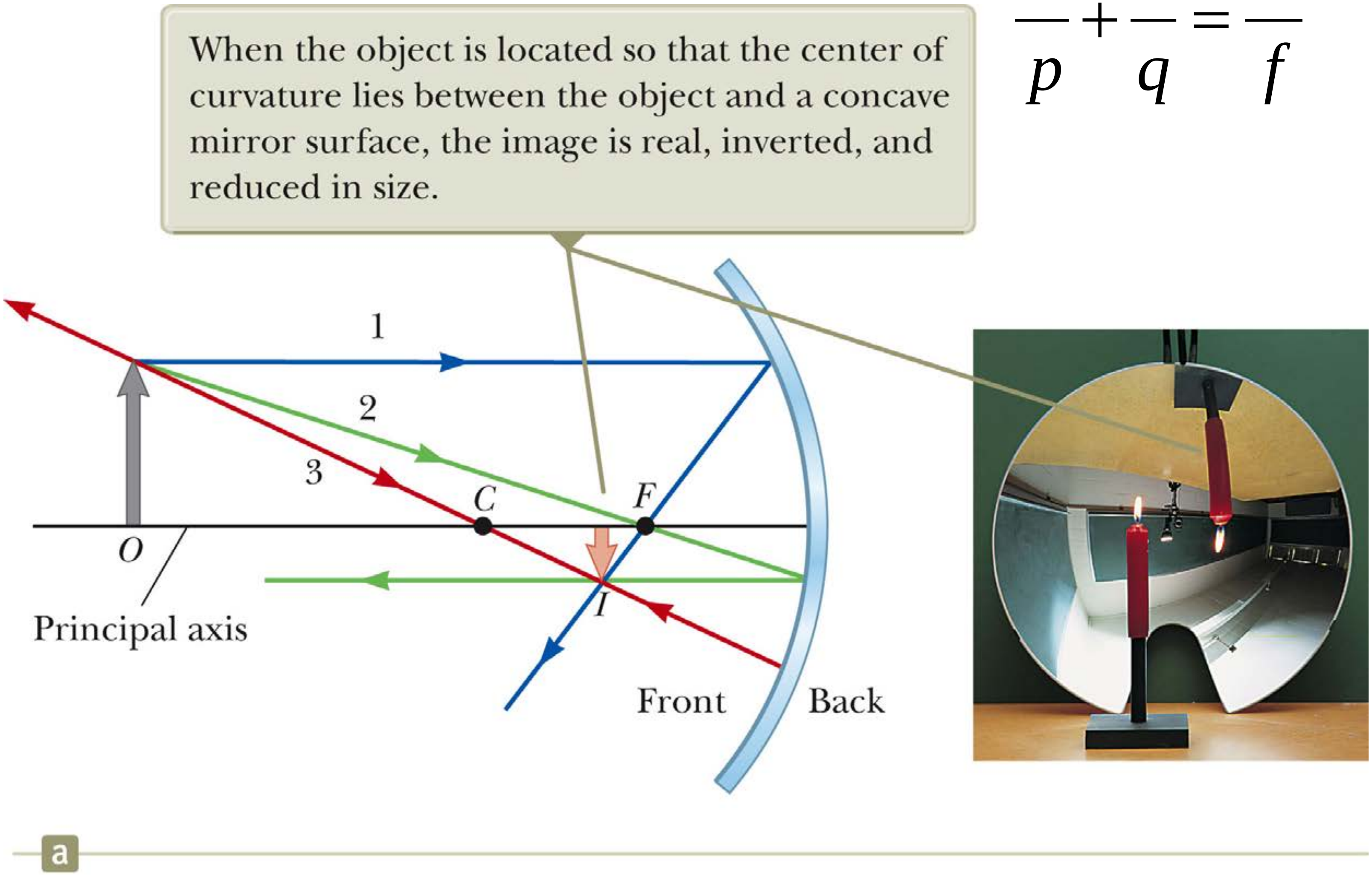
$$\frac{1}{p}+\frac{1}{q}=\frac{1}{f}$$



Real image ➔ **really** there

Mirror equation :

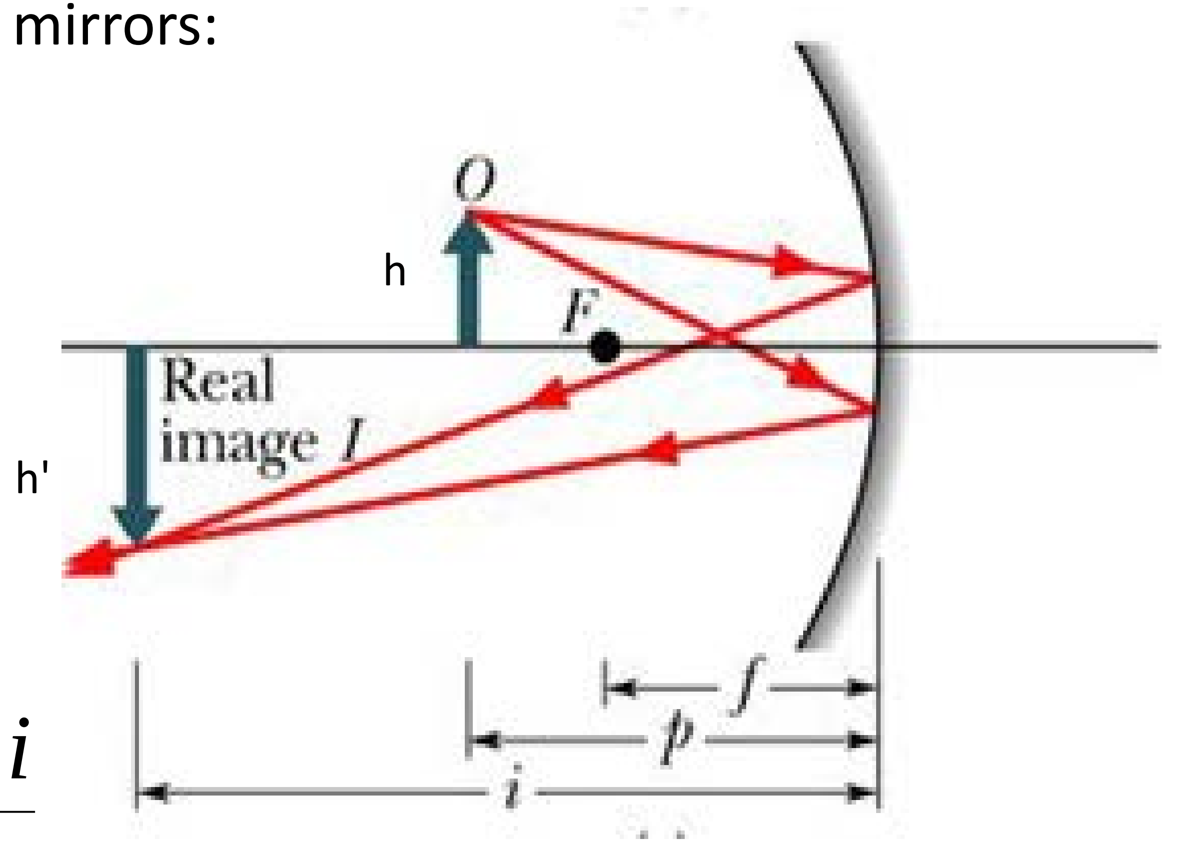
$$\frac{1}{p}+\frac{1}{q}=\frac{1}{f}$$



Summary of results for mirrors:

The mirror equation:

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



$$\text{Magnification}:$$

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

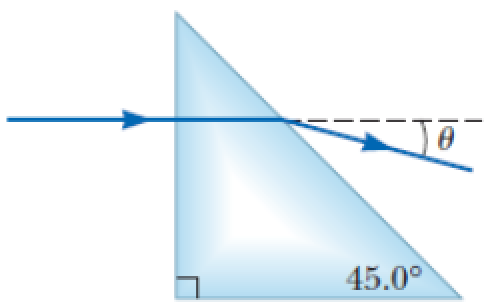
+ signs for: *p, f* (concave mirror),*i* (real image),*m* (upright image)

– signs for: *f* (convex mirror),*i* (virtual image),*m* (inverted image)

Homework hint: (HW 16)

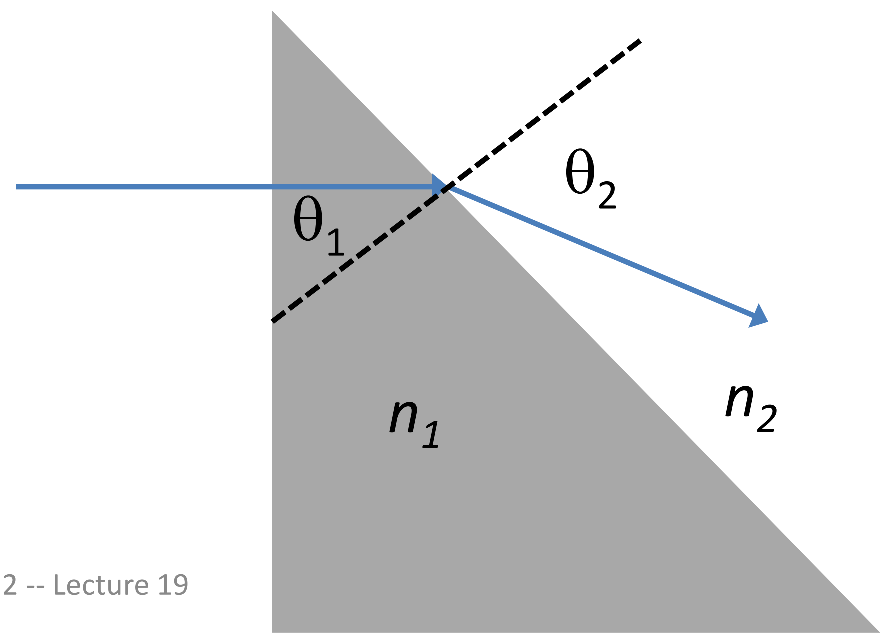
3. –/0.333 points | My Notes | SerPSE8 35.

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 θ = 28.8° with the direction of the incident beam. Find the index of refraction of the prism.



Basic principle : Snell's law

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



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

4. –/0.333 points My Notes | SerPSE8 36.P.031.

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.)

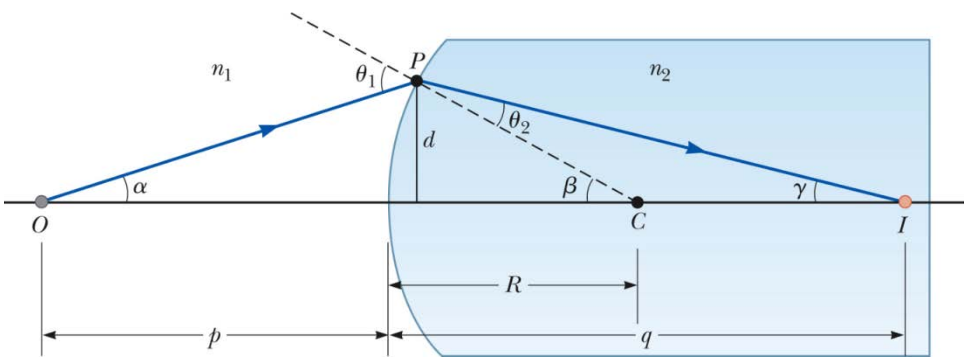
[ ] cm

Basic principle : Snell's law

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

For small angles :

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



For HW problem $R \to \infty$:

$$\frac{n_1}{p} + \frac{n_2}{q} = 0$$

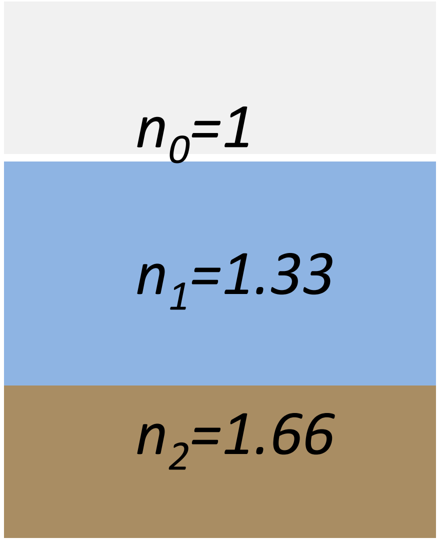
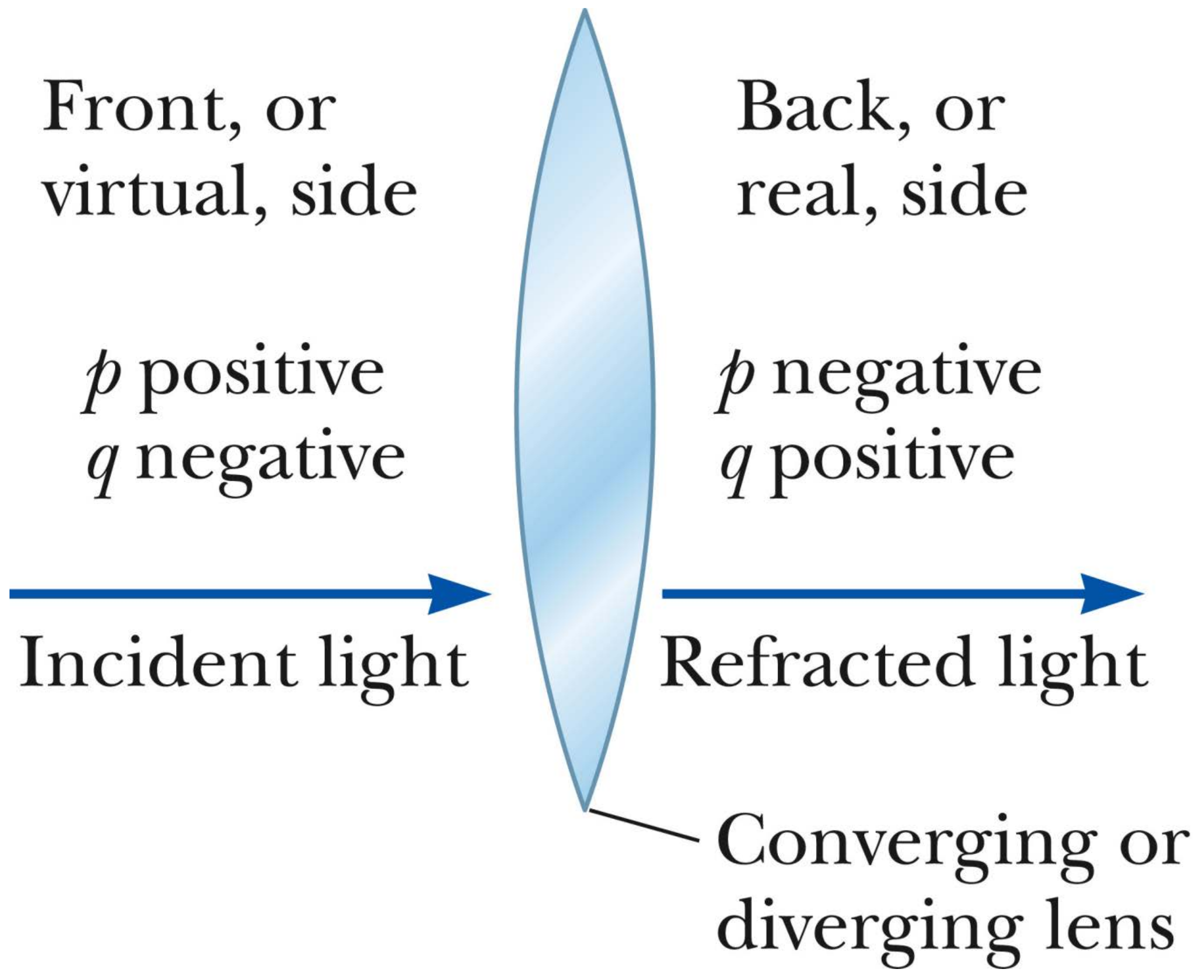


Image formation by refraction -- lenses

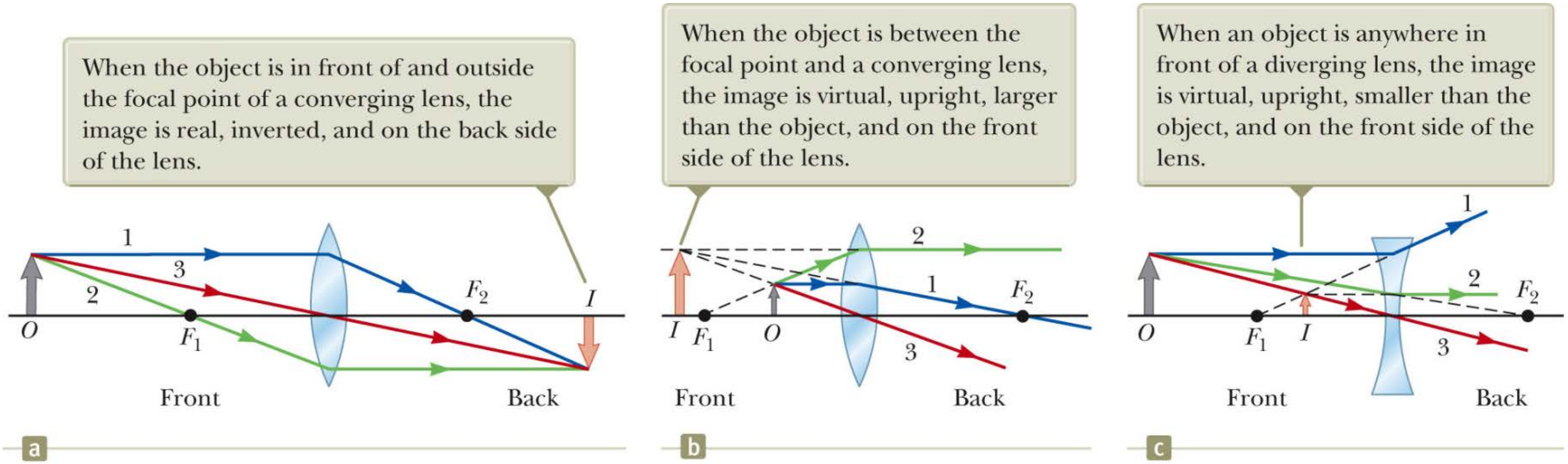
Thin lens equation

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



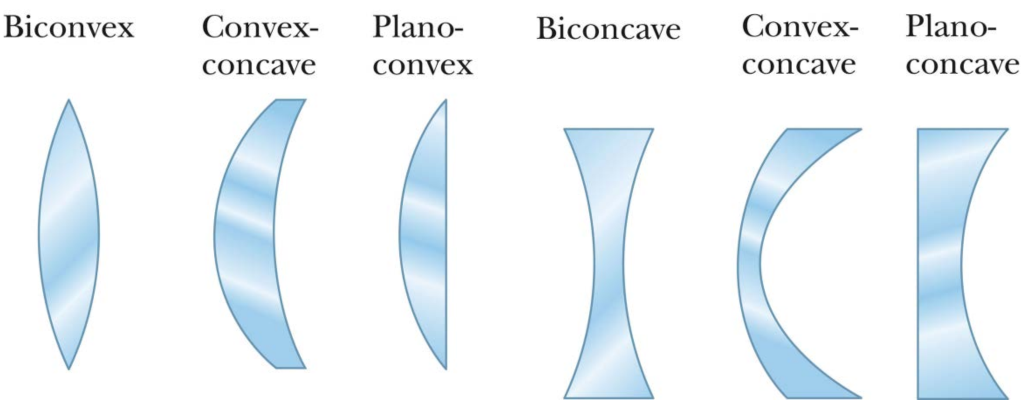
Summary of thin lens configurations

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



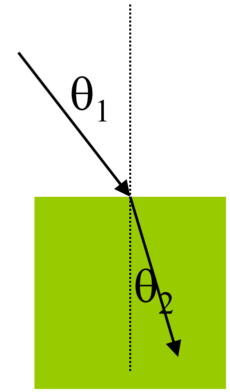
Lens makers' equation

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

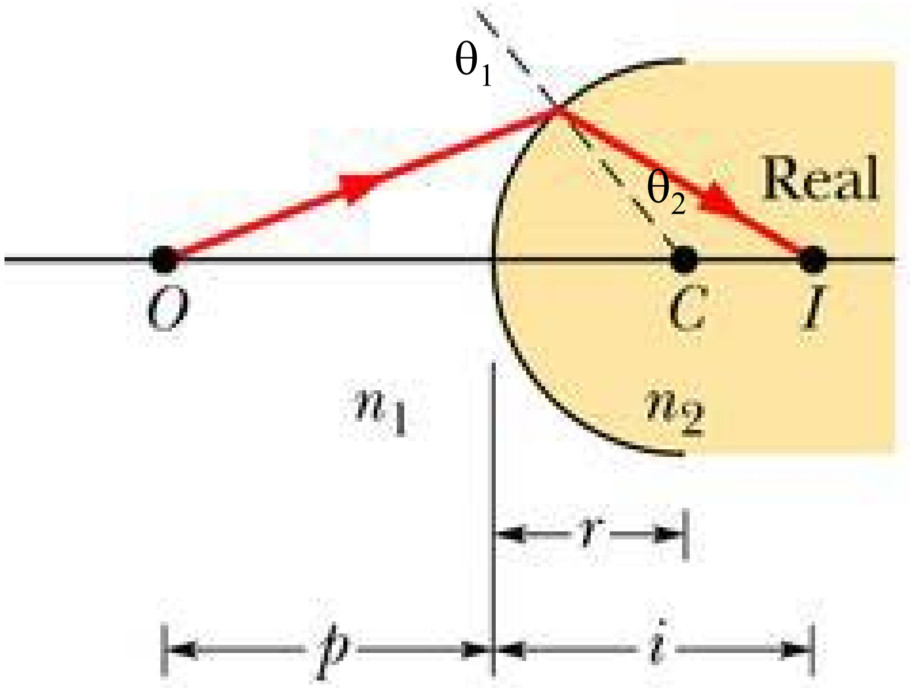


Basic physics of lenses:

Snell's law: $n_1 \sin \theta_1 = n_2 \sin \theta_2$



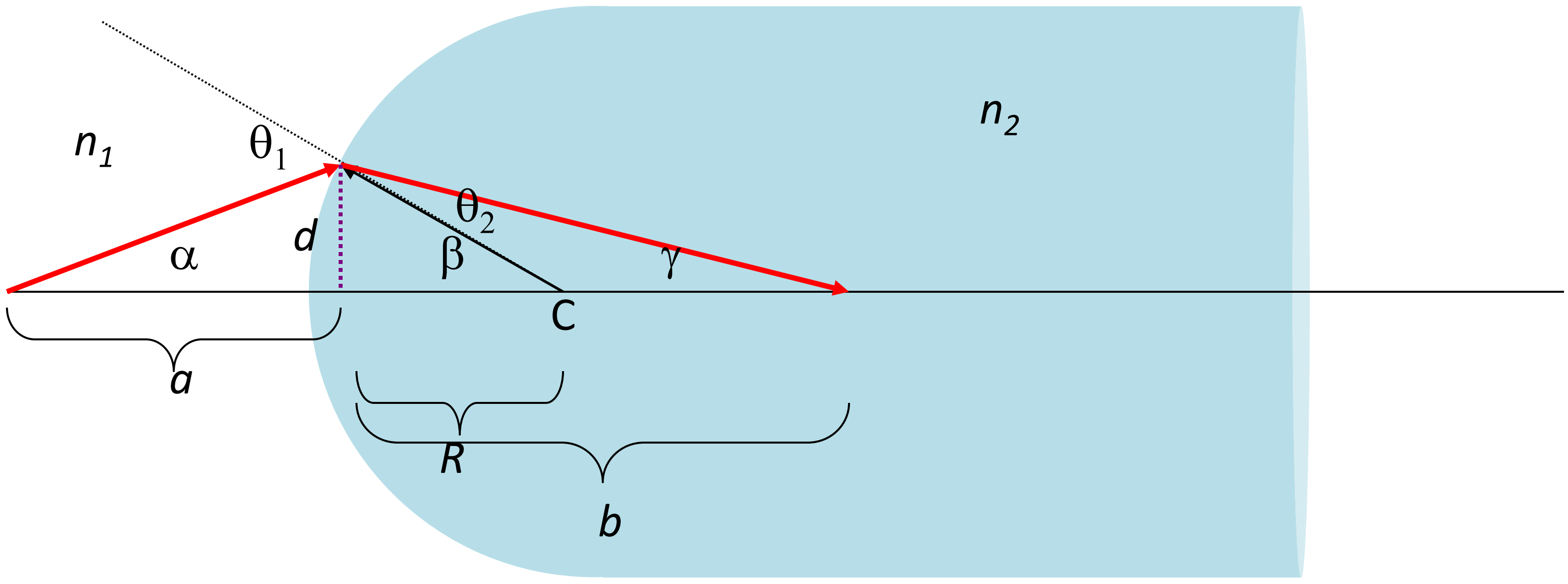
Refraction at a spherical surface:



Notation note:

$q \leftrightarrow i$

Refraction at a spherical surface



$$\theta_1 = \alpha + \beta$$

$$\theta_2 = \beta - \gamma$$

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

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \quad \Rightarrow n_1\theta_1 \approx n_2\theta_2$$

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

Refraction at a spherical surface – continued

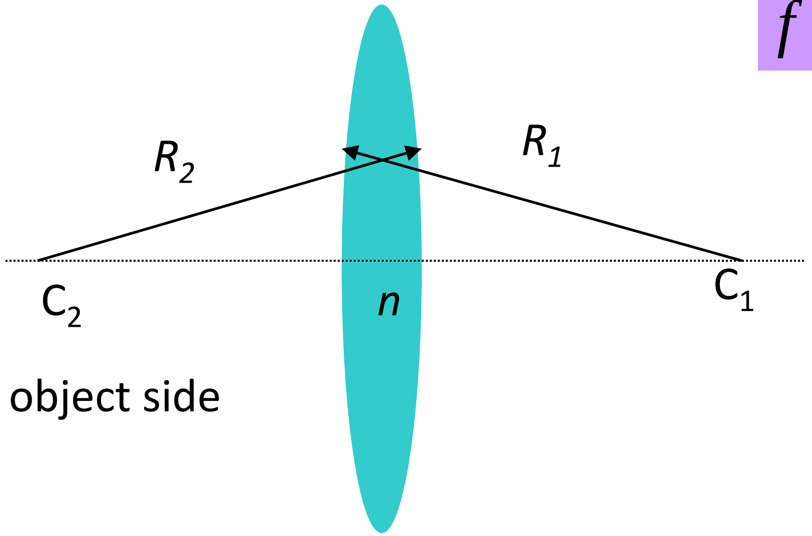
$$\frac{n_1}{a}+\frac{n_2}{b}=\frac{n_2-n_2}{R}$$

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

Application to 2 surfaces in thin lens geometry

➔ "lens makers' equation"

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

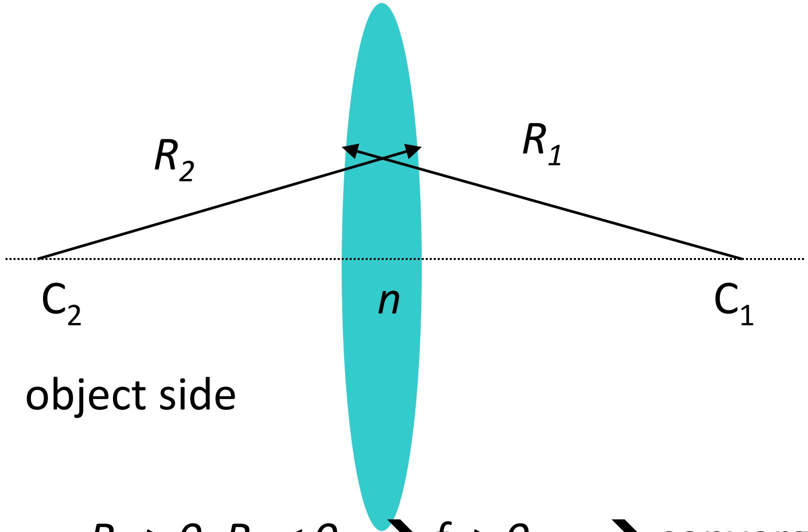


Sign convention:

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

Lens makers' equation – continued:

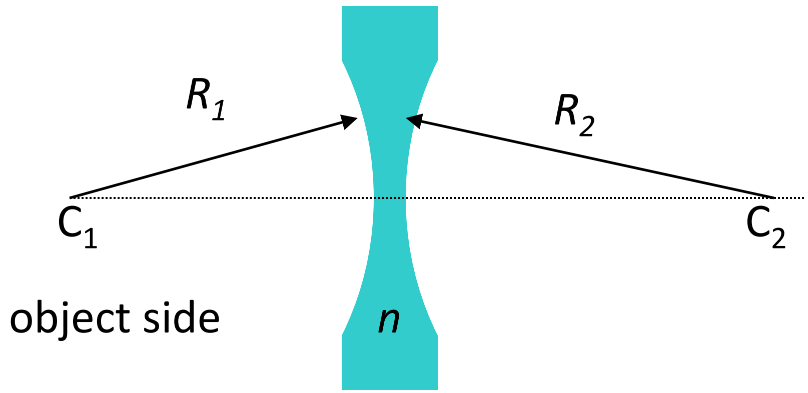
$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$



Sign convention:

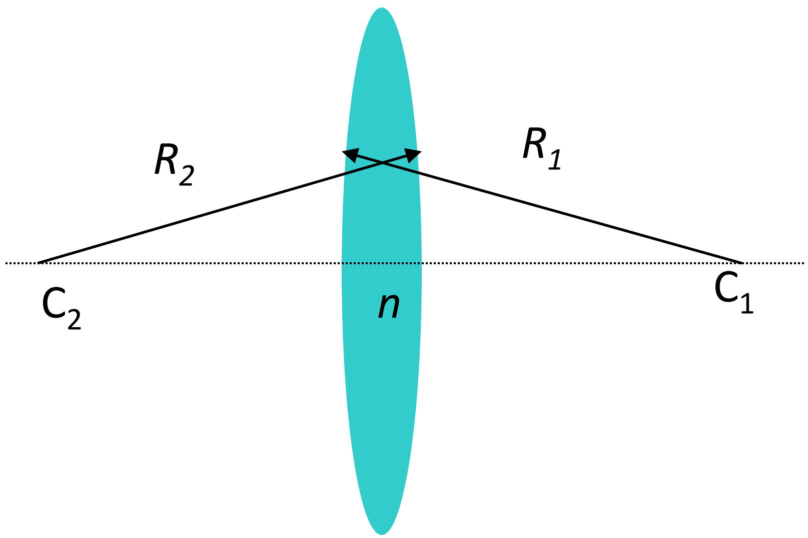
R_i is positive if it is convex relative to object and negative if it is concave relative to object.

$R_1 > 0$, $R_2 < 0$ ➔ $f > 0$ ➔ converging lens



$R_1 < 0$, $R_2 > 0$ ➔ $f < 0$ ➔ diverging lens

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

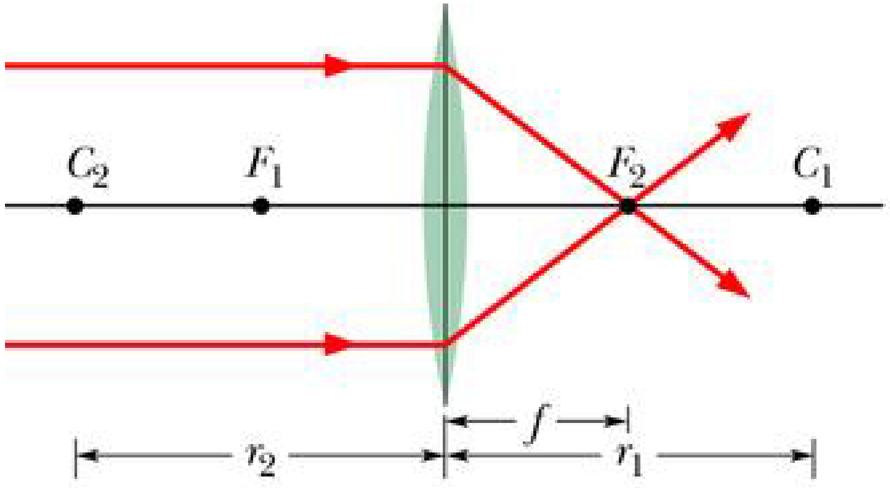
- Snell's law: $n_1 \sin\theta_1 = n_2 \sin\theta_2$
- small angle approximation: $\sin\theta_1 \approx \tan\theta_1 \approx \theta_1$
- thin lens approximation: thickness << *f,p,i*

➔ Lens equation:

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

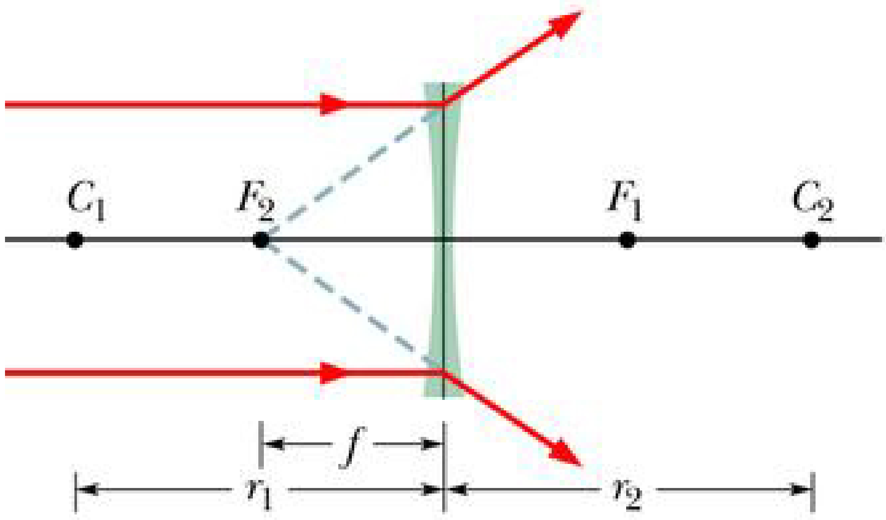
Example of thin lenses:

Converging lens: $f > 0$

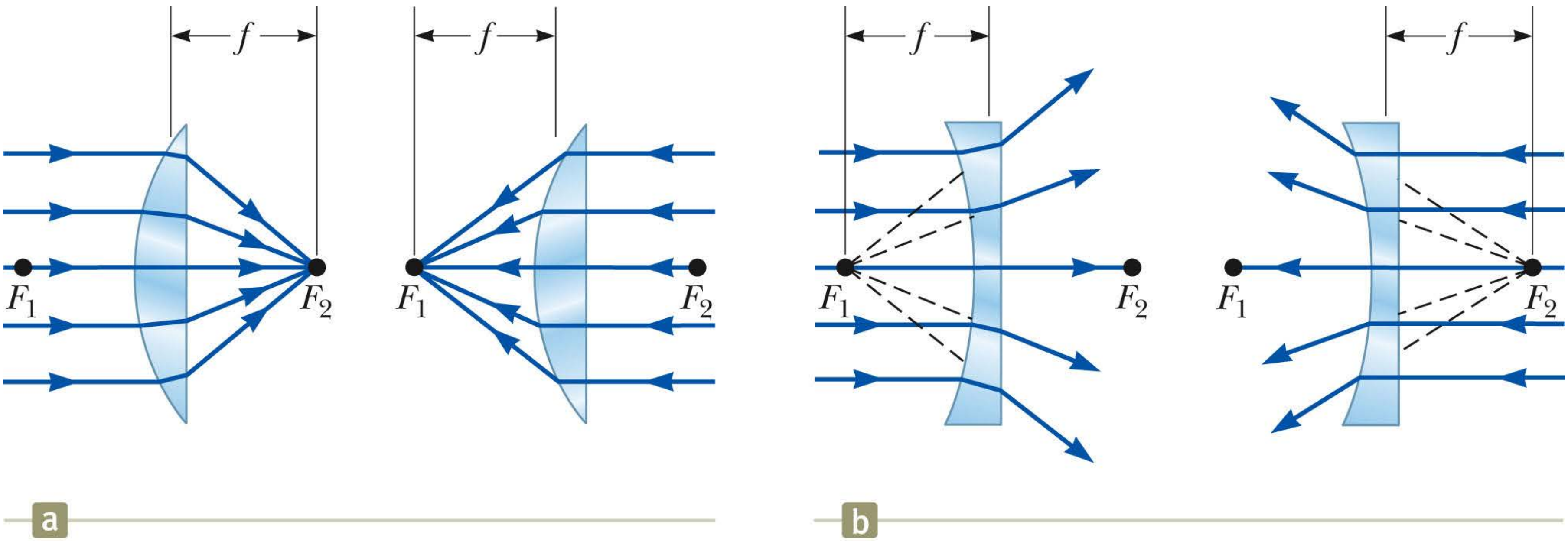


(a)

Diverging lens: $f > 0$

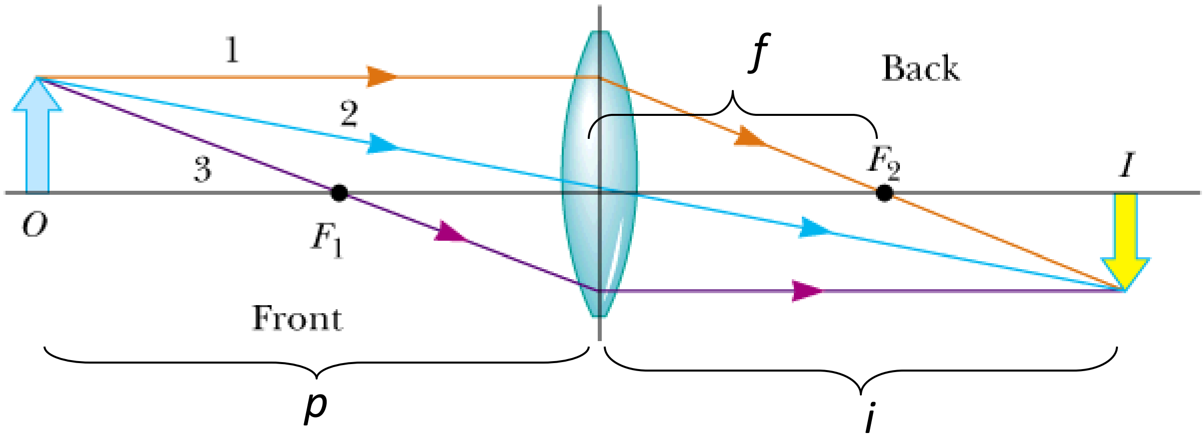


(c)


f
f
f
f
F_1
F_2
F_1
F_2
F_1
F_2
F_1
F_2
a
b

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 cm, p = 5 cm

➔ i = 3.33 cm

(real image)

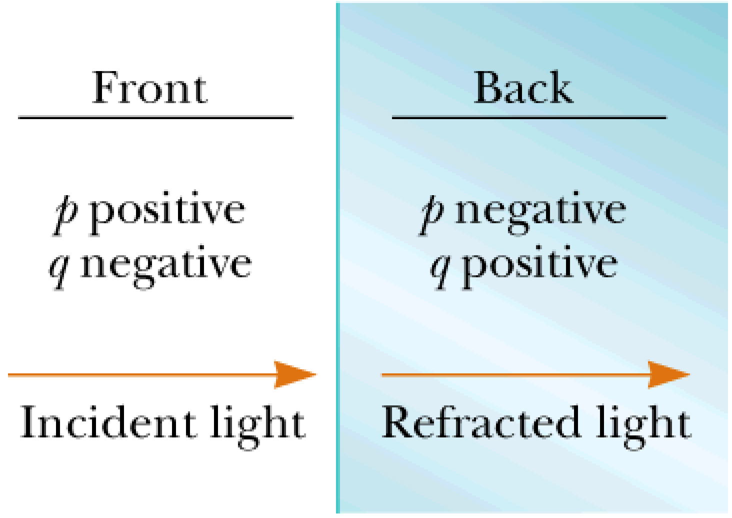
$$\frac{1}{5}+\frac{1}{i}=\frac{1}{2}$$

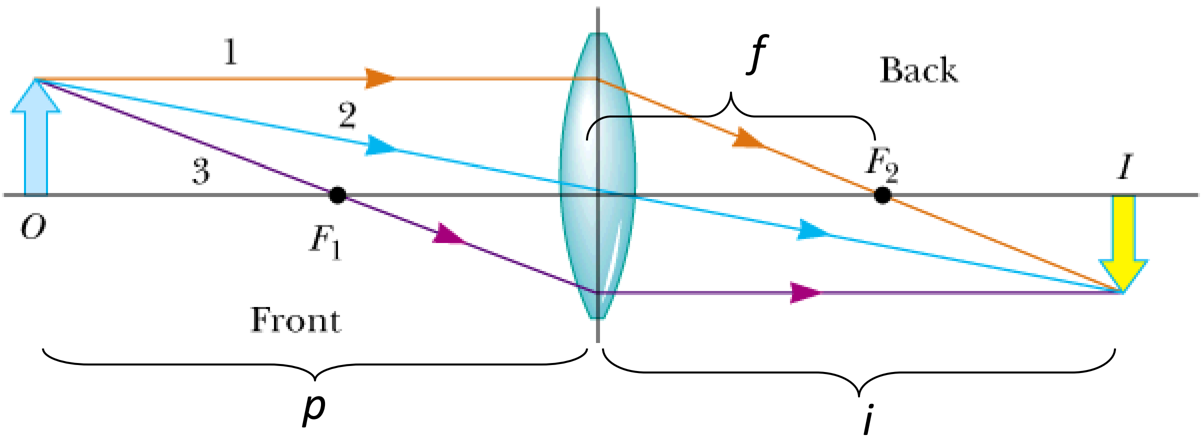
$$\Rightarrow i = 3.333$$

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

$$= \frac{-3.33}{5} = -0.67$$

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





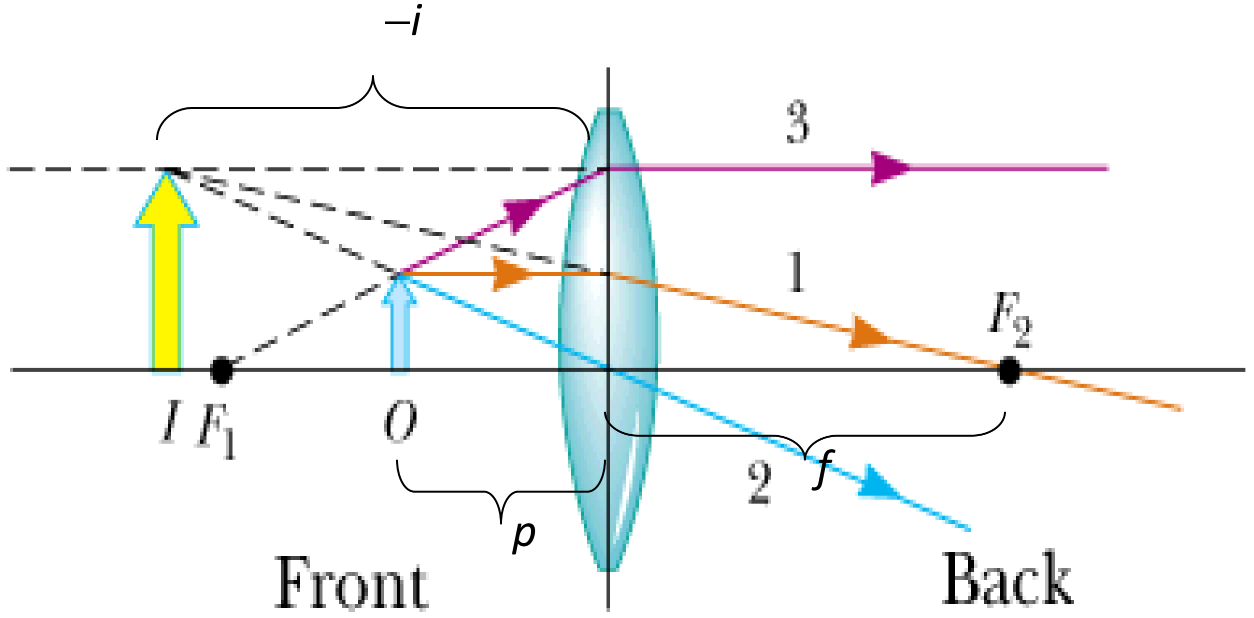
Example:

f = 2 cm, p = 5 cm

➔ i = 3.33 cm

(real image)

Thin lens refraction -- continued



Example:

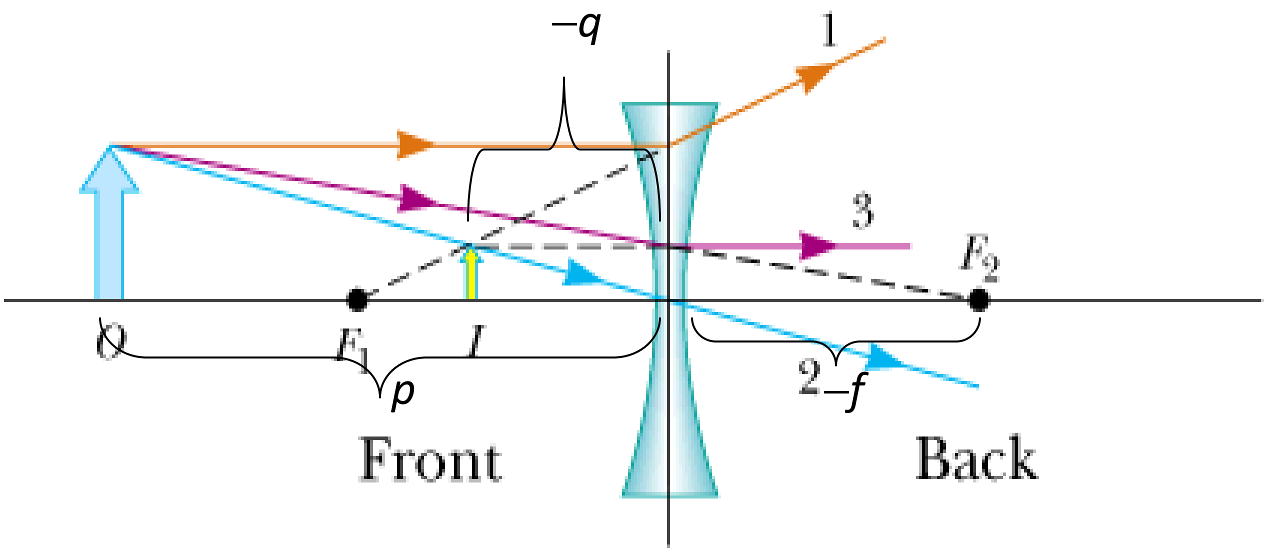
f = 2 cm, p = 1.2 cm

➔ i = -3 cm

(virtual image)

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

Thin lens refraction -- continued



Example:

f = -2 cm, *p* = 4 cm

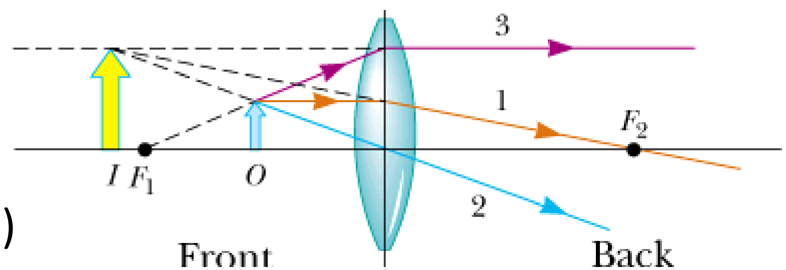
➔ *i* = -1.333 cm

(virtual image)

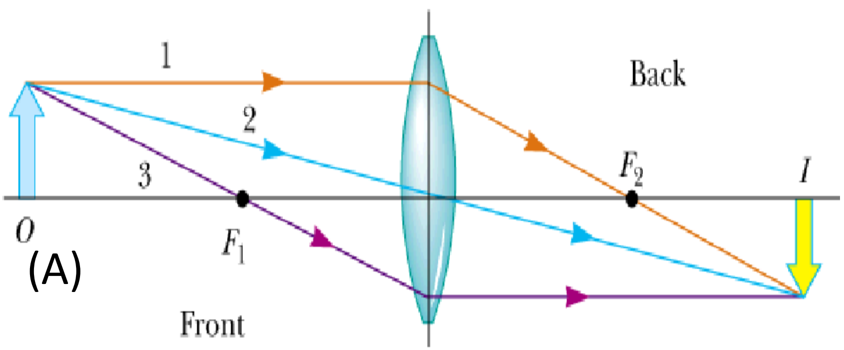
$$M = \frac{-i}{p} = 0.333$$

Sherlock Holmes is apparently examining some evidence.

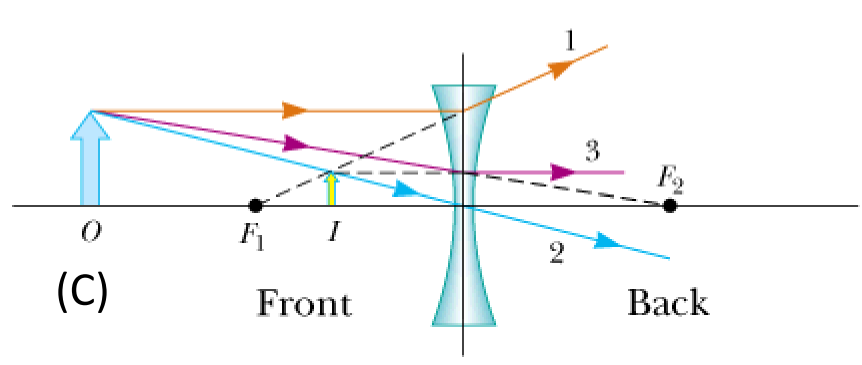
Which ray diagram most closely describes this situation:



(B)

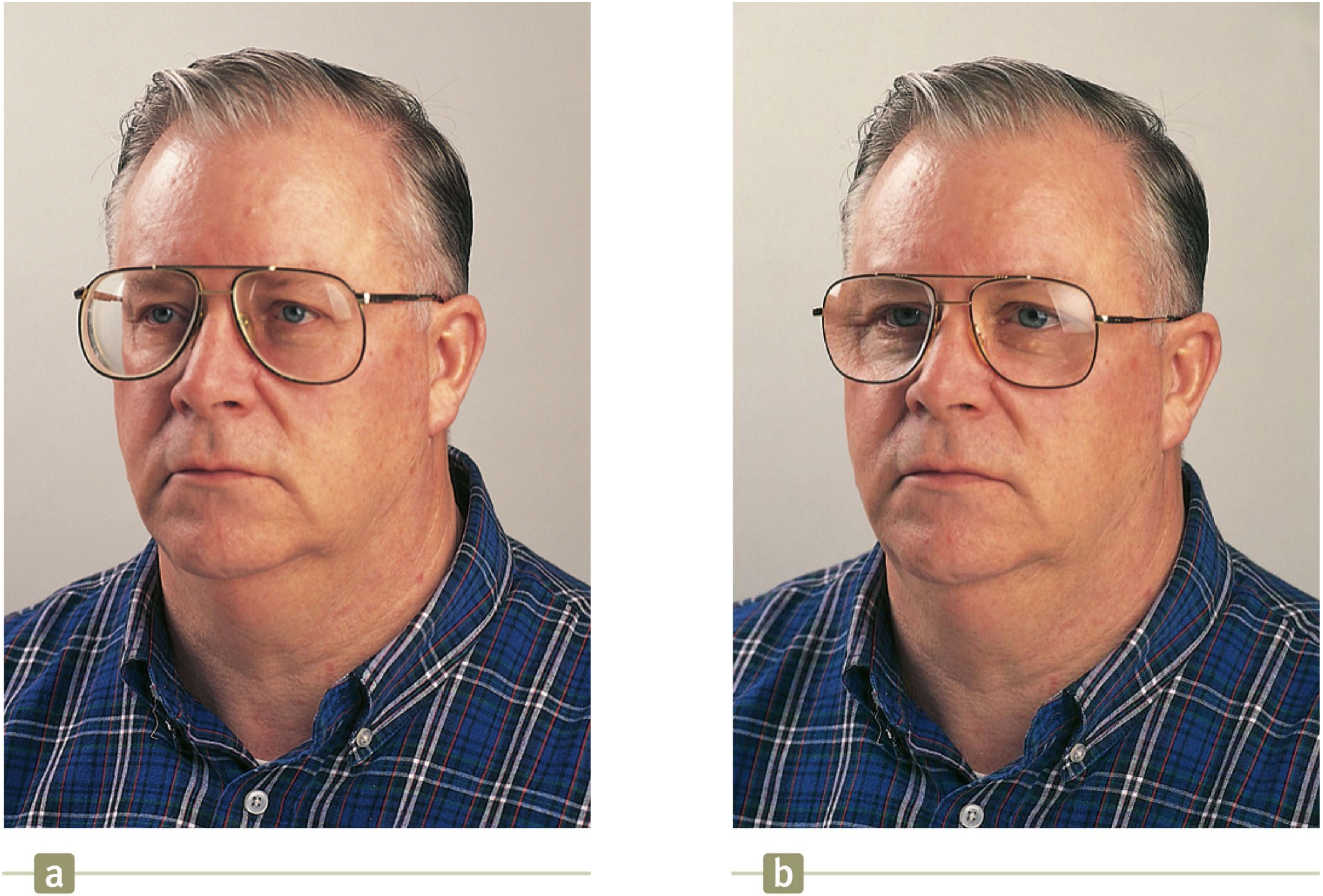


(A)



(C)

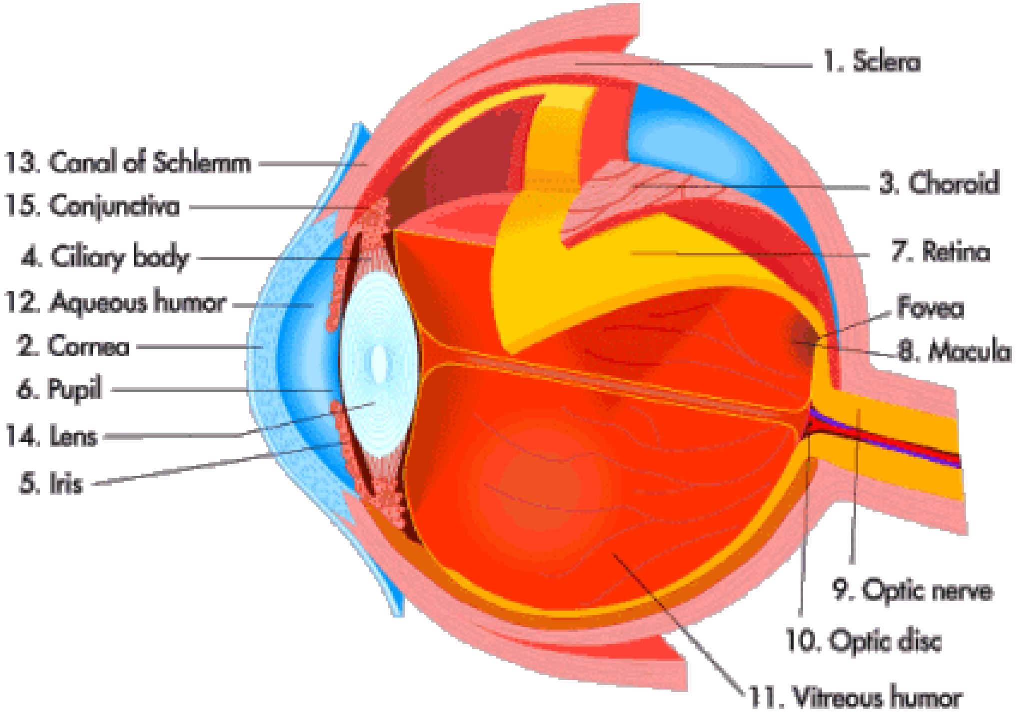
Which picture shows diverging corrective lenses? (A or B)

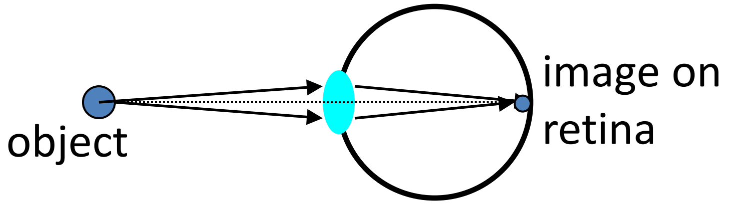


Which corrective lens is appropriate for nearsighted person?   (A or B)

View of the eye from

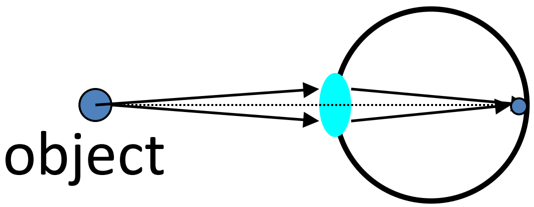
http://science.howstuffworks.com/eye1.htm





Vision problems and corrective lenses

Ideal vision:



Near sighted vision – problem with "Far point"

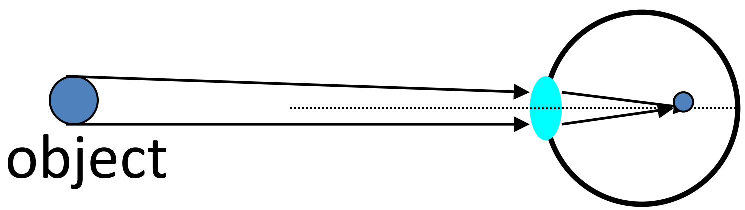


image in front of retina ➔ need diverging corrective lens

Far sighted vision – problem with "Near point"

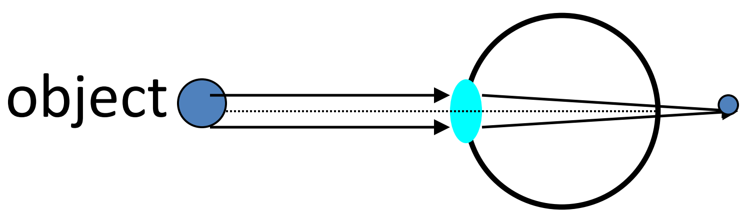
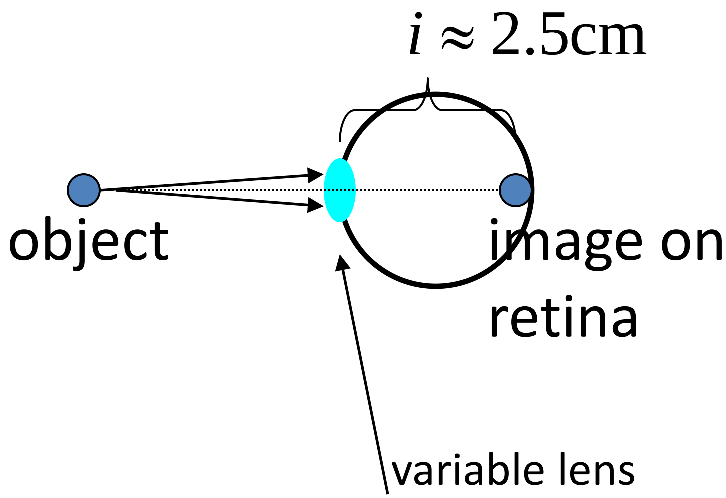


image in back of retina ➔ need converging corrective lens

More details about eye:



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

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

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

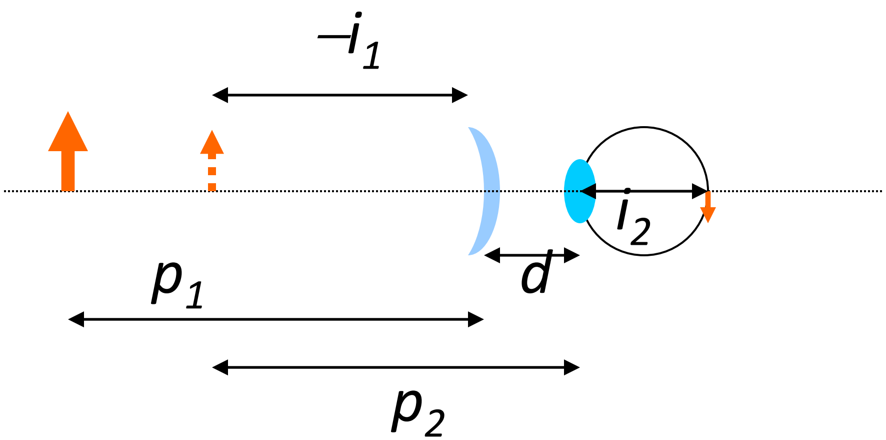
"near point" ≡ closest point that the eye can focus

25 cm standard value

7-200 cm depending on person

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:

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

We find:

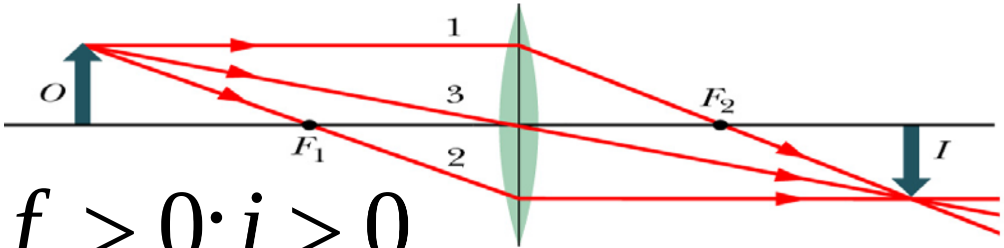
$i_1=-16.667\ \text{cm};\quad i_2=1.52\ \text{cm}$

Without the diverging lens:

$i_2=1.44\,\text{cm}$ (short of retina)

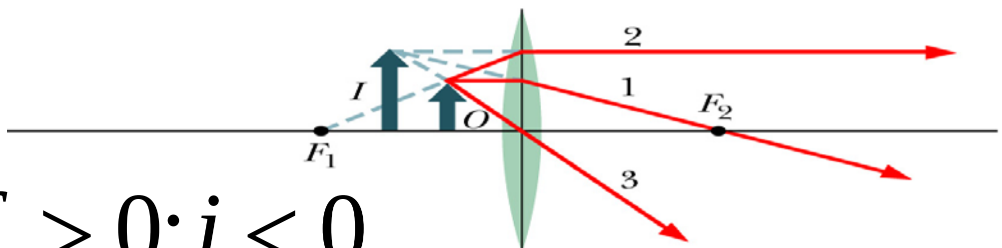
Thin lens equation:

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



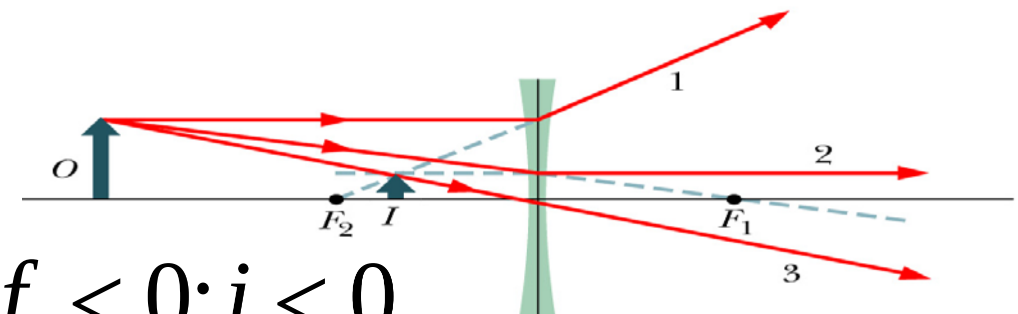
$f > 0; i > 0$

(a)



$f > 0; i < 0$

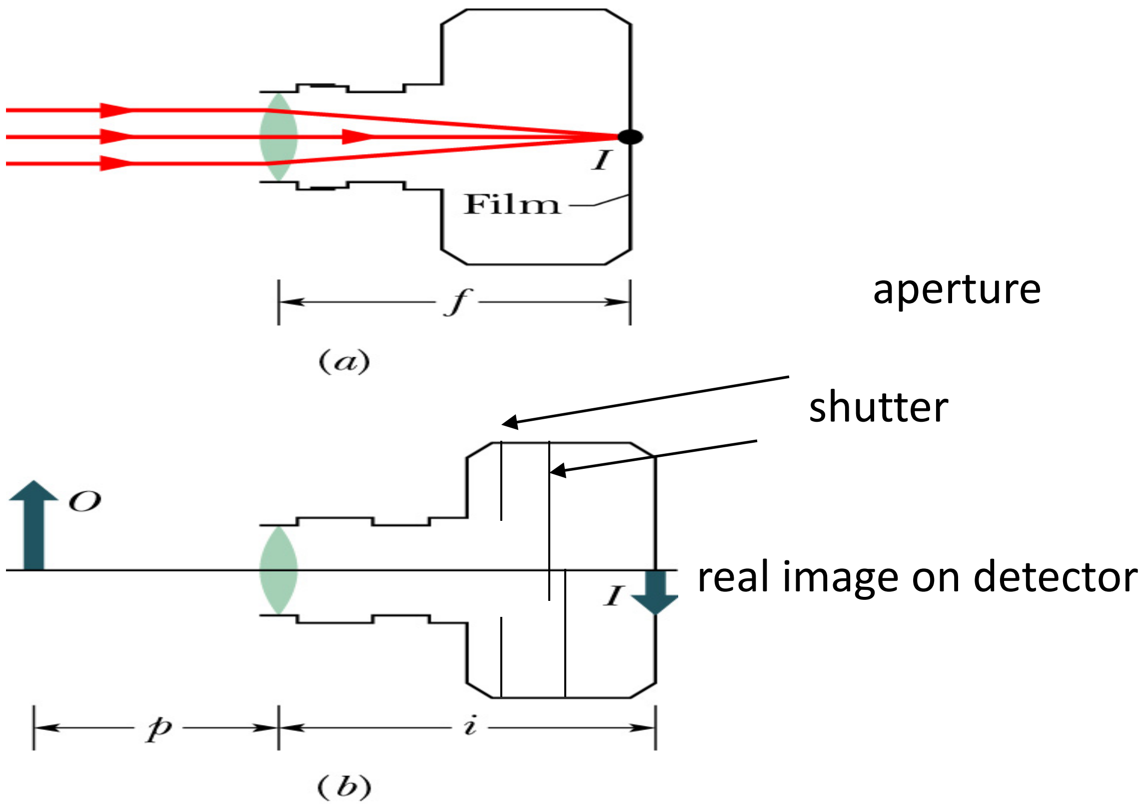
(b)



$f < 0; i < 0$

(c)

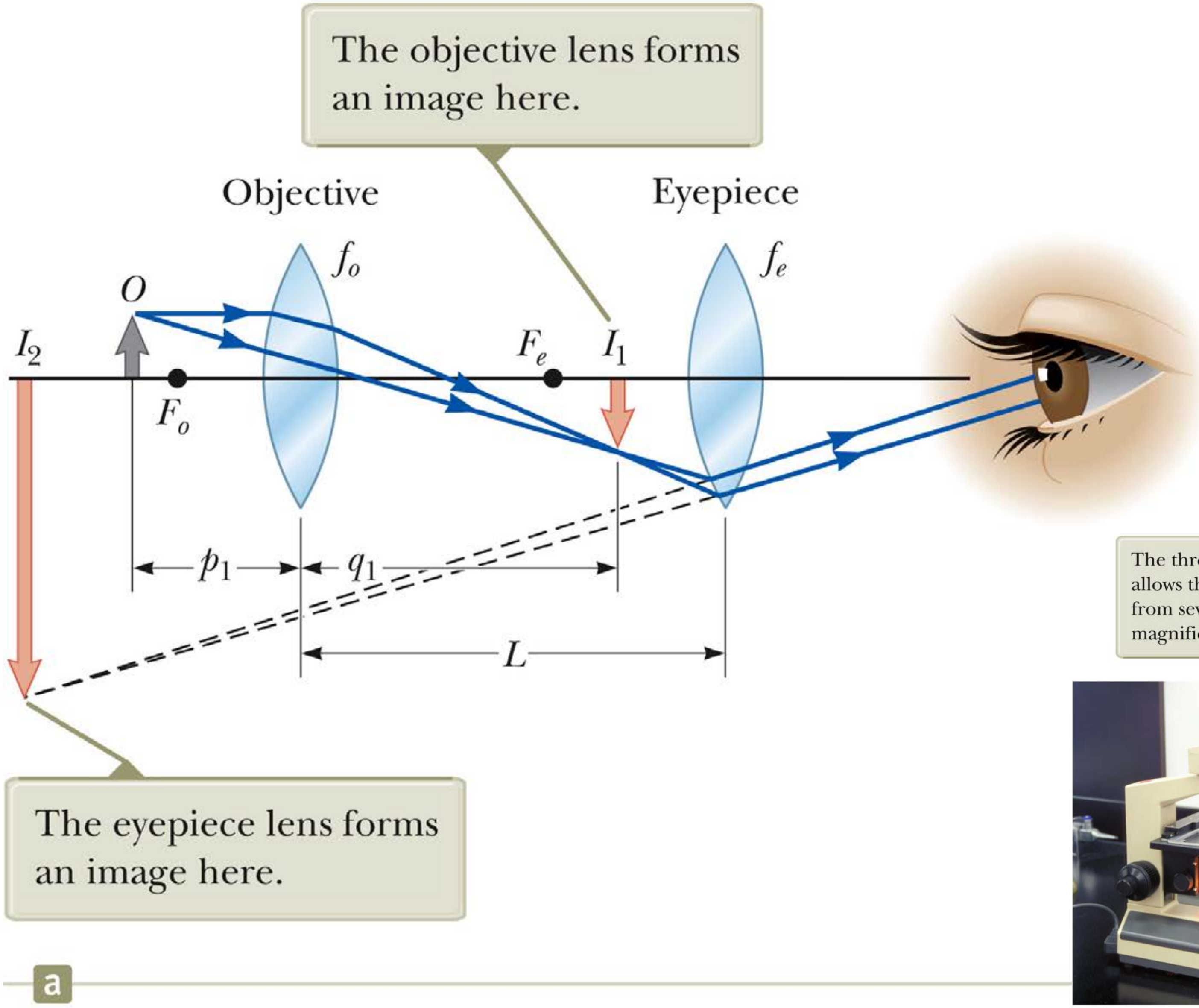
Physics of the camera

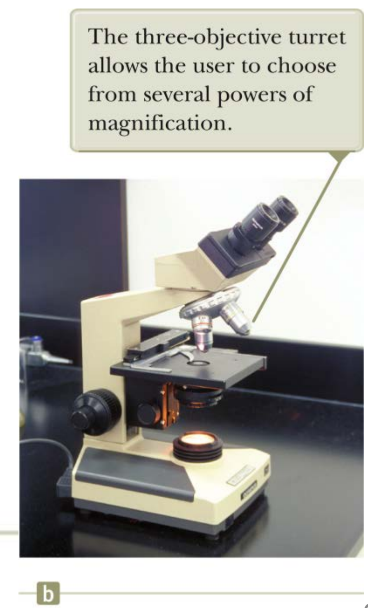


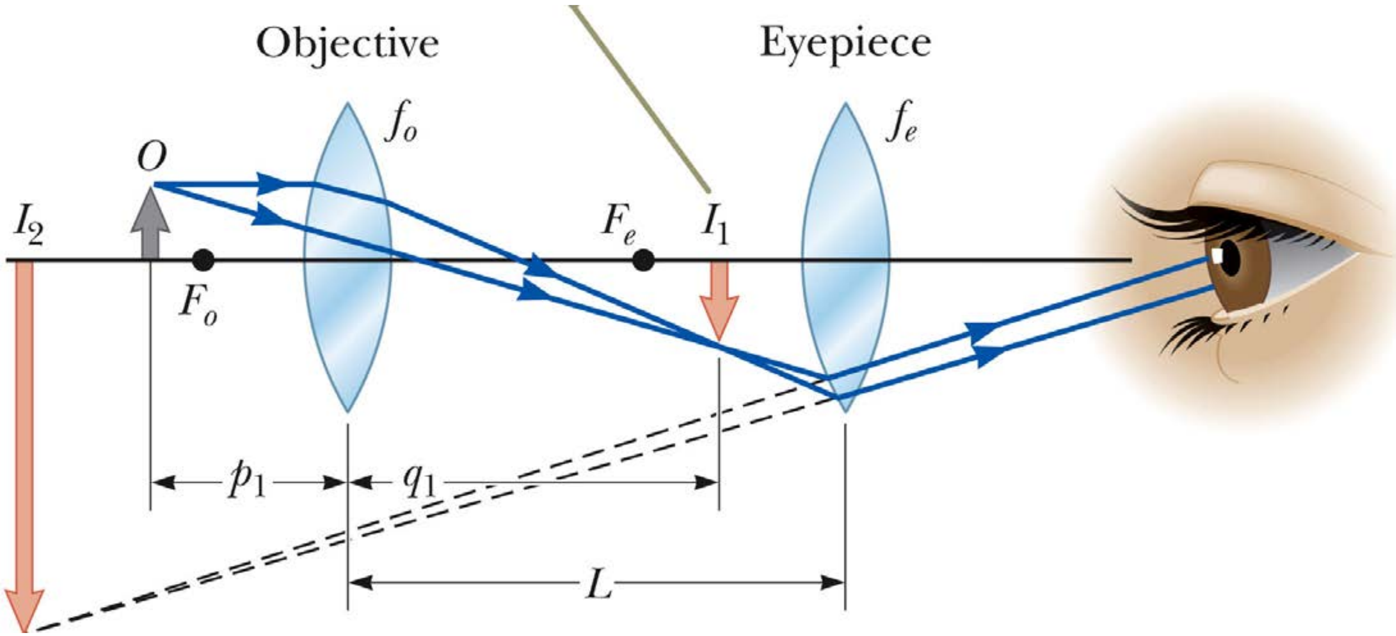
Example: *f*=50mm $\rightarrow$ *i*=50mm for *p*=∞

$\rightarrow$ *i*=51.3mm for *p*=2m

Compound microscope





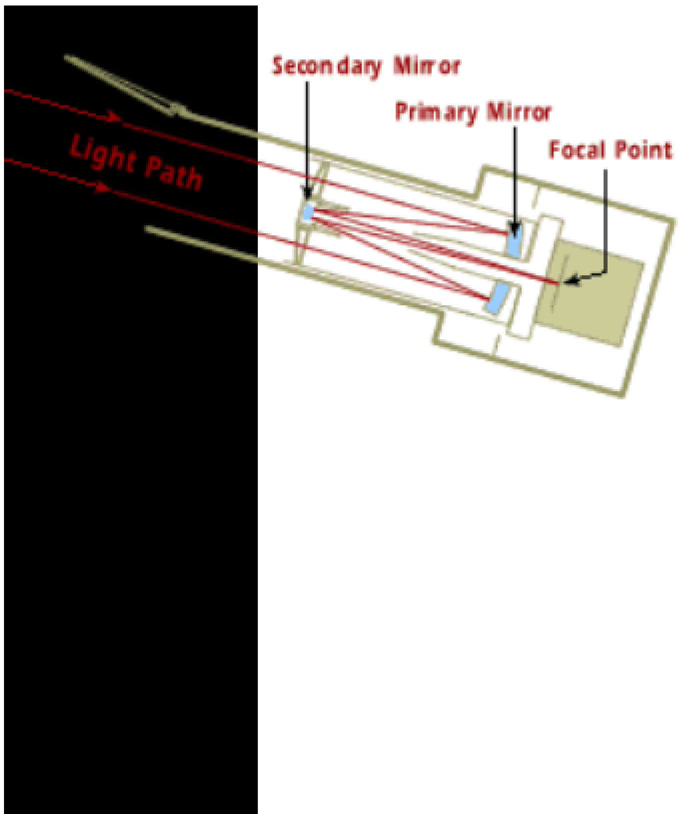


Suppose you want to record an microscope image. Where would you place the camera?

A. Where eye is
B. Not at eye position

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 x 10^{-8} m Al and 3 x 10^{-8} m MgF_2 (early version had 10^{-6} curvature error which was subsequently corrected)

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