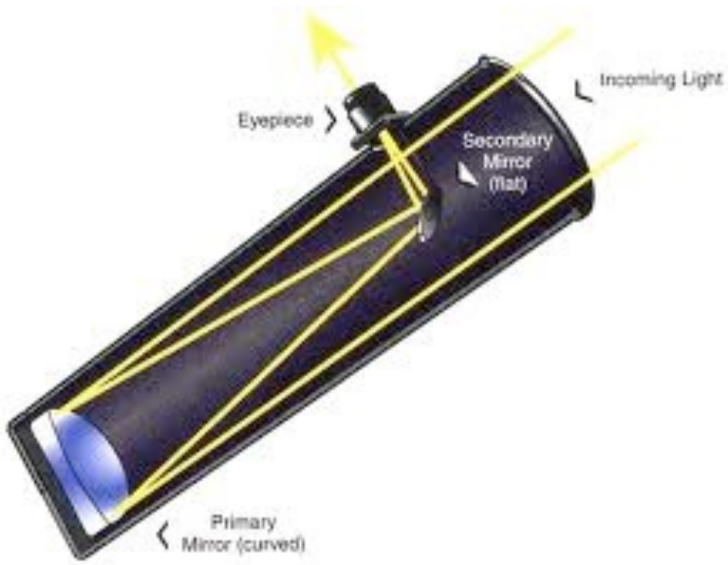
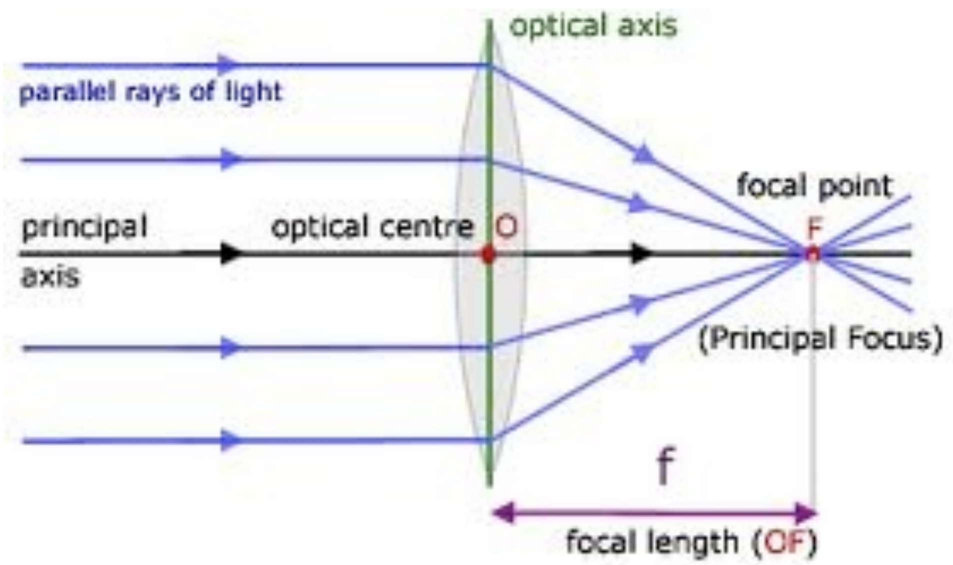
Optics

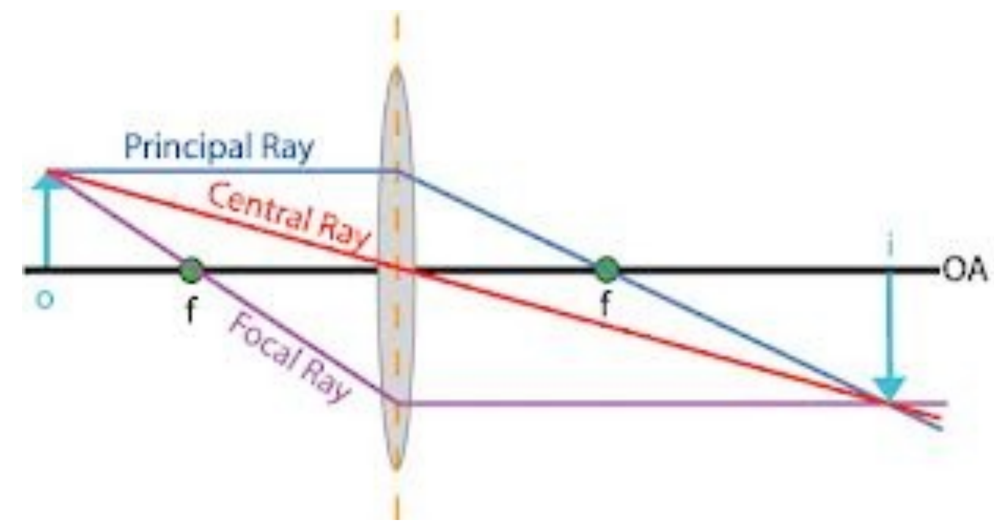
Ken Intriligator's week 8 lectures, Nov. 18, 2013



Recall Fermat principle

Light always takes the path of least (better: extremal) time. Ray diagrams: all paths take the same time.

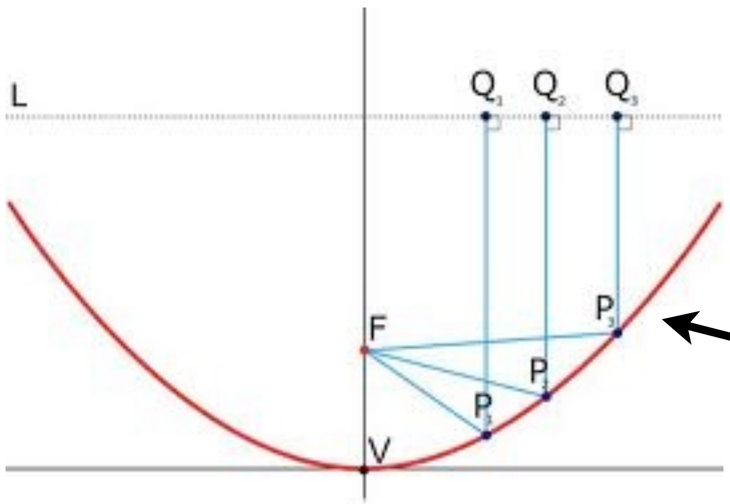




Fermat's principle gives a nice way to derive all of the formulae we'll be discussing this week. Another way is to just use Snell's law at each surface (see the book for this way).

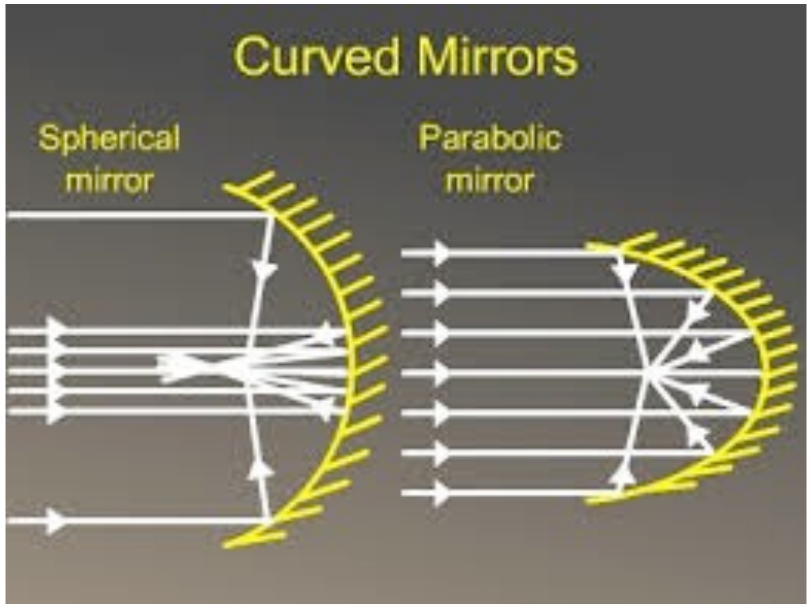
Focus plane waves:

(By reflection)



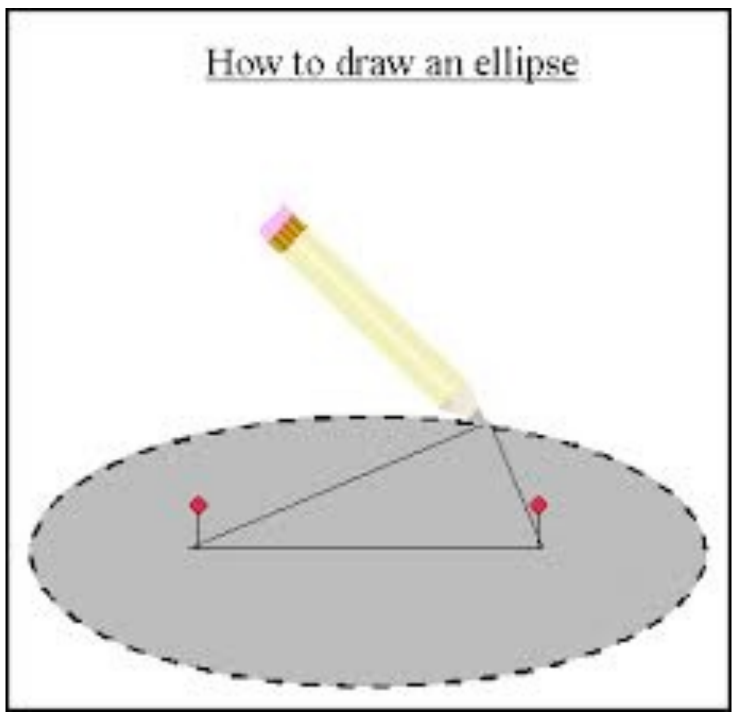
All these ray paths take same time, so same distance. The red curve is a **parabola, or paraboloid** in 3d. The shape of satellite dishes.

It is easier to make a spherical surface than a parabolic one, gives approximately good focusing.

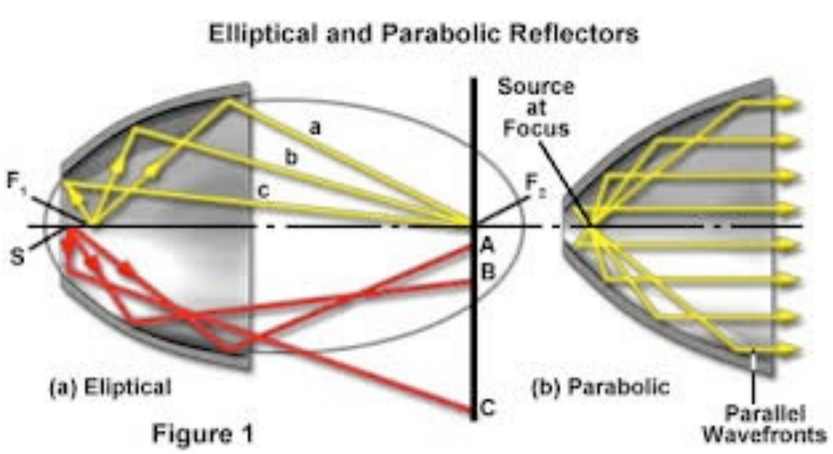


Focus point to point

Find the shape to focus the light rays, coming off a point source, to an image point.



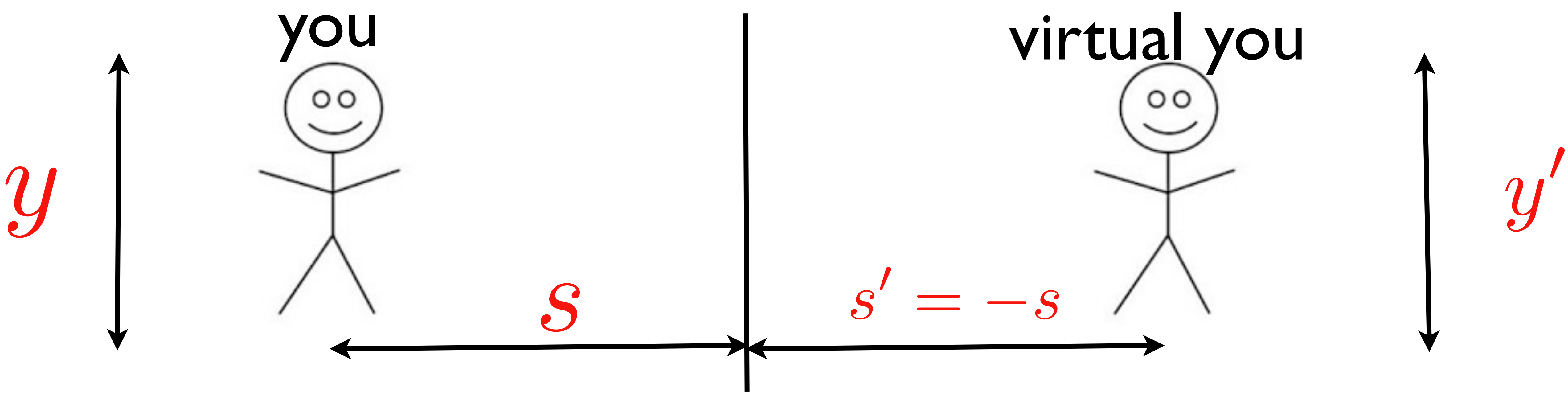
Ellipse does this. Sometimes you can find an elliptical room. Listening from one focal point, you can perfectly hear your friend wispering at the other focal point.



Taking one of the focal points to infinity gives the parabola.

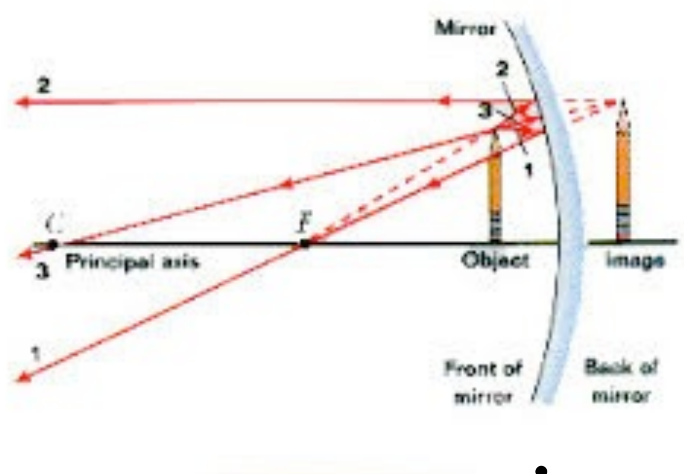
Real vs virtual images

Previous examples were focusing light to a point, gives a "real image," i.e. one that can be projected on a screen. A "virtual image" is only apparent, e.g. your reflection in a plane mirror:

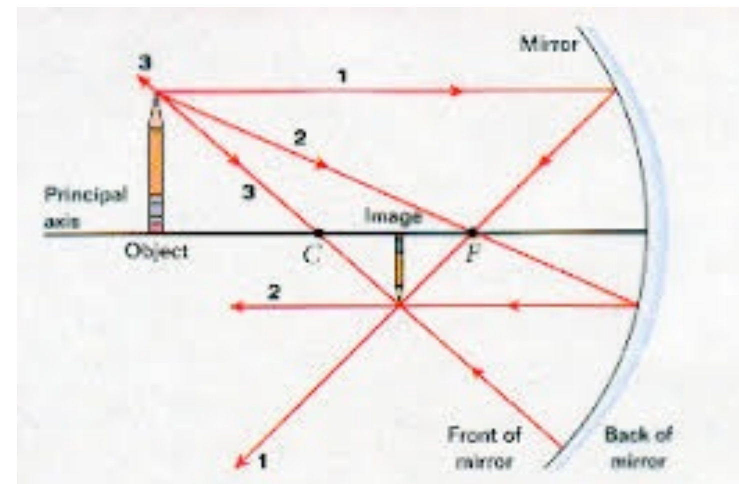


Magnification $m \equiv \frac{y'}{y}$ $m_{plane\ mirror} = 1$

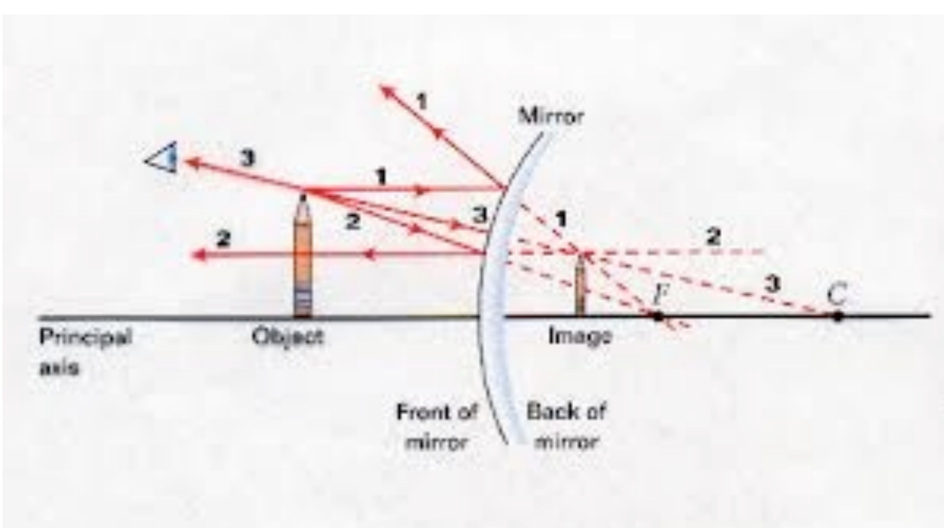
spherical mirrors



or



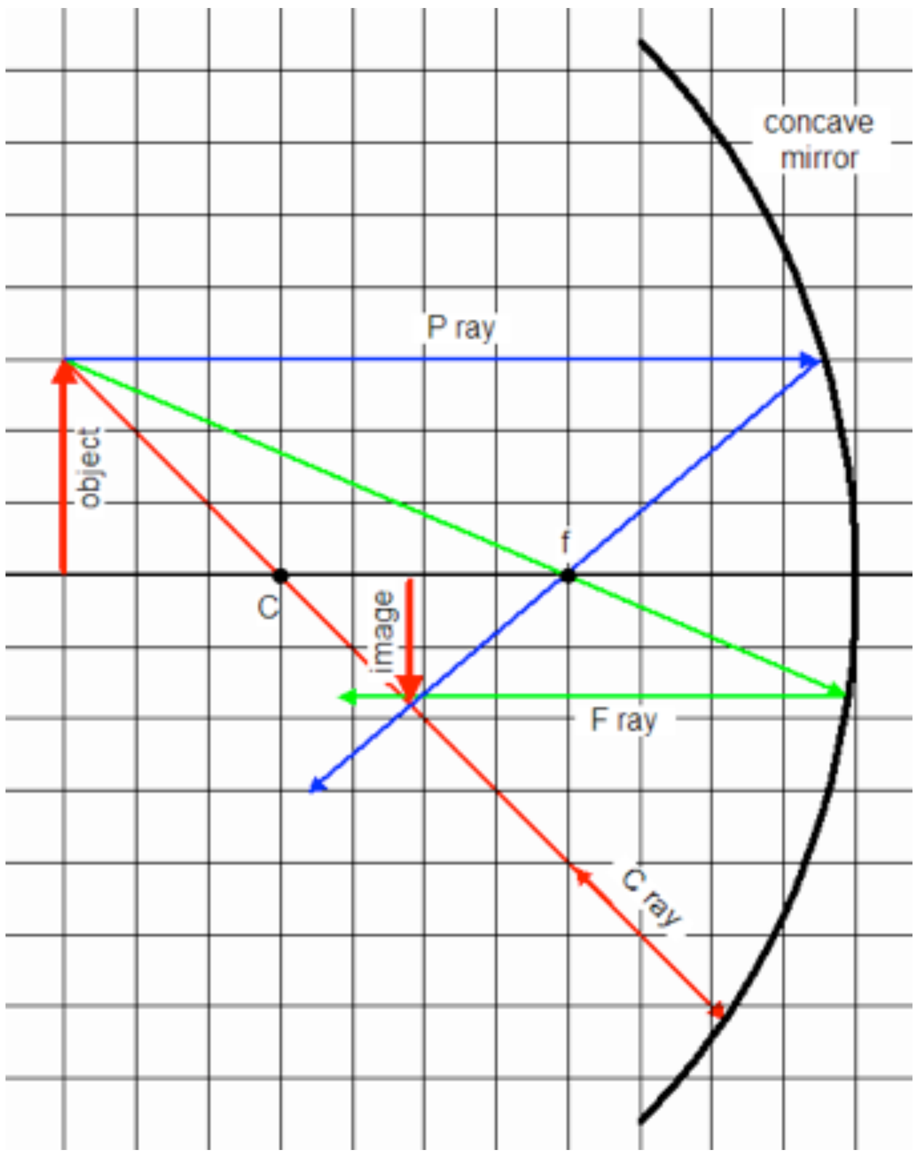
try it with a spoon..



Darrell suspected someone had once again slipped him a spoon with the concave side reversed.

Spherical mirror eqn.

Can derive from Fermat's principle:



$$\frac{1}{s} + \frac{1}{s'} = \frac{2}{R} = \frac{1}{f}$$

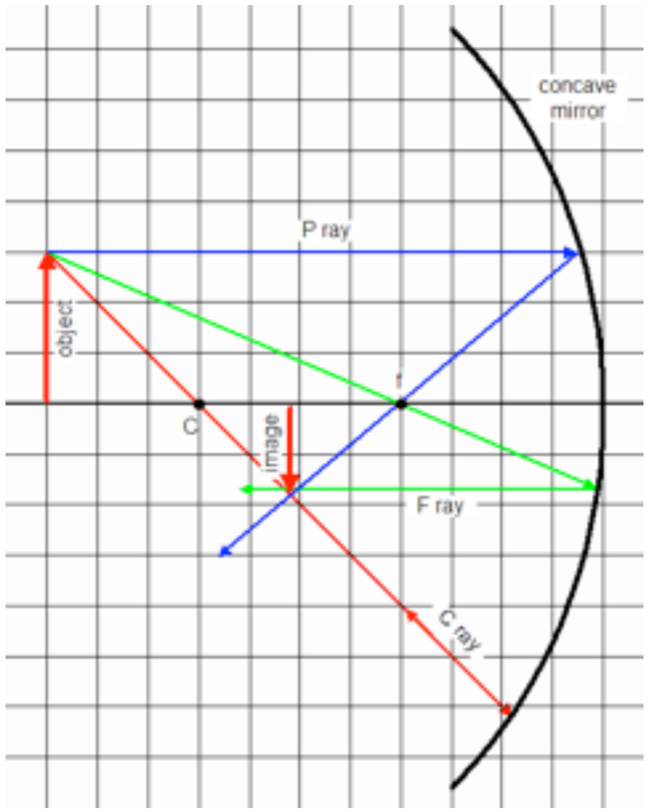
s = distance of object to mirror along axis.

s' = distance of image to mirror along axis. s'>0 if a real image, on same side of mirror as object. s'< 0 if virtual image, on the other side of mirror.

R = radius of sphere. Positive for concave mirror, and negative for convex mirror. Infinite for flat mirror.

f= focal length. Rays from s=infinity go here.

Concave* mirror



$$\frac{1}{s} + \frac{1}{s'} = \frac{2}{R} = \frac{1}{f} \overset{*}{>} 0$$

$s > f \rightarrow s' > 0$ real image

$s < f \rightarrow s' < 0$ virtual image

magnification: $m = \frac{y'}{y} = -\frac{s'}{s}$

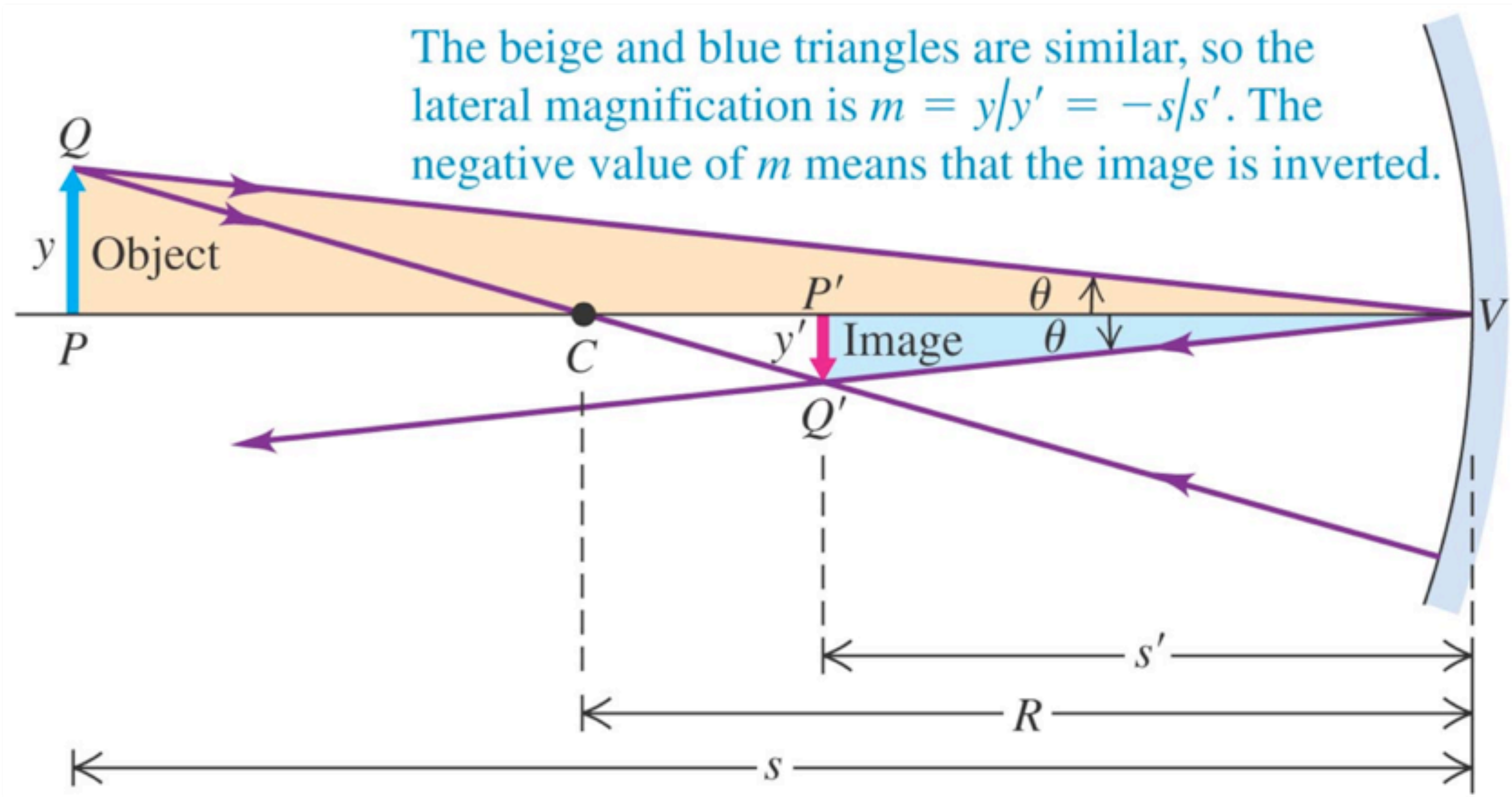
m>1: bigger, rightside up
0<m<1: smaller, rightside up.
m<0: upside down

E.g. plane mirror: infinite R, s'=-s, m=1.

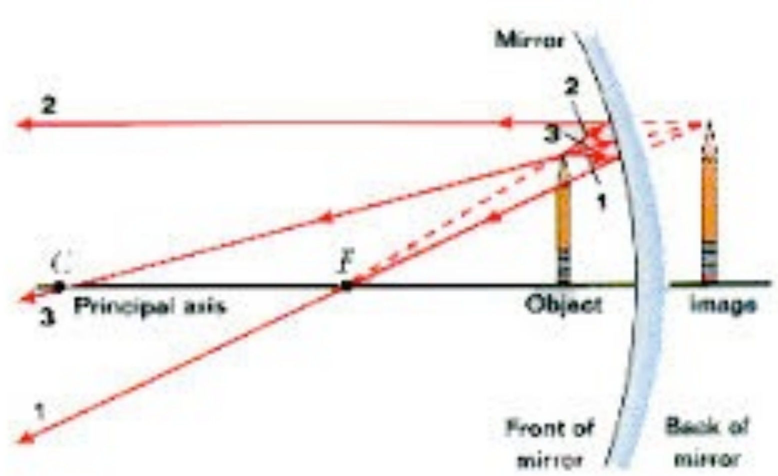
Can get upside down real image or rightside up virtual image.

Image of an extended object

- Figure 34.14 below shows how to determine the position, orientation and height of the image.

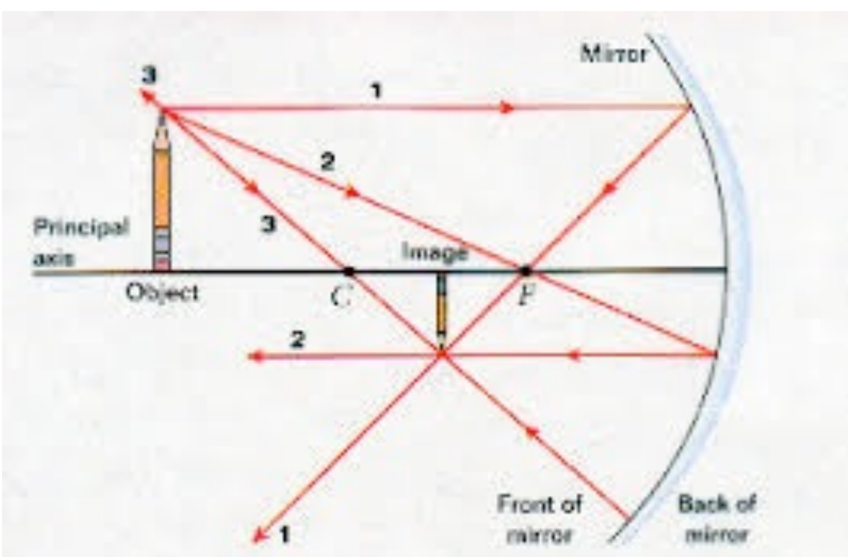


Concave mirror, cont.



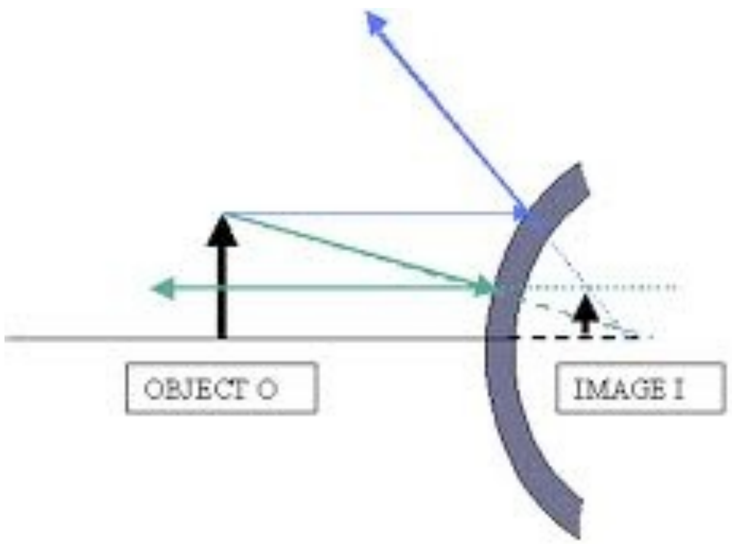
$s > f \rightarrow s' > 0$ real image

$s < f \rightarrow s' < 0$ virtual image



$$m = \frac{y'}{y} = -\frac{s'}{s}$$

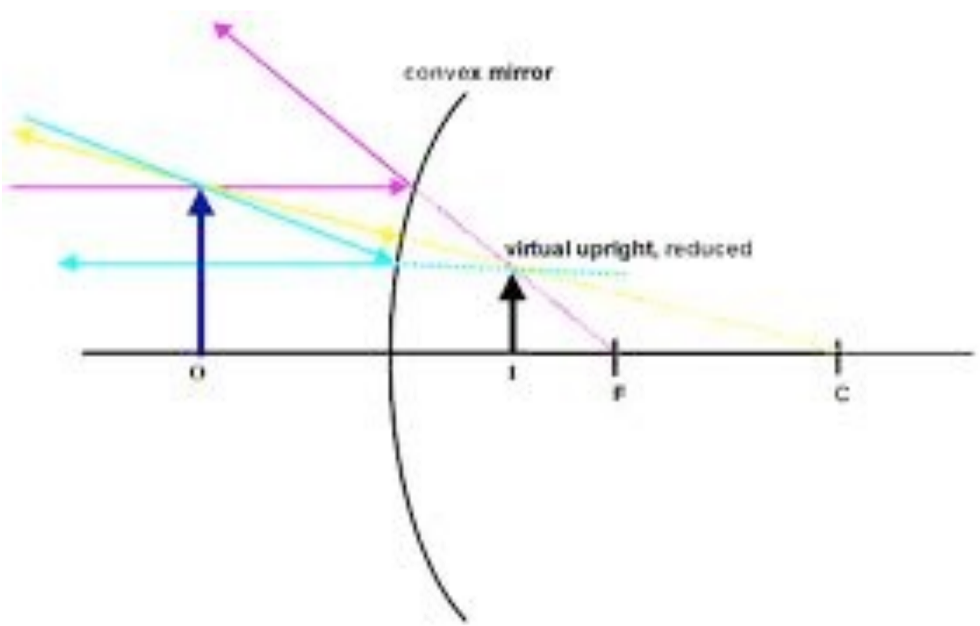
Convex* mirror



$$\frac{1}{s}+\frac{1}{s'}=\frac{2}{R}=\frac{1}{f}^{*}<0$$

$$s'<0 \qquad |s'|<s$$

magnification: $m=\frac{y'}{y}=-\frac{s'}{s}$

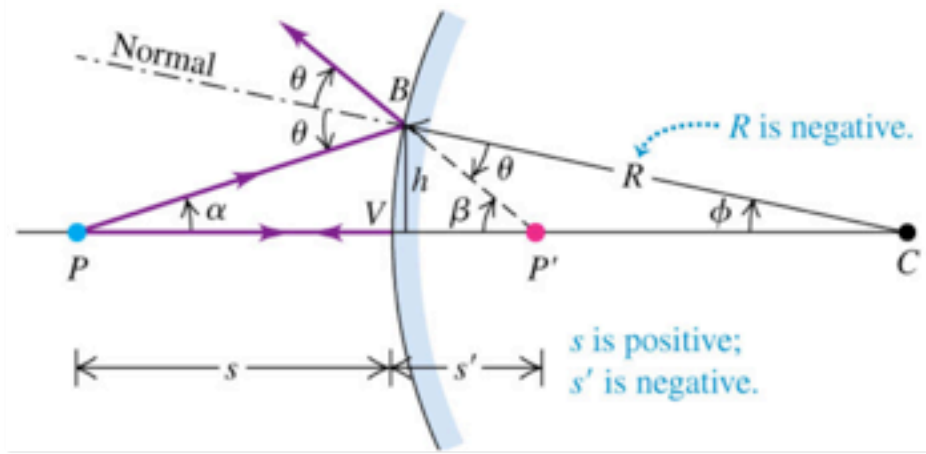


0<m<1: smaller, rightside up

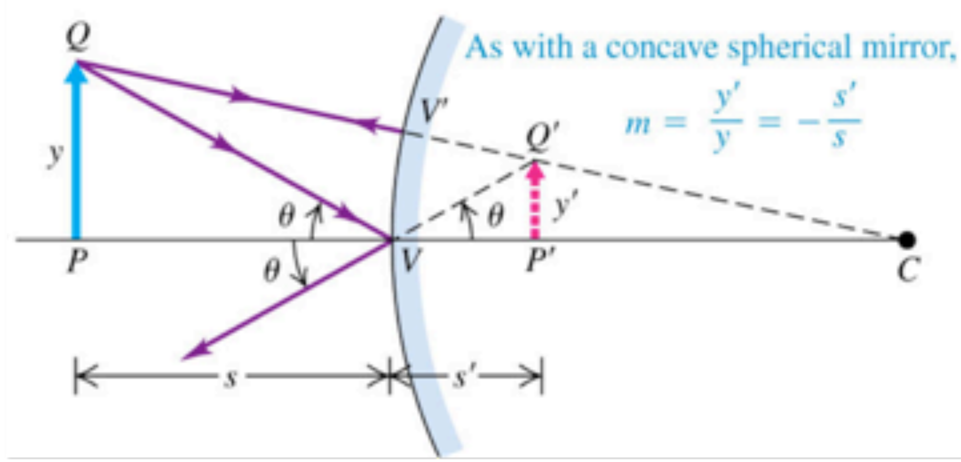
Image formation by a convex mirror

- Figure 34.16 (right) shows how to trace rays to locate the image formed by a convex mirror.

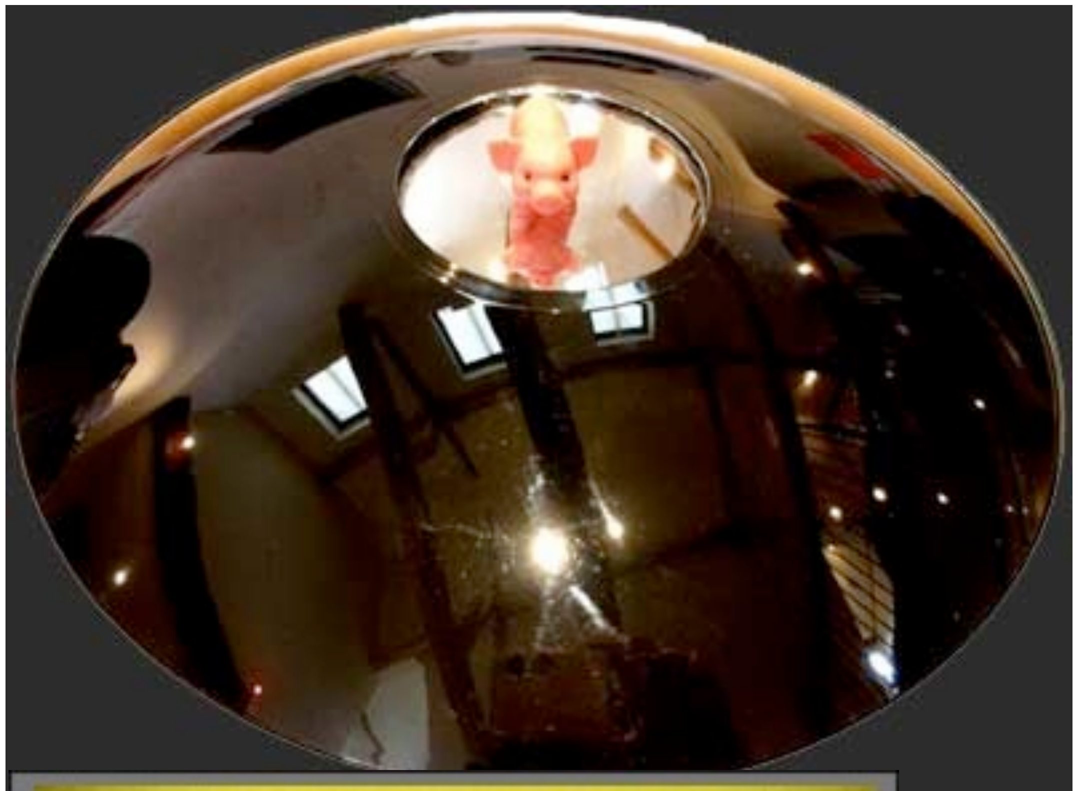
(a) Construction for finding the position of an image formed by a convex mirror

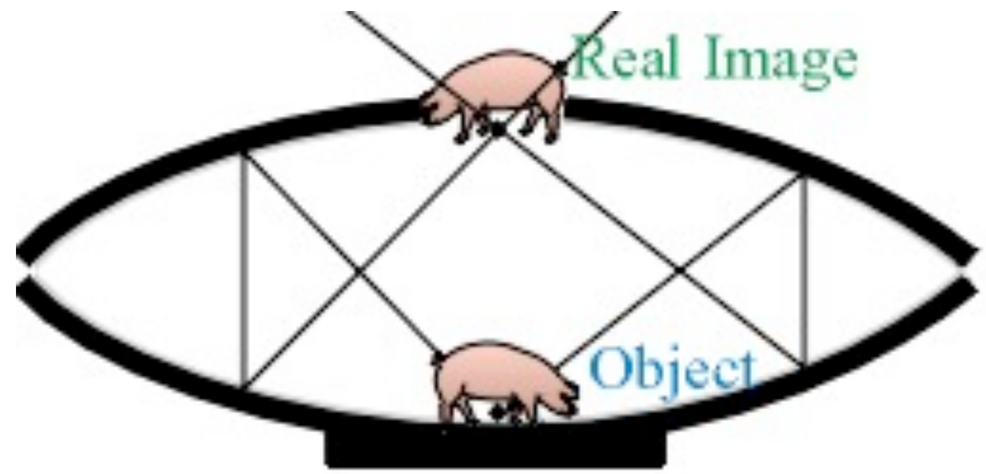


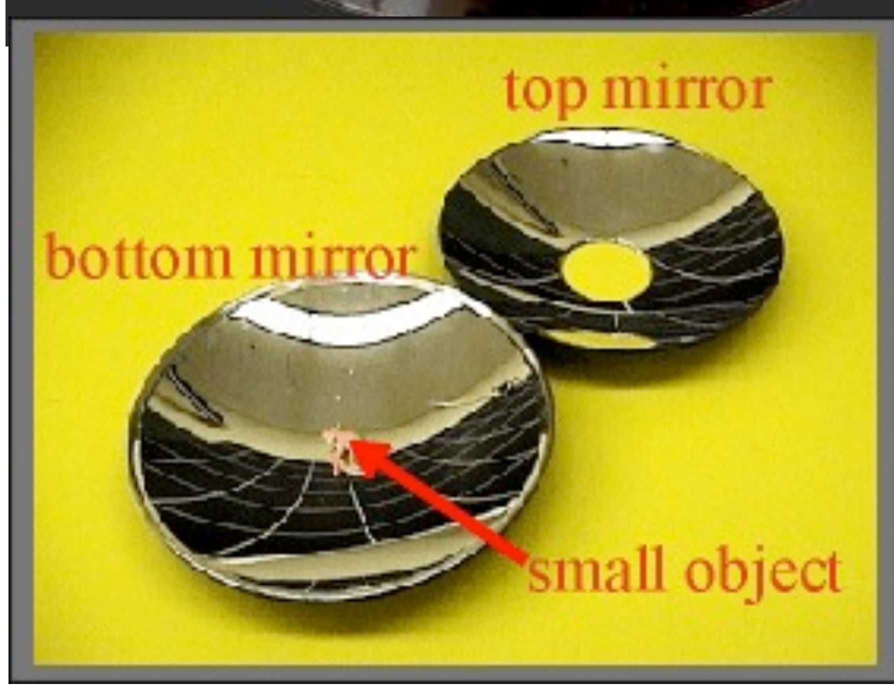
(b) Construction for finding the magnification of an image formed by a convex mirror



Mirage mirror demo



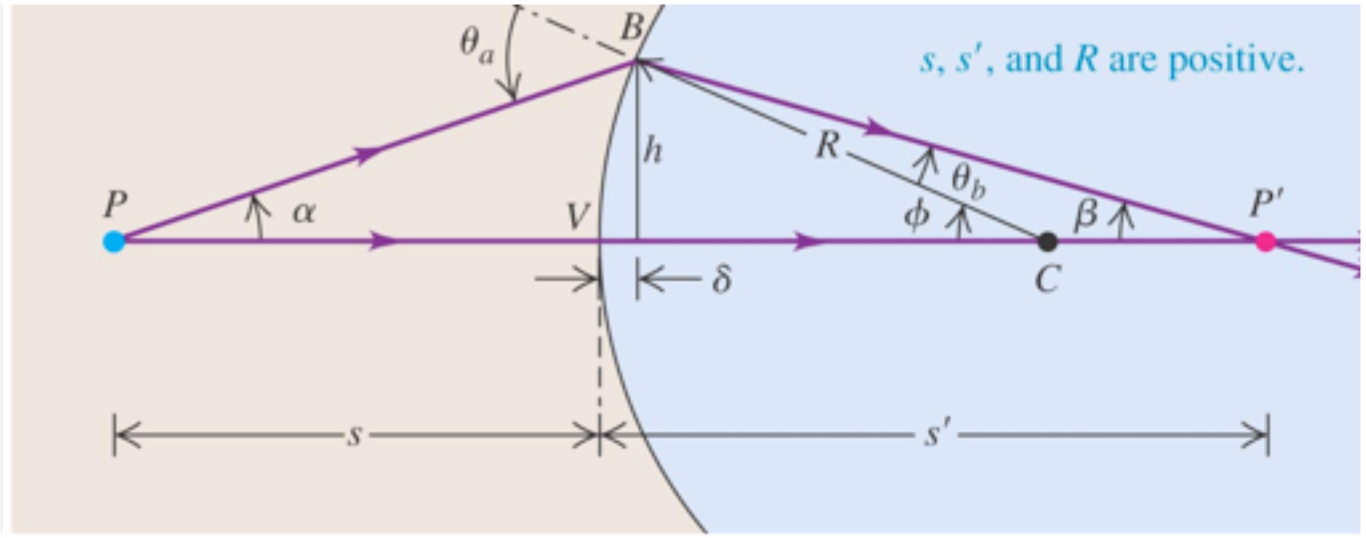




great gift for the holidays!

http://www.amazon.com/Mirage-3-D-Instant-Hologram-Maker/dp/B0002W3J7M

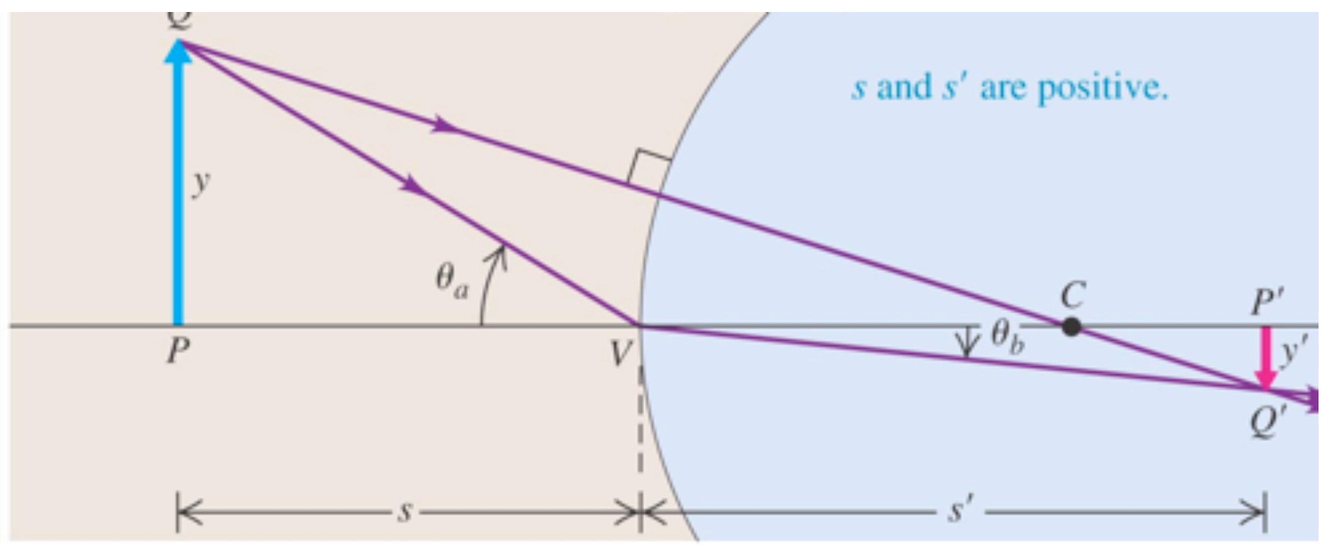
spherical refracting lens



$$\frac{n_1}{s} + \frac{n_2}{s'} = \frac{n_2 - n_1}{R} \equiv \frac{1}{f}$$

Again follows from Fermat principle:
all rays from object to image take same time.

Here R>0 means convex surface. General rule: R>0 if center on same sign as outgoing rays.



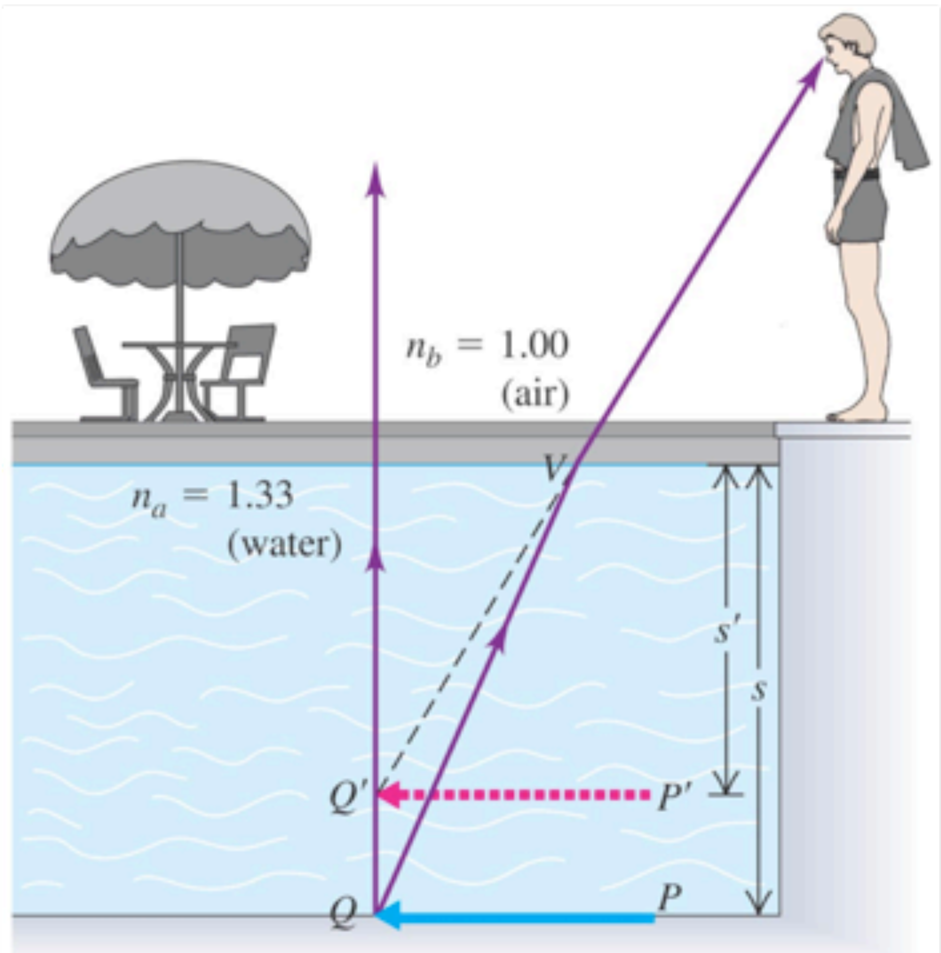
$$n_1 \sin\theta_a = n_2 \sin\theta_b$$

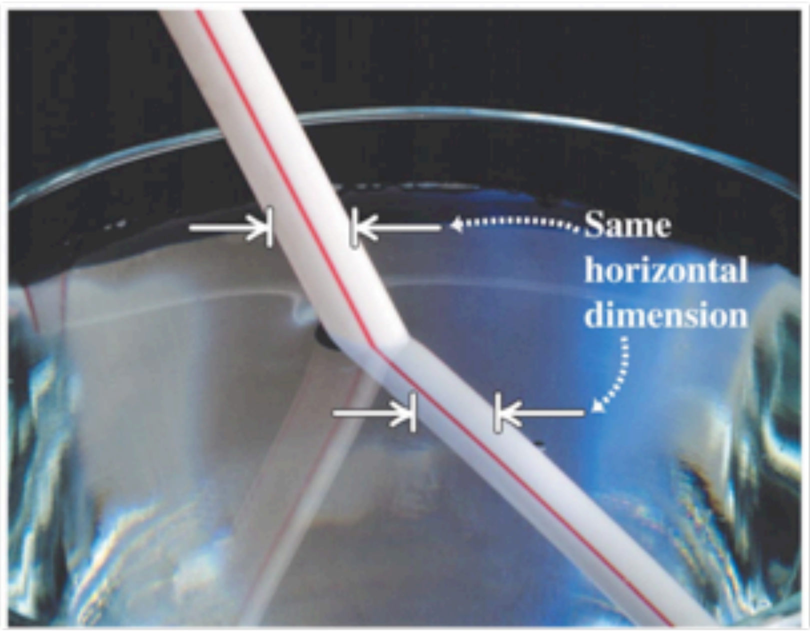
$$(n_1 \equiv n_a,\ \ n_2 \equiv n_b)$$

$$m = \frac{y'}{y} = \frac{-s' \tan\theta_b}{s \tan\theta_a} \approx -\frac{s' \sin\theta_b}{s \sin\theta_a} = -\frac{n_1 s'}{n_2 s}$$

Apparent depth of a swimming pool

- Follow Example 34.7 using Figure 34.26 at the left.
- Figure 34.27 (right) shows that the submerged portion of the straw appears to be at a shallower depth than it actually is.





$$\frac{n_1}{s} + \frac{n_2}{s'} = \frac{n_2 - n_1}{R} \equiv \frac{1}{f}$$

$R \to \infty$

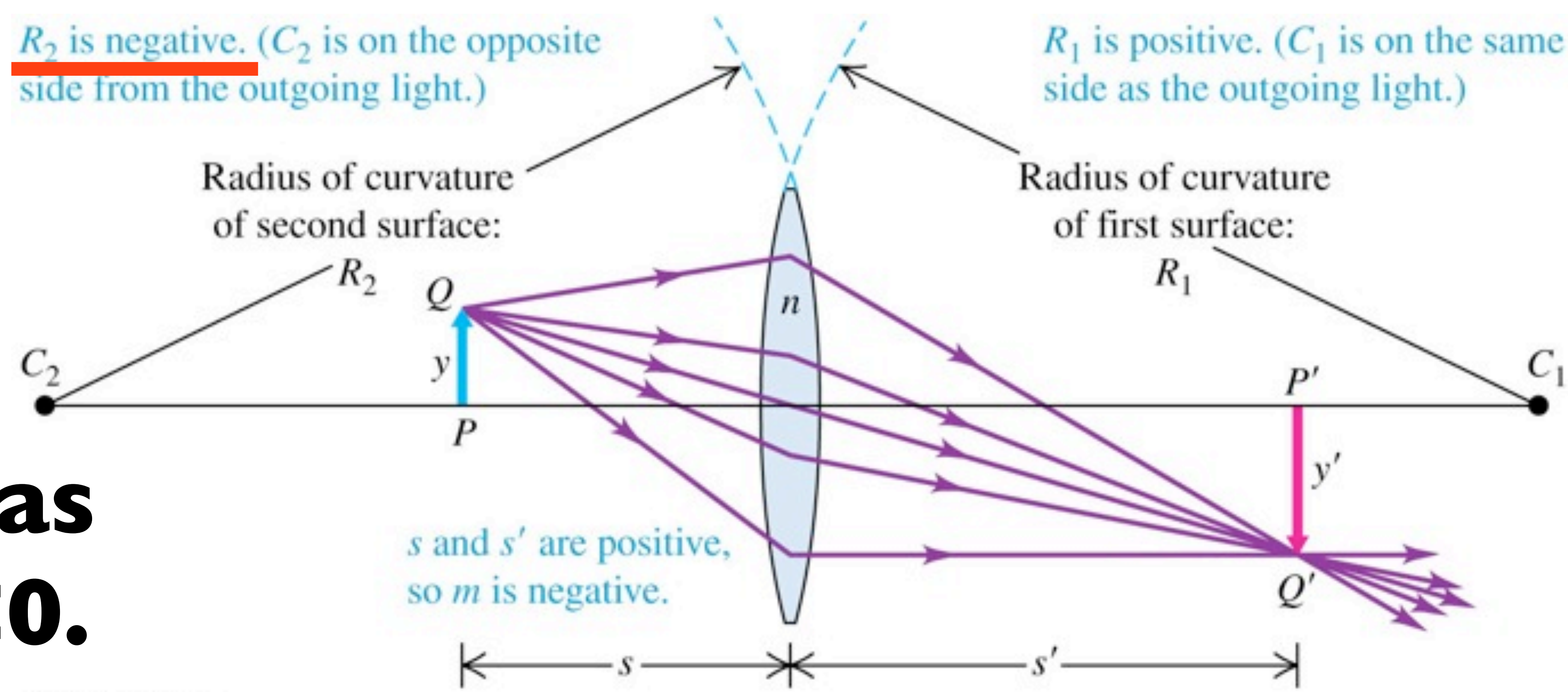
$$\frac{n_1}{s} + \frac{n_2}{s'} = 0.$$

Thin lenses

Use equation for two spherical surfaces, almost on top of each other (thin). Get a nice, simple eqn.:

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

$$m = -\frac{s'}{s}$$



!signs: this lens has R1>0, R2<0.

Derivation:

Step 1: refraction from surface 1: $\frac{n_0}{s} + \frac{n_L}{\tilde{s}} = \frac{n_L - n_0}{R_1}$

Step 2: refraction from surface 2: $-\frac{n_L}{\tilde{s}} + \frac{n_0}{s'} = \frac{n_0 - n_L}{R_2}$

add: $\frac{n_0}{s} + \frac{n_0}{s'} = (n_L - n_0)(\frac{1}{R_1} - \frac{1}{R_2})$

$n_0 =$ index of refraction outside lens, =1 for air.

signs

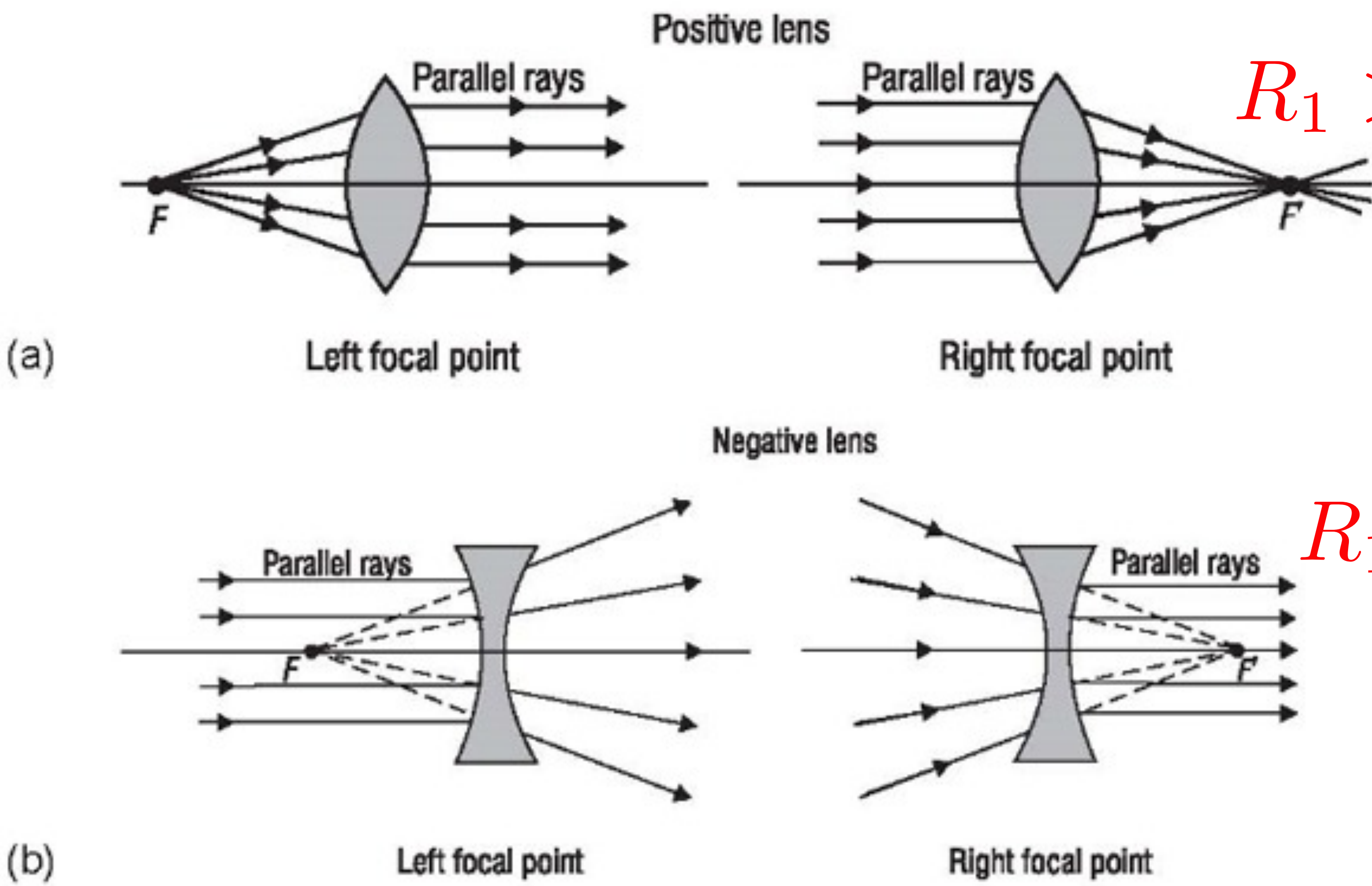


Figure 3-23 *Relationship of light rays to right and left focal points in thin lenses*

$R_1 > 0,\ R_2 < 0,\ f > 0$

converging lens

$R_1 < 0,\ R_2 > 0,\ f < 0$

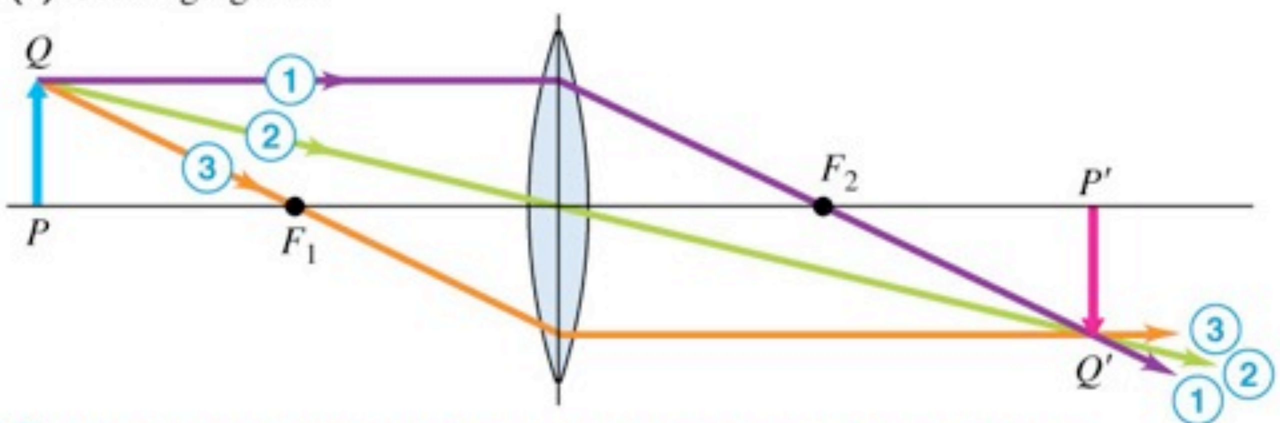
diverging lens

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

Graphical methods

$f > 0$

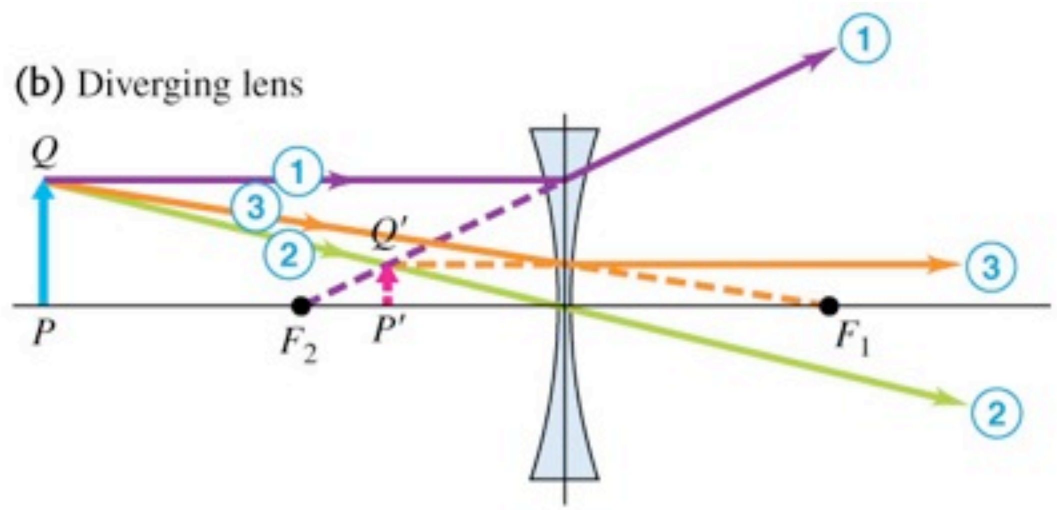
(a) Converging lens



1 Parallel incident ray refracts to pass through second focal point F_2.
2 Ray through center of lens does not deviate appreciably.
3 Ray through the first focal point F_1 emerges parallel to the axis.

$f < 0$

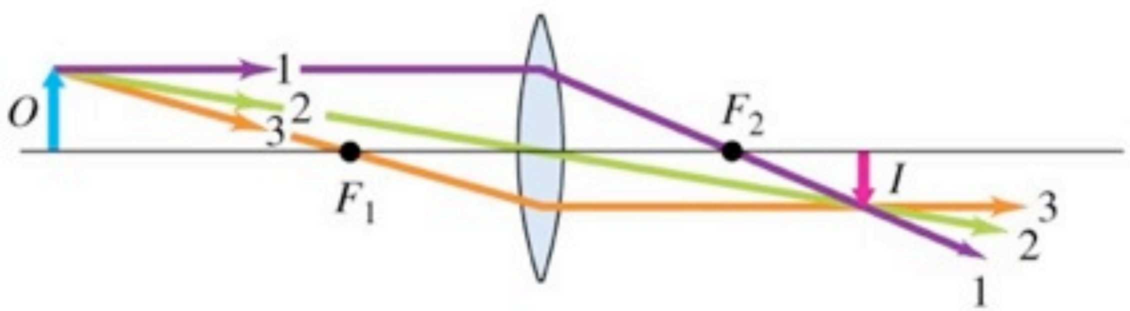
(b) Diverging lens



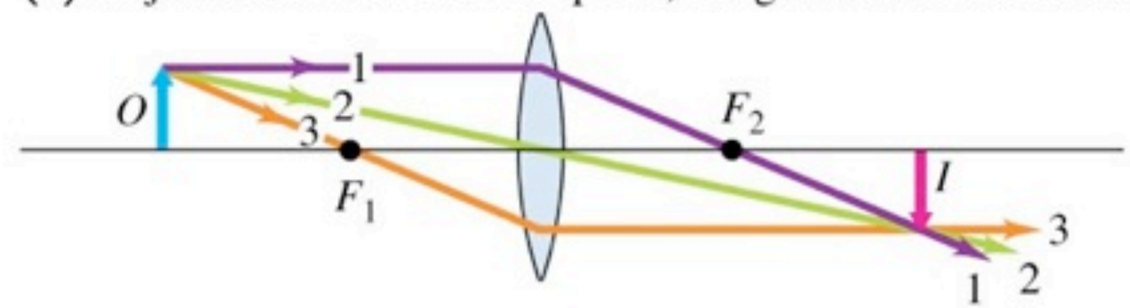
1 Parallel incident ray appears after refraction to have come from the second focal point F_2.
2 Ray through center of lens does not deviate appreciably.
3 Ray aimed at the first focal point F_1 emerges parallel to the axis.

More examples

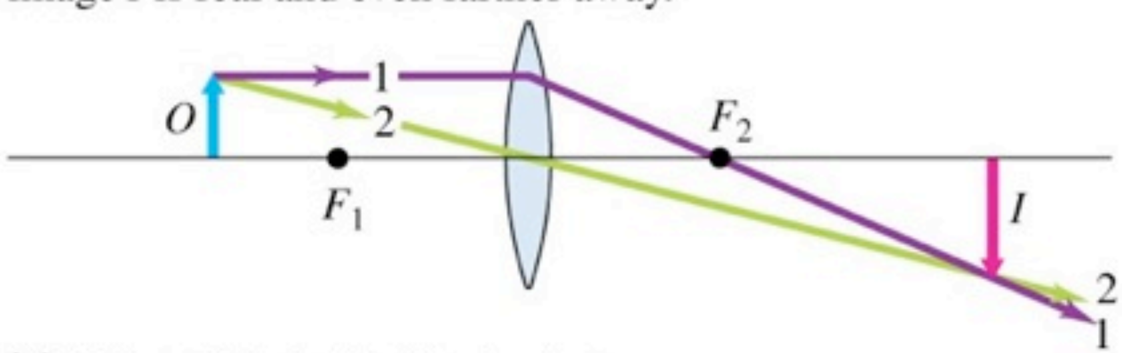
(a) Object O is outside focal point; image I is real.



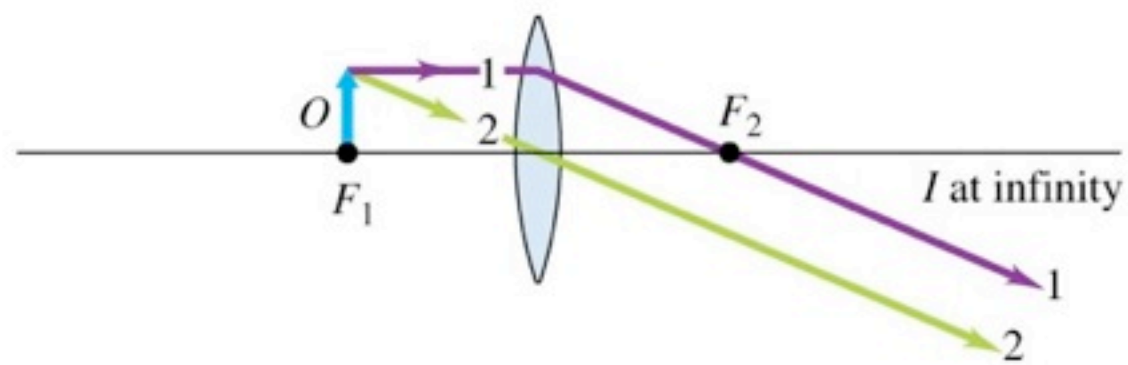
(b) Object O is closer to focal point; image I is real and farther away.



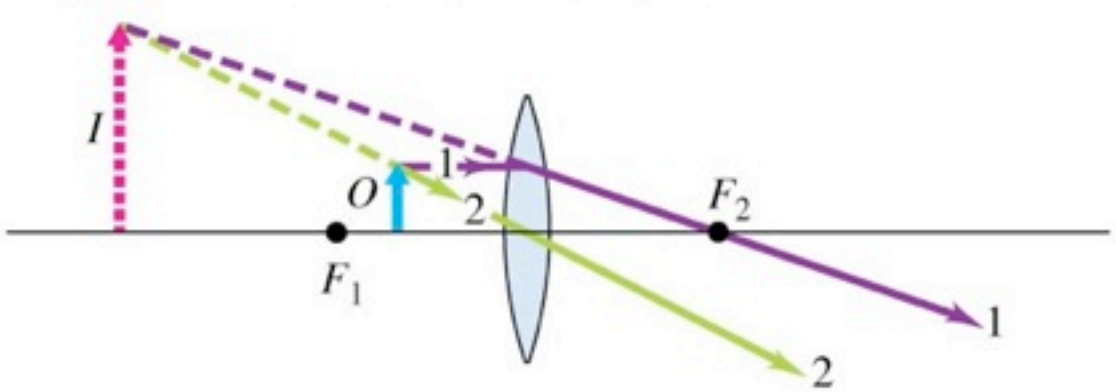
(c) Object O is even closer to focal point;
image I is real and even farther away.



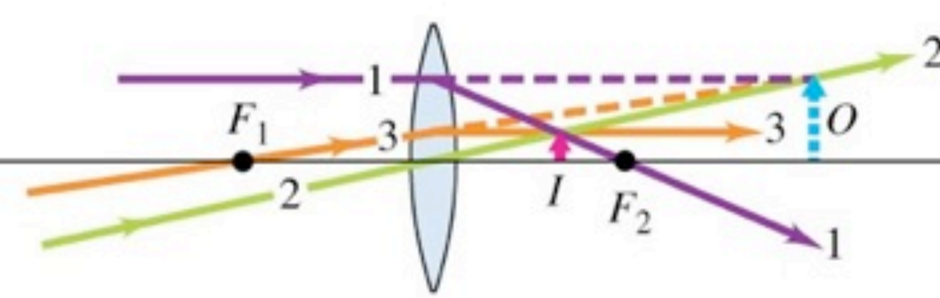
(d) Object O is at focal point; image I is at infinity.



(e) Object O is inside focal point;
image I is virtual and larger than object.

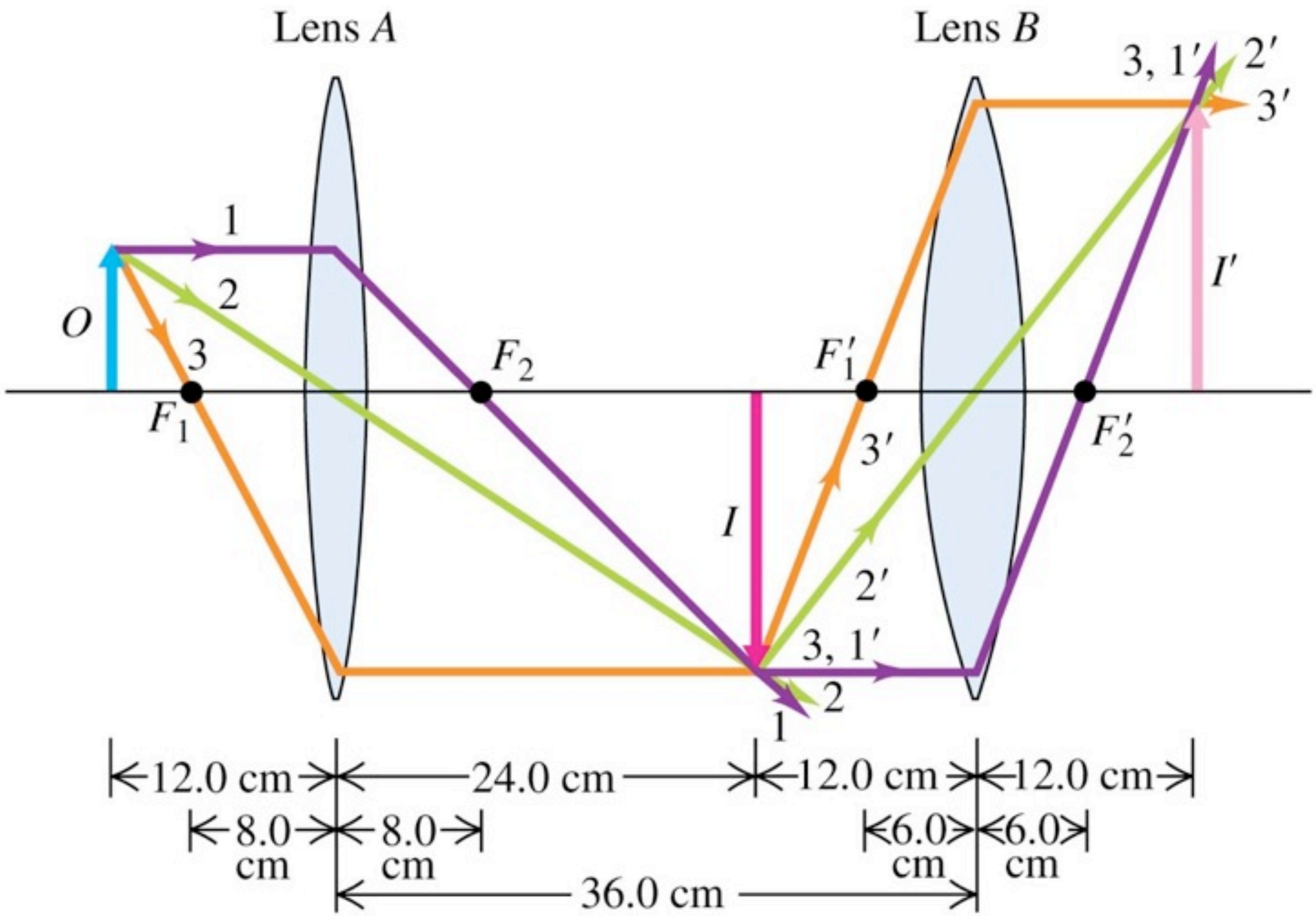


(f) A virtual object O (light rays are *converging* on lens)



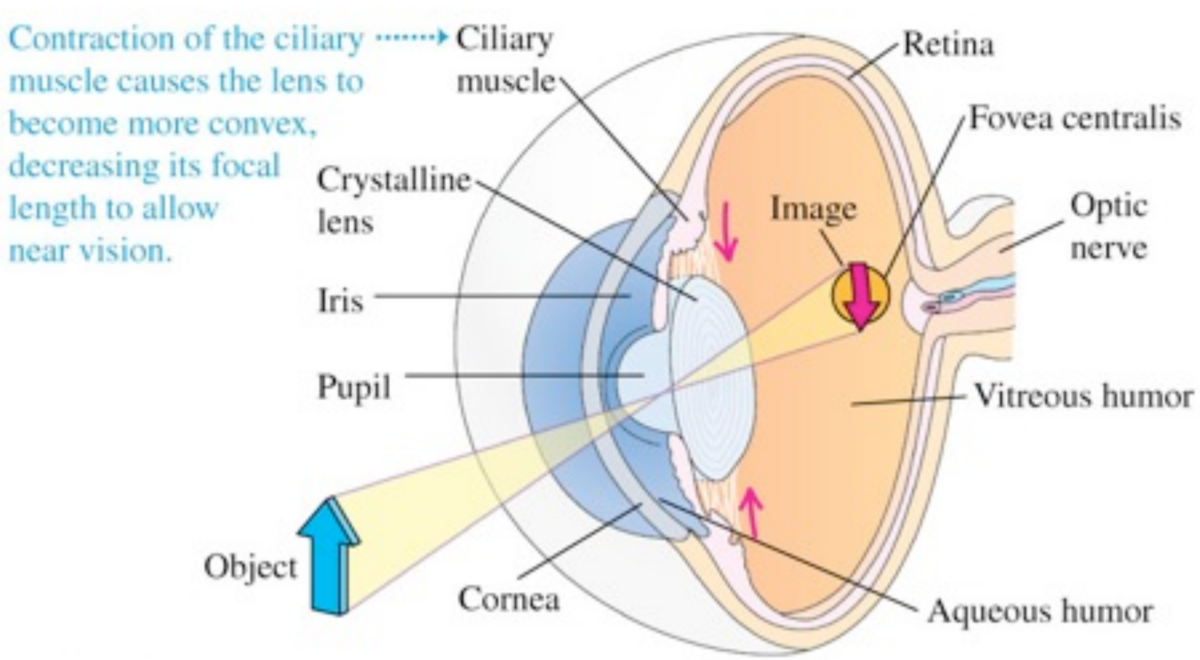
Combining lenses

Image from first lens = "object" for next lens:

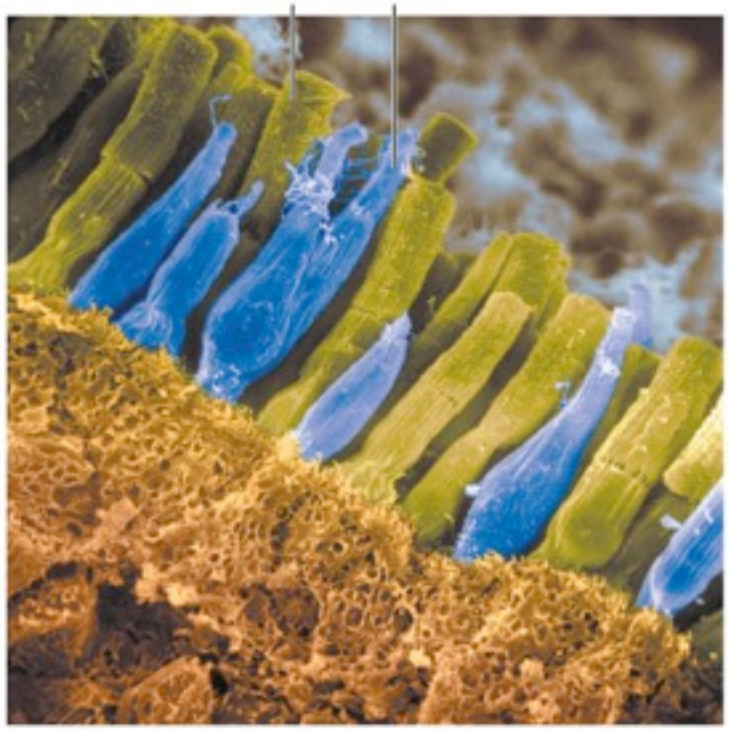


Eyes

(a) Diagram of the eye



(b) Scanning electron micrograph showing retinal rods and cones in different colors



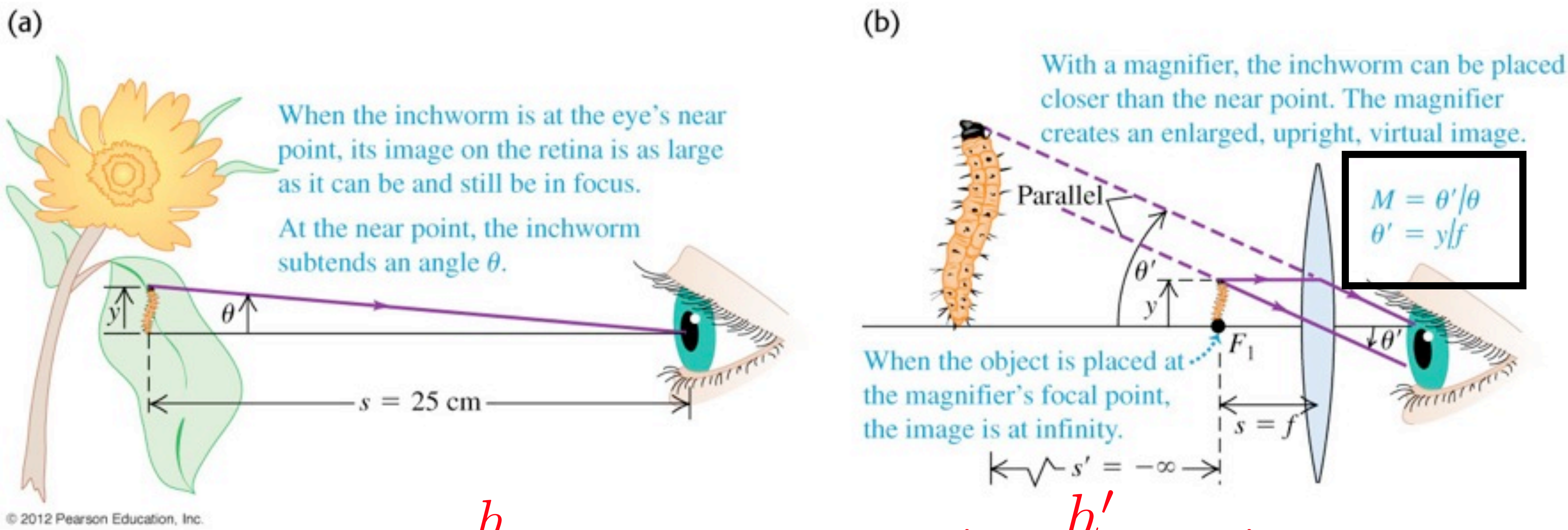
Curious fact: we have a blind spot from where the "wiring" goes in front of the detectors. All other animals have the same issue, except the octopus. Their wiring has the better seeming design of going out the back side, behind the detectors. Discussed in Feynman Lectures, see

http://www.feynmanlectures.caltech.edu/I_36.html

eye's near point

Look at some text and slowly bring it closer to your eye. At some point, you can't focus anymore. That is your eye's near point. If you're in your 20s, it's probably around 10cm. If you're in your 40s, it's probably more like 20cm. As you age, it goes farther out, why people need reading or bifocal glasses. If you're looking at something small, you want to bring it as close to your eye as possible, so bring it to your near point. The book often takes it to be 25cm.

Magnifier



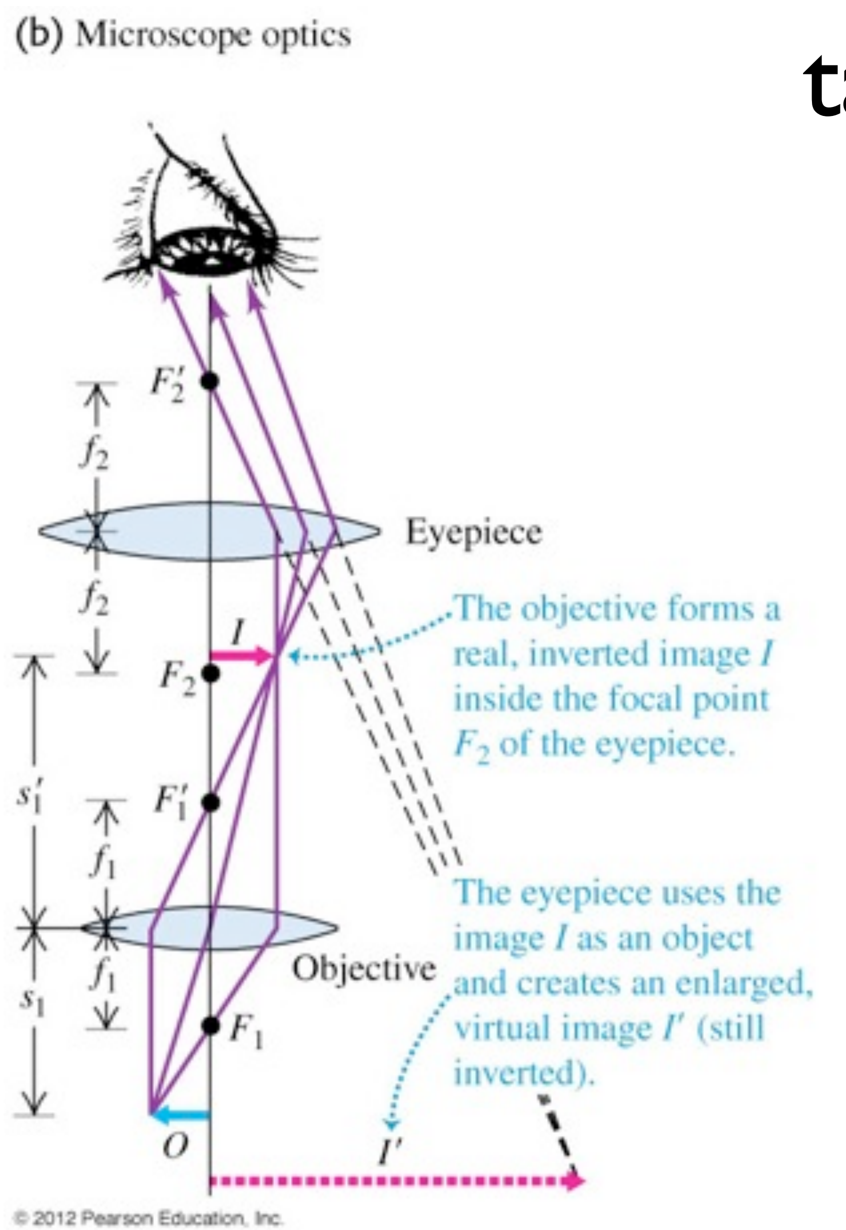
$$\tan\theta = \frac{h}{s} \approx \theta \qquad \tan\theta' = \frac{h'}{s'} \approx \theta'$$

$$m = \frac{\theta'}{\theta} \qquad \theta \approx h/L_{min} \qquad \theta' \approx h/f$$

How close your eye can focus

$$M \approx L_{min}/f$$

Microscopes



take: $s_1 \approx f_1$

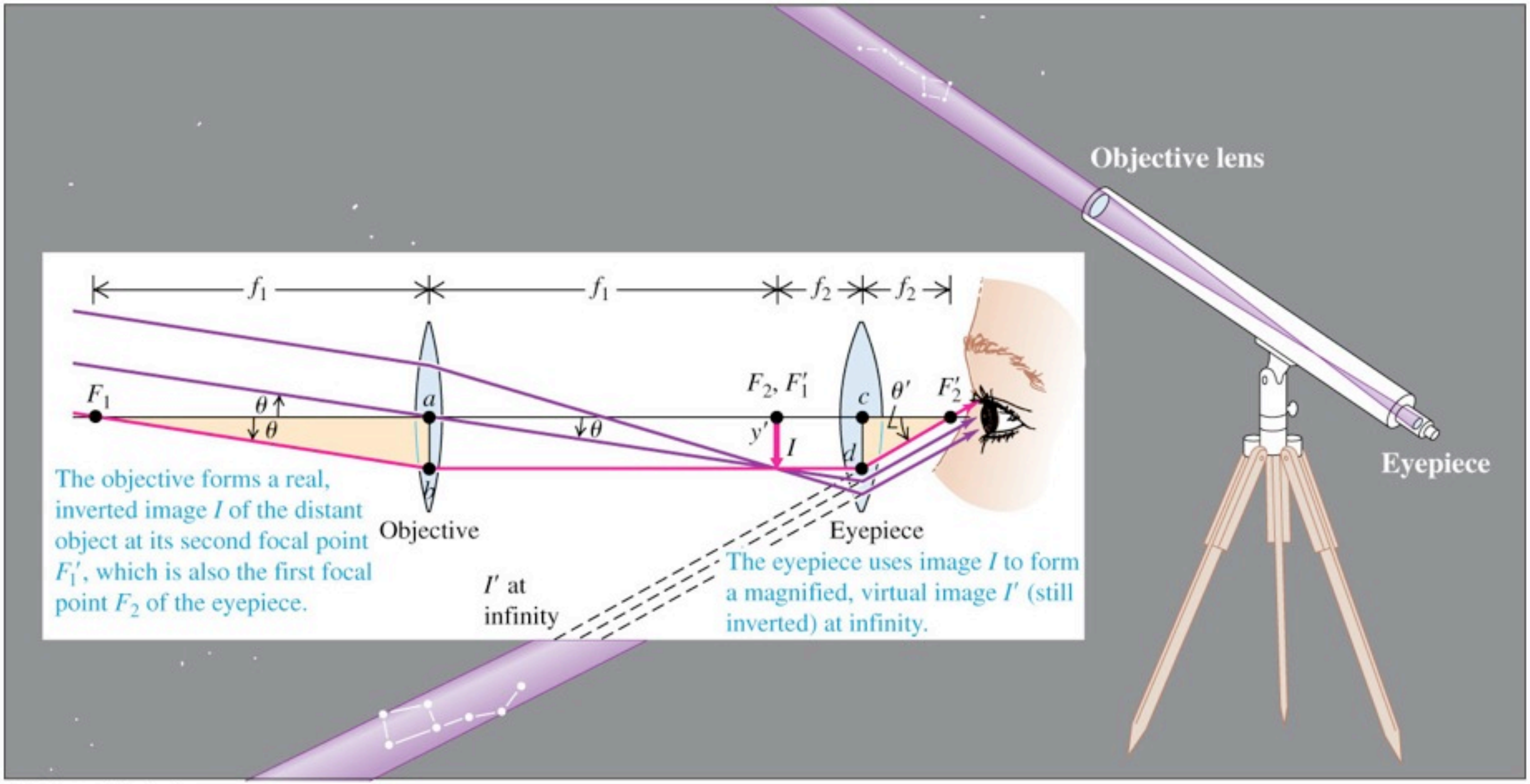
$$m_1 = -\frac{s_1'}{s_1} \approx -\frac{s_1'}{f_1}$$

$$M_2 = L_{min}/f_2$$

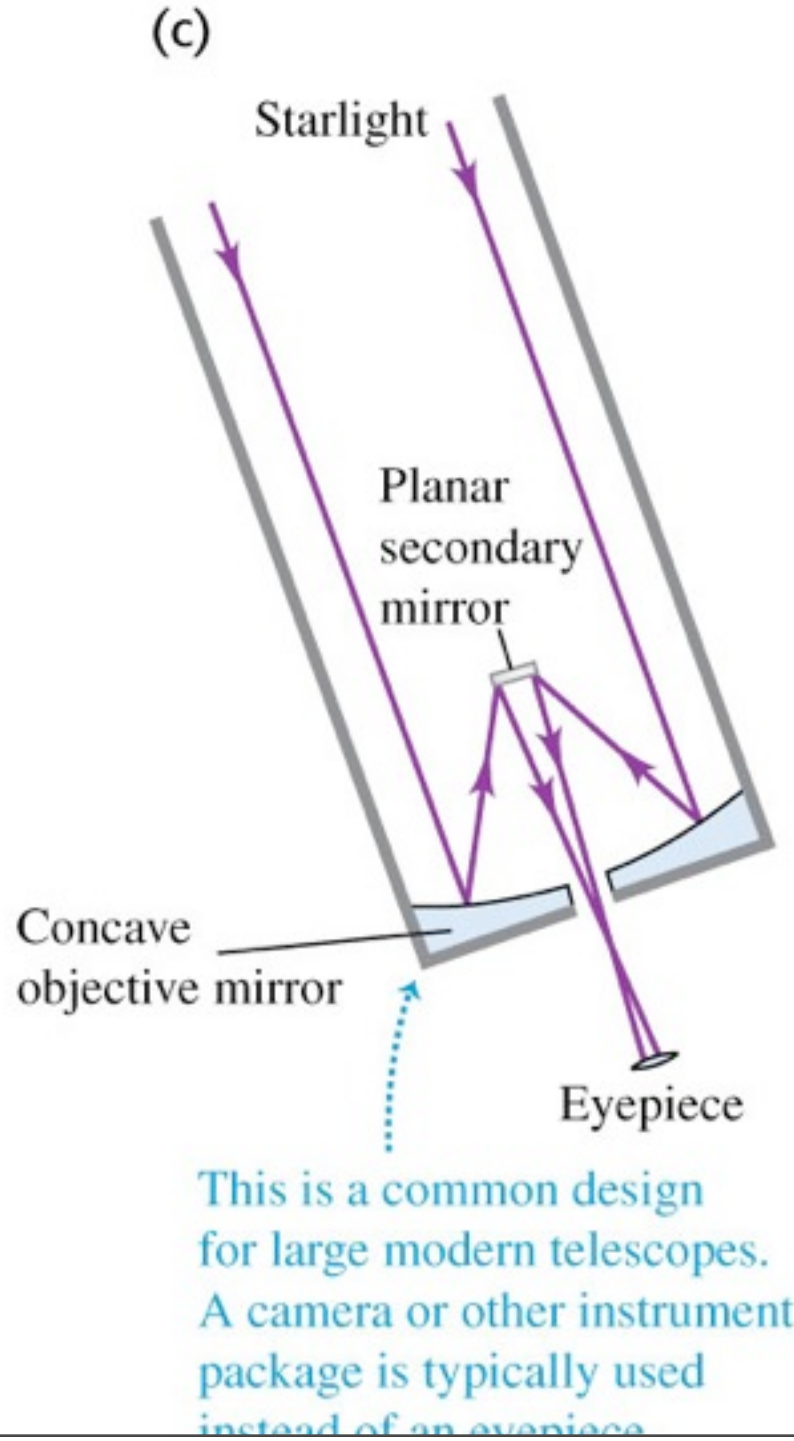
$$M = m_1 M_2 = \frac{L_{min} s_1'}{f_1 f_2}$$

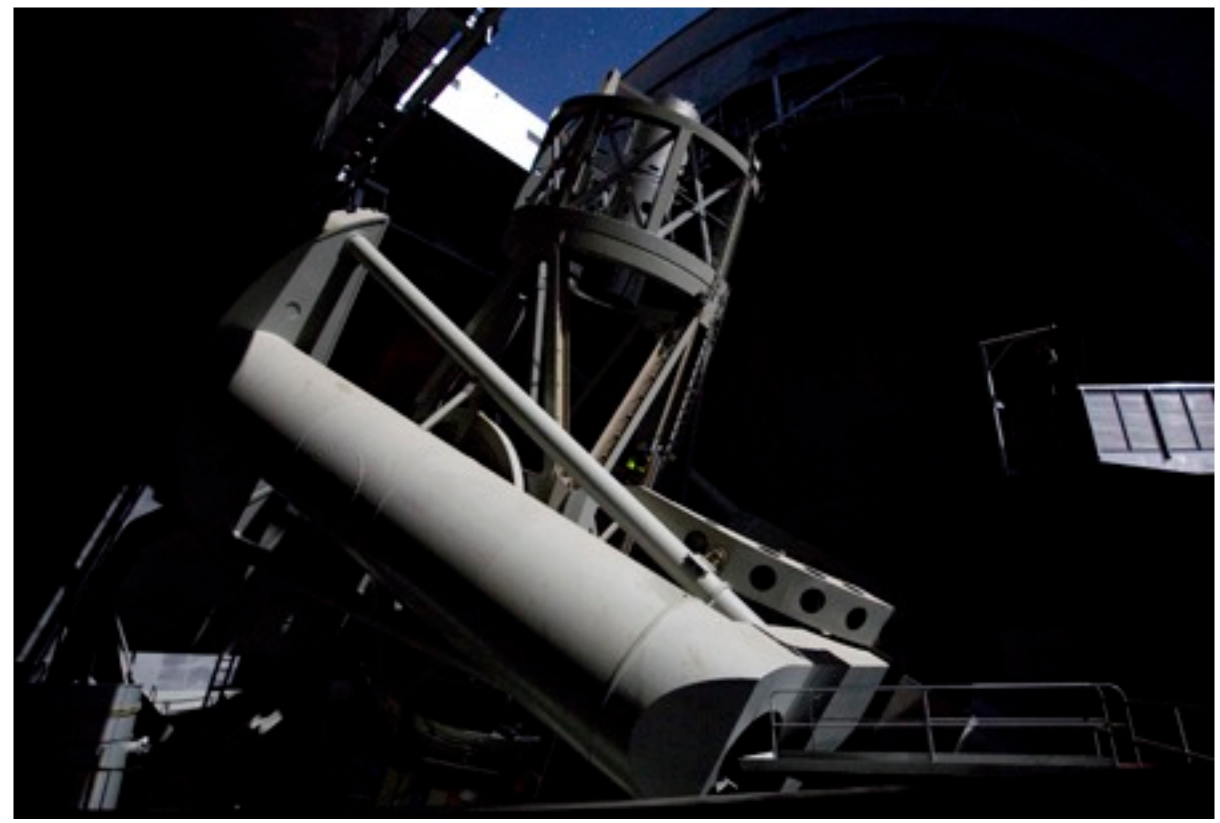
telescopes

$$M = \frac{\theta'}{\theta} = \frac{y'/f_2}{-y'/f_1} = -\frac{f_1}{f_2}$$



modern telescopes

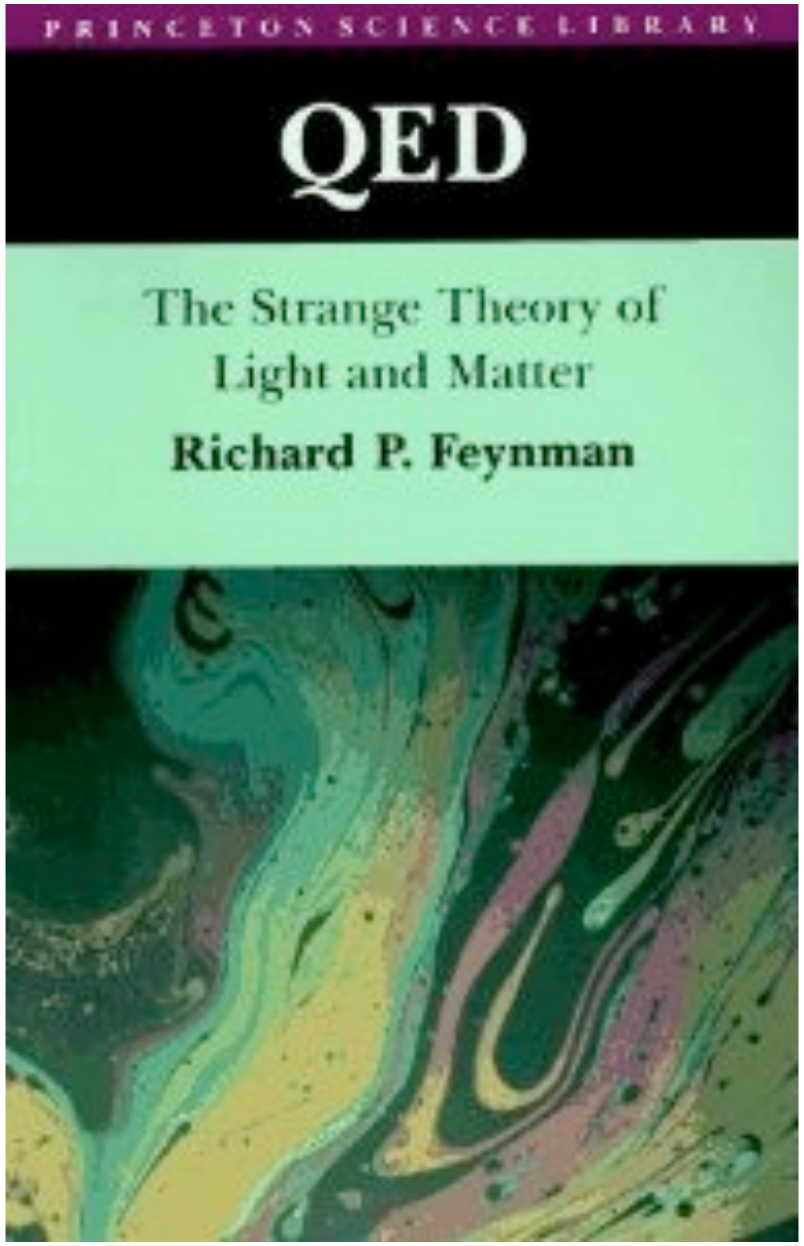




Local: Mt. Palomar, Caltech's telescope, open to public.

http://www.astro.caltech.edu/palomar/

just for fun (I think so):



Light's actual path can be understood in terms of summing over all possible paths, with arrows (complex phases). The classical path is where this sum doesn't completely cancel out. Other paths allowed, important in QM, connects description of light as a classical E & M wave with the QM description in terms of photons. There's more to optics than meets the eye! (Was inspirational for me.)

Reminder: quiz=Mon.