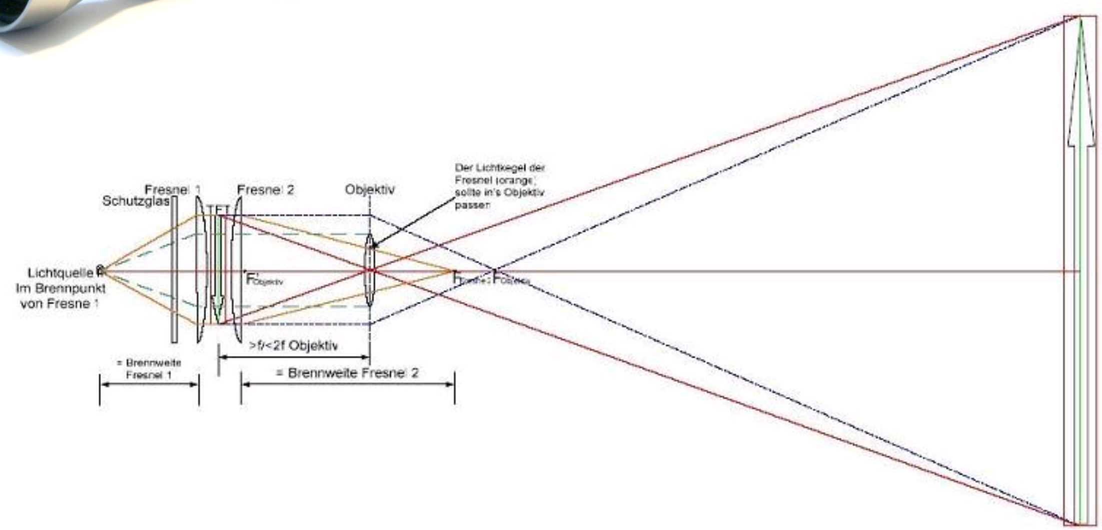
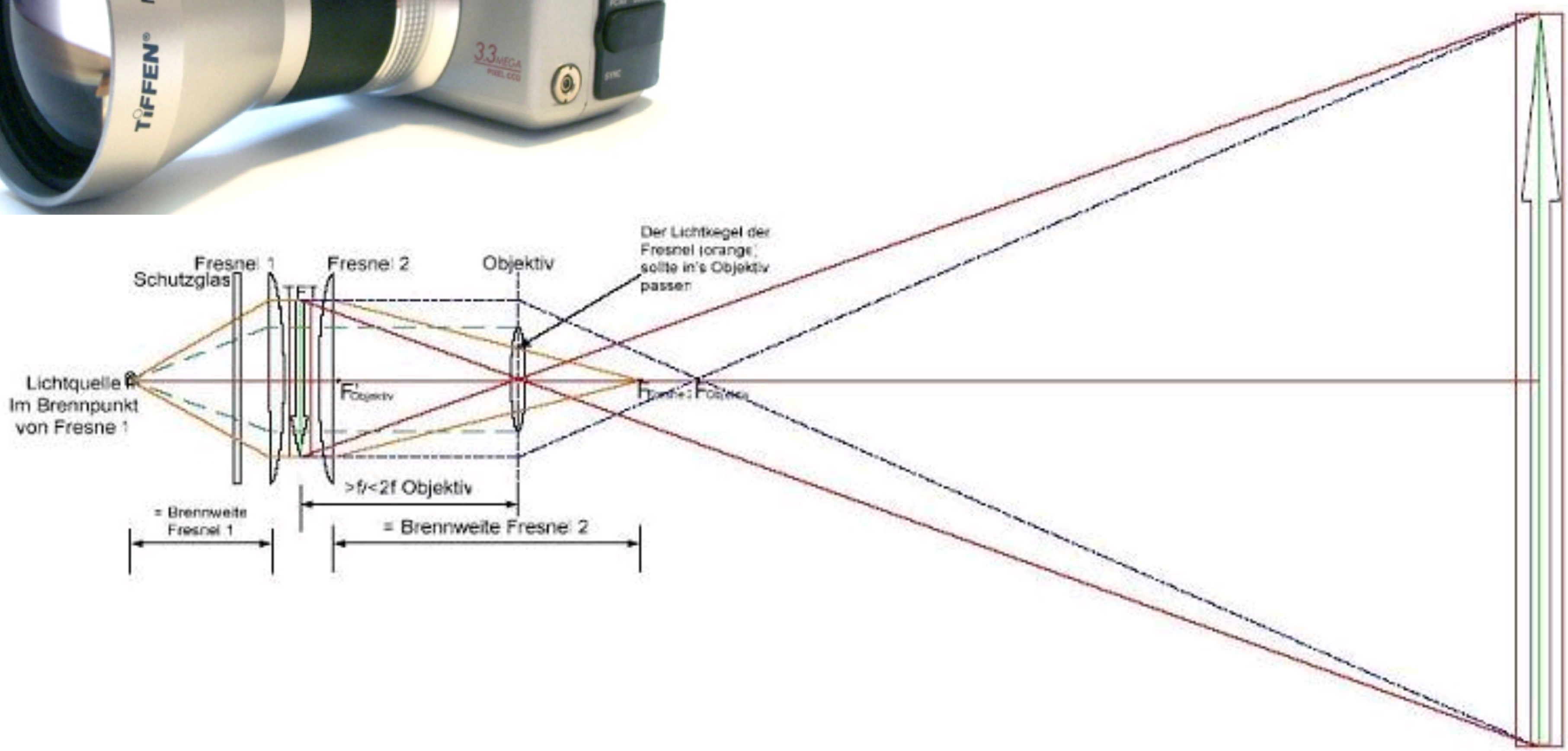
Chapter 34 Images



Lens


TOSHIBA
TIFFEN
MEGAPLUS
2X TELE
3.3 MEGA


Der Lichtkegel der
Fresnel (orange)
sollte in's Objektiv
passen
Fresnel 1
Fresnel 2
Objektiv
Schutzglas
TFT
Lichtquelle
Im Brennpunkt
von Fresnel 1
>f/<2f Objektiv
= Brennweite
Fresnel 1
= Brennweite Fresnel 2

Review: Spherical mirror formulas

Focal length and sphere radius:

$$f = \frac{|r|}{2}$$ Converging mirror

$$f = -\frac{|r|}{2}$$ Diverging mirror

Object distance, image distance and focal length:

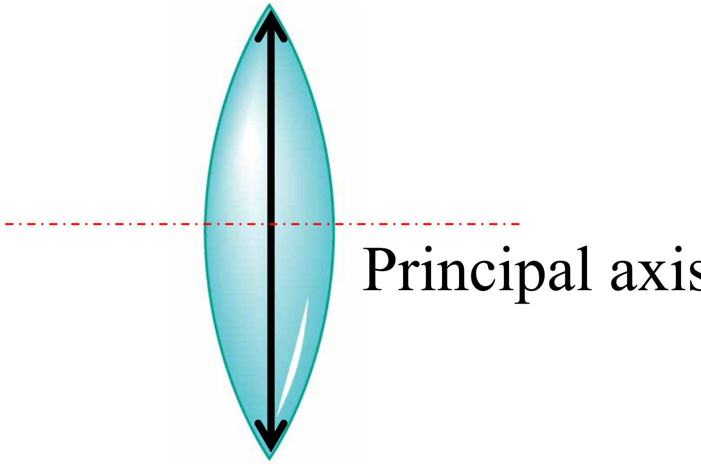
$$\frac{1}{p} + \frac{1}{i} = \frac{1}{f}$$

Object distance, image distance and magnification:

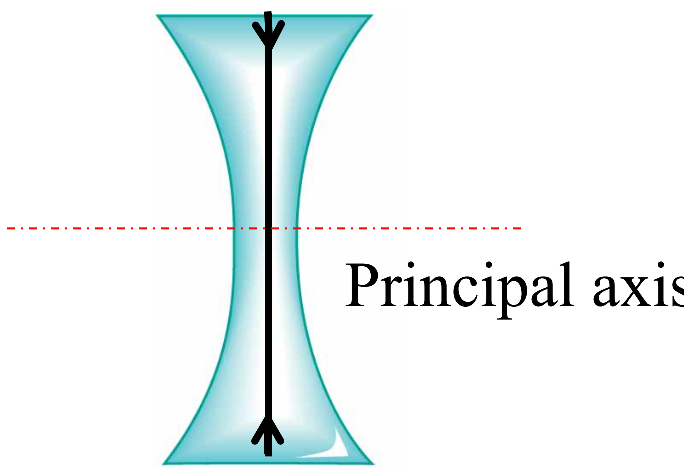
$$m \equiv \frac{H_I}{H_O} = -\frac{i}{p}$$

Thin lenses -- again

- Lenses are commonly used to form images by refraction.
- We discuss about spherical lenses only. They are part of two spheres.
- There are two types of lenses
  - Converging
  - Diverging
- When the thickness of the lens is negligible, the lens is called thin lens.
- Principal axis: the line that goes through the two centers of the two spheres.
- Paraxial rays are those close to the principal axis.
- Lenses are used in optical instruments
  - Cameras
  - Telescopes, binoculars
  - Microscopes



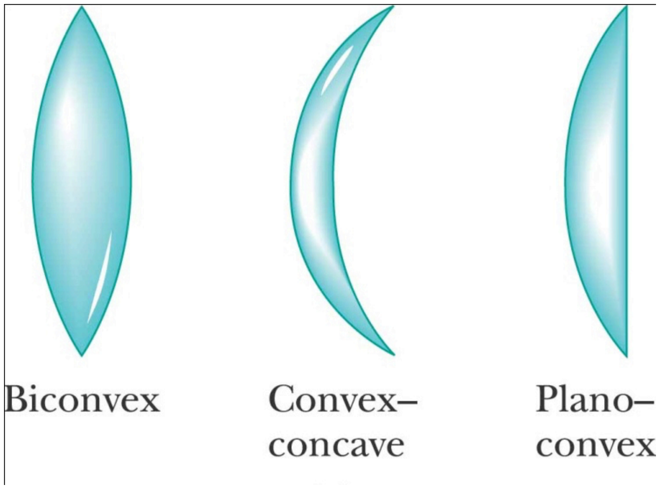
converging



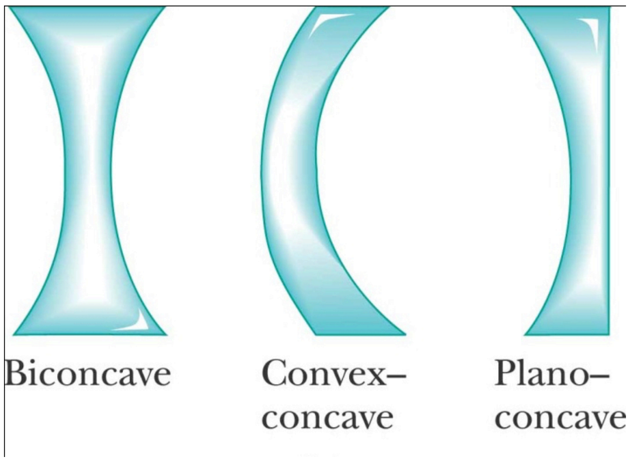
diverging

Converging and diverging Lens Shapes

- Converging:
  - positive focal lengths
  - thickest in the middle



- Diverging:
  - negative focal lengths
  - thickest at the edges



34.7: Thin Spherical Lenses:

A **spherical lens** is a transparent object with two refracting surfaces whose central axes coincide. The common central axis is the central axis of the lens.

A lens that causes light rays initially parallel to the central axis to converge is called a **converging lens.** If, instead, it causes such rays to diverge, the lens is a **diverging lens.**

A **thin lens** is a lens in which the thickest part is thin relative to the object distance p, the image distance i, and the radii of curvature r_1 and r_2 of the two surfaces of the lens. If one considers only light rays that make small angles with the central axis, and if f is the focal length, then

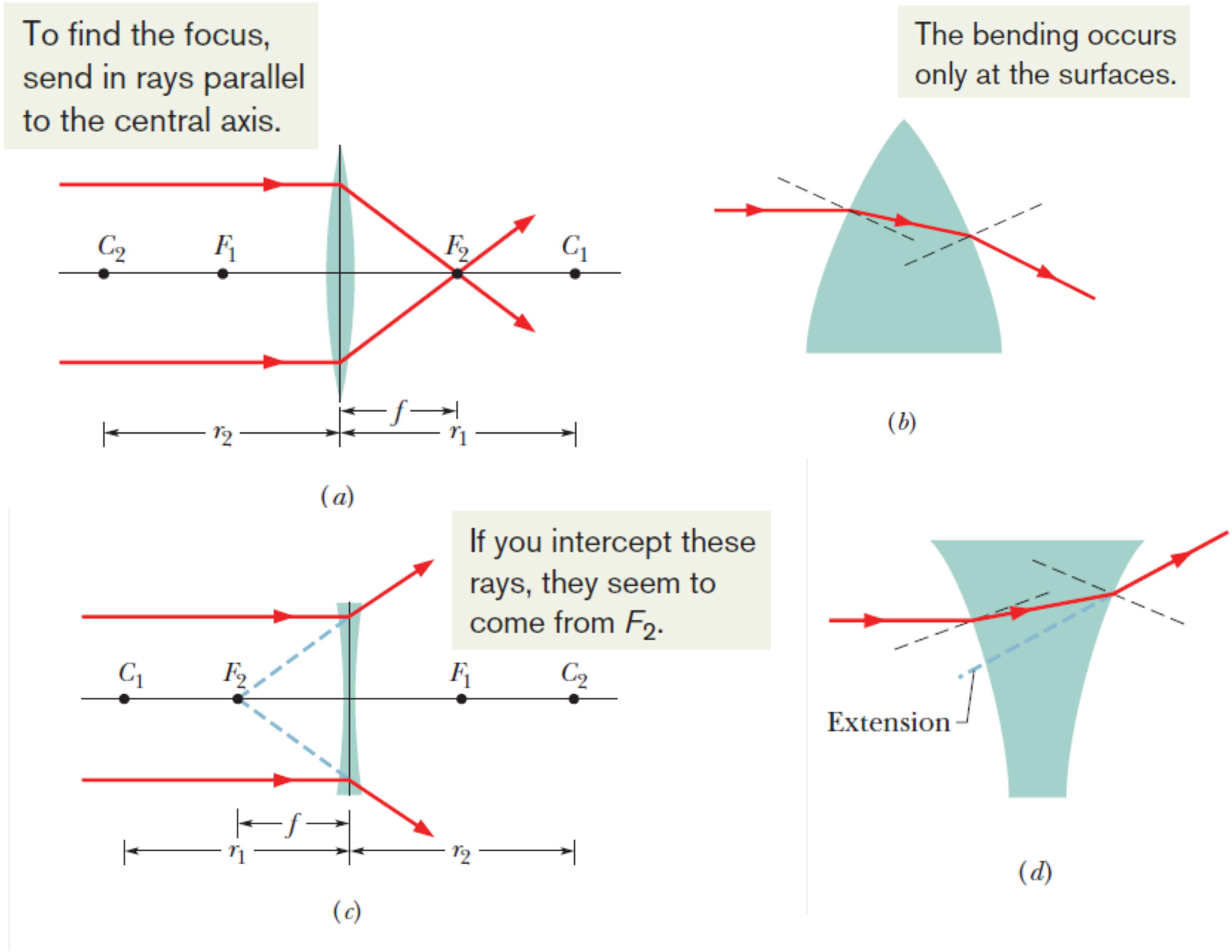
$$\frac{1}{f} = \frac{1}{p} + \frac{1}{i} \qquad \text{(thin lens)},$$

Also,

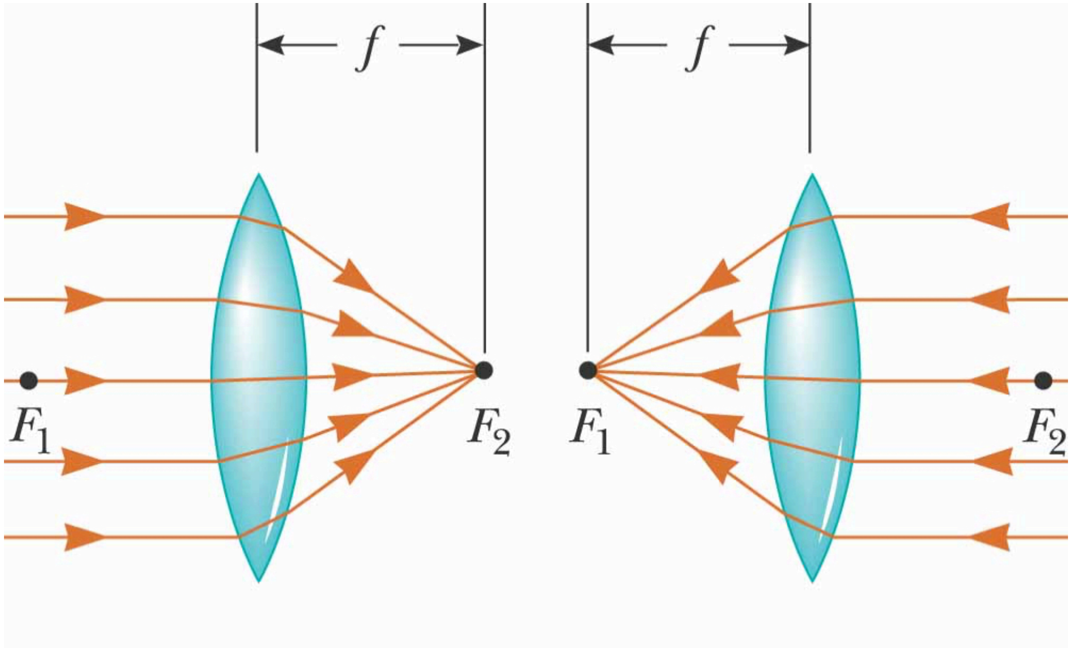
The lens maker's equation in air. More about it later.

$$\frac{1}{f} = (n-1)\left(\frac{1}{r_1} - \frac{1}{r_2}\right) \qquad \text{(thin lens in air)},$$

34.7: Thin Lenses:

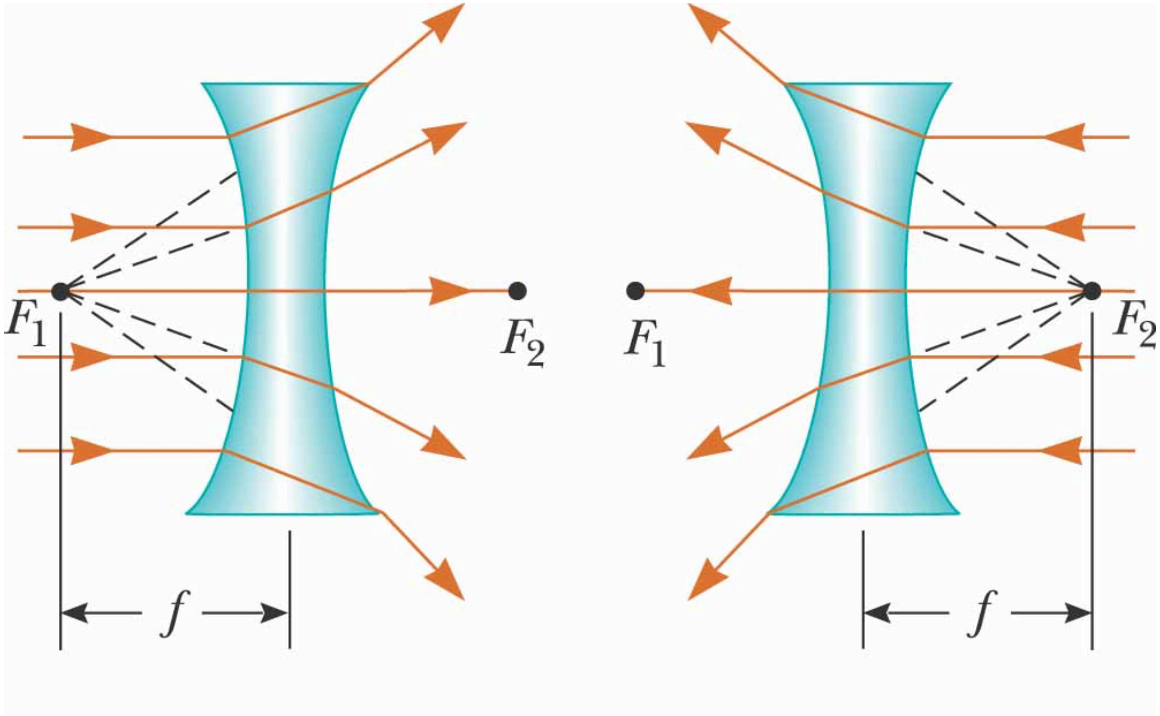


Focal Length of a Converging Lens



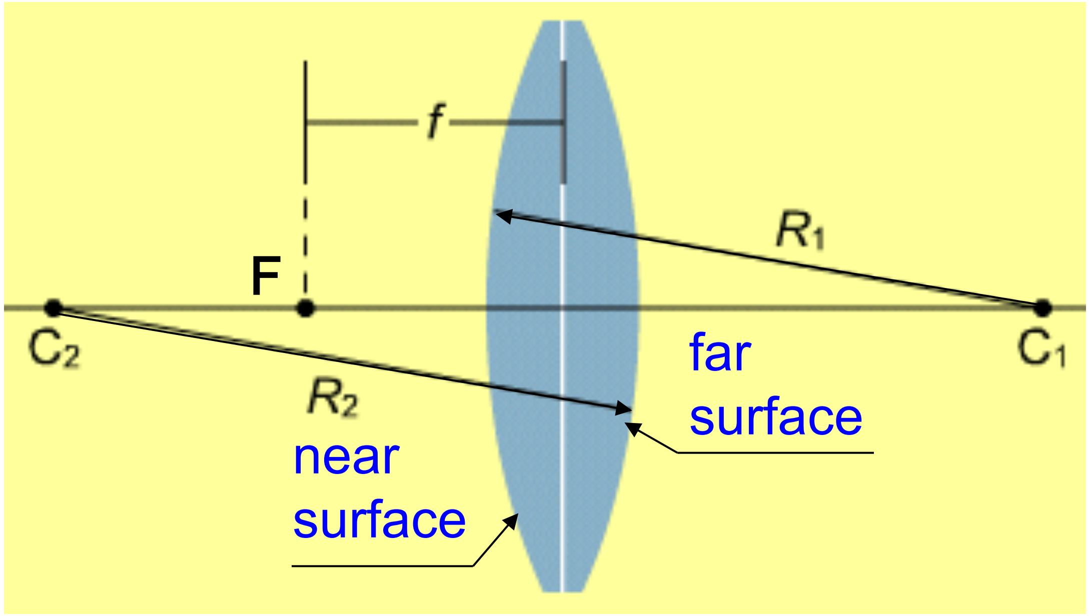
- The parallel rays pass through the lens and converge at the focal point
- The parallel rays can come from the left or right of the lens

Focal Length of a Diverging Lens



- The parallel rays diverge after passing through the diverging lens
- The focal point is the point where the rays appear to have originated

The lens maker's formula (lens in vacuum or air)



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

n : index of refraction of the lens material.

R_1 : radius of near surface.

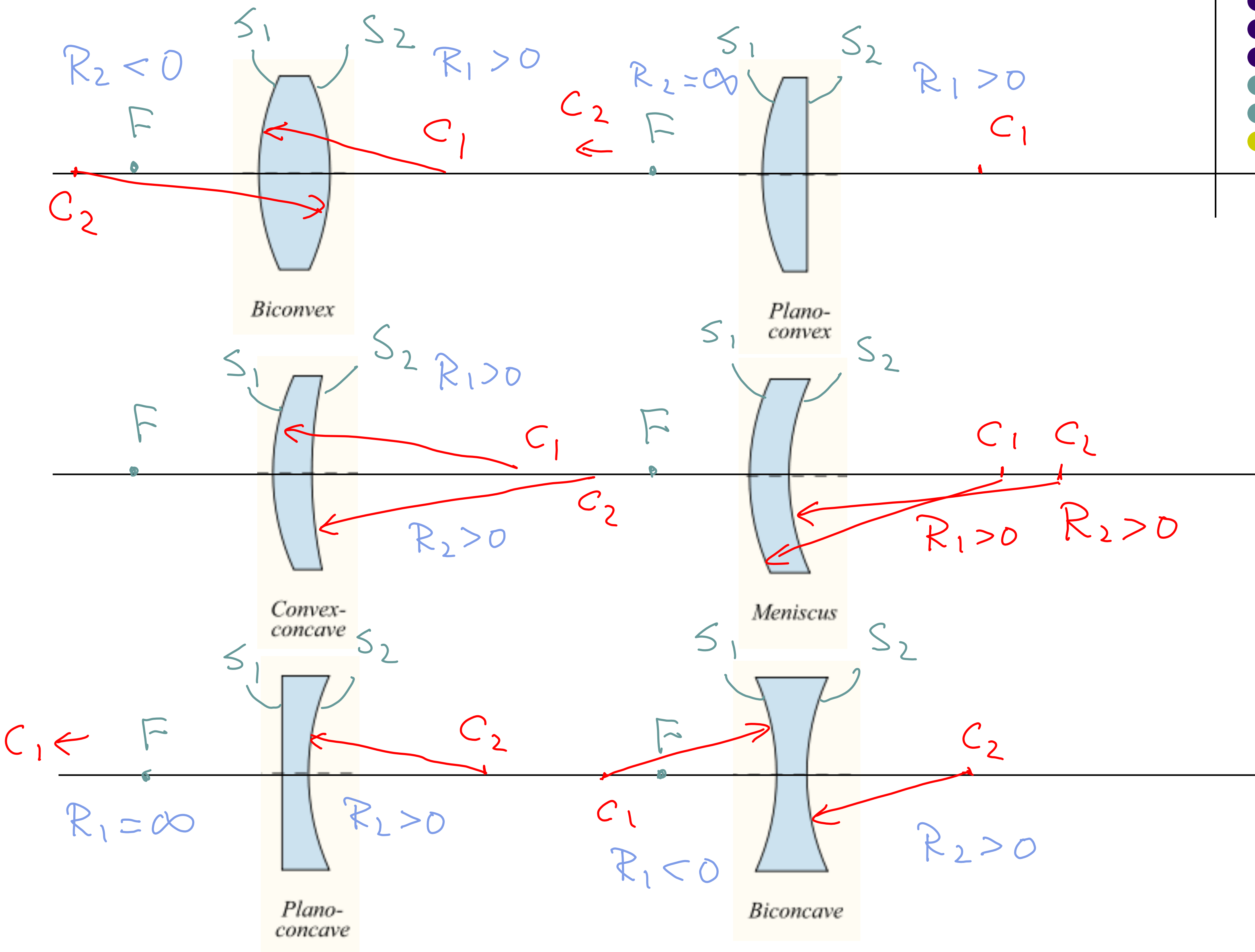
R_2 : radius of far surface.

The sign conventions for the radii of the two surfaces:

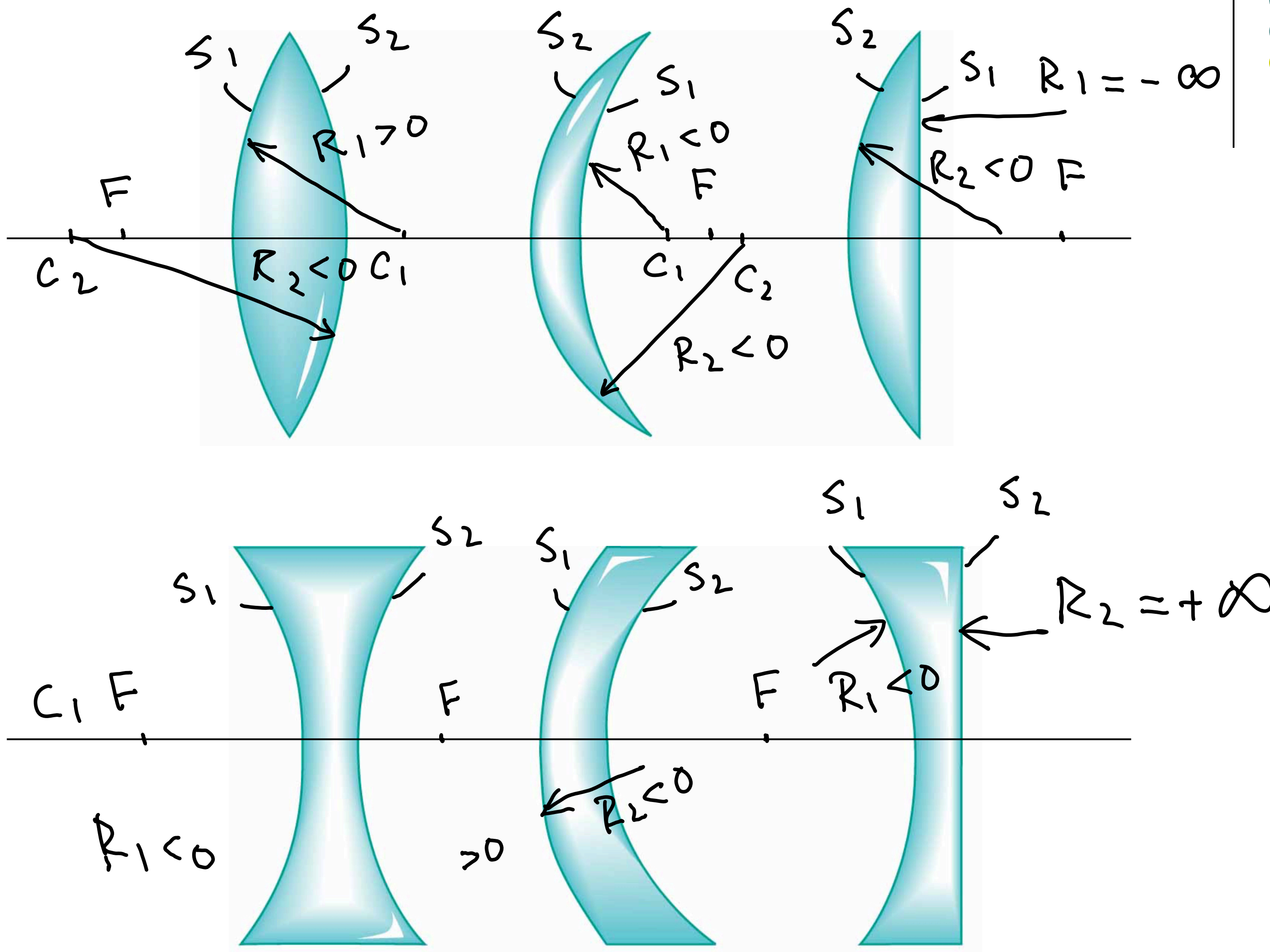
1. The near or far surface of the lens is with respect to the focal point **F**. Near side is surface 1 and R_1, far side is surface 2 and R_2.
2. The sign of the radius is then defined as:

   "**+**" if the center is on the far side; "**-**" if the center is on the near side

1. In this convention, positive f means converging lens, negative f means diverging lens.


Biconvex
Plano-convex
Convex-concave
Meniscus
Plano-concave
Biconcave
S1
S2
R2 < 0
R1 > 0
R2 = ∞
R1 = ∞
R1 < 0
R2 > 0
F
C1
C2

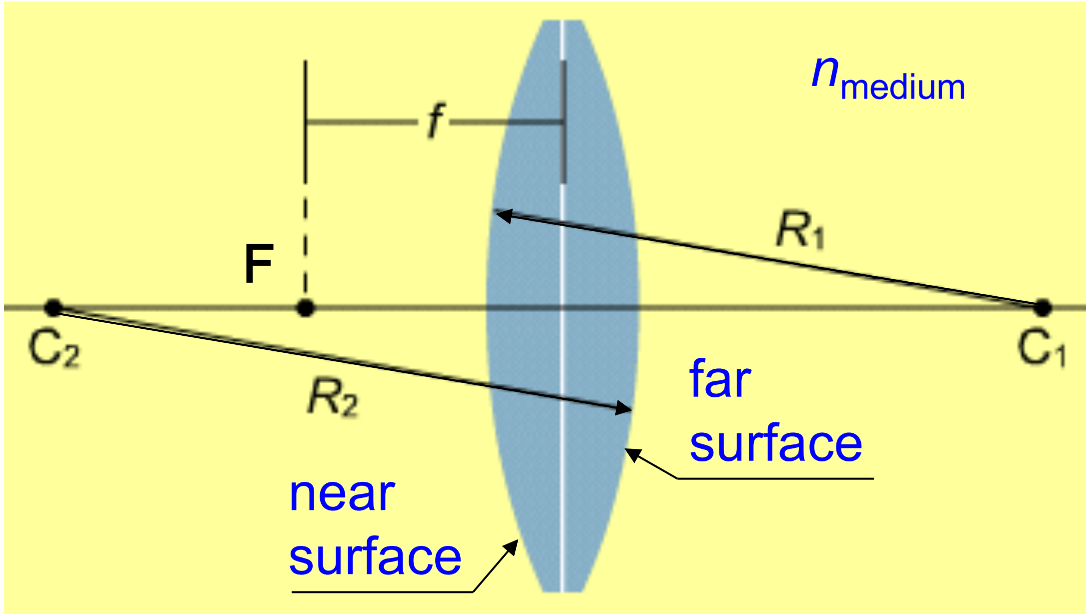
More examples



Steps to determine the signs

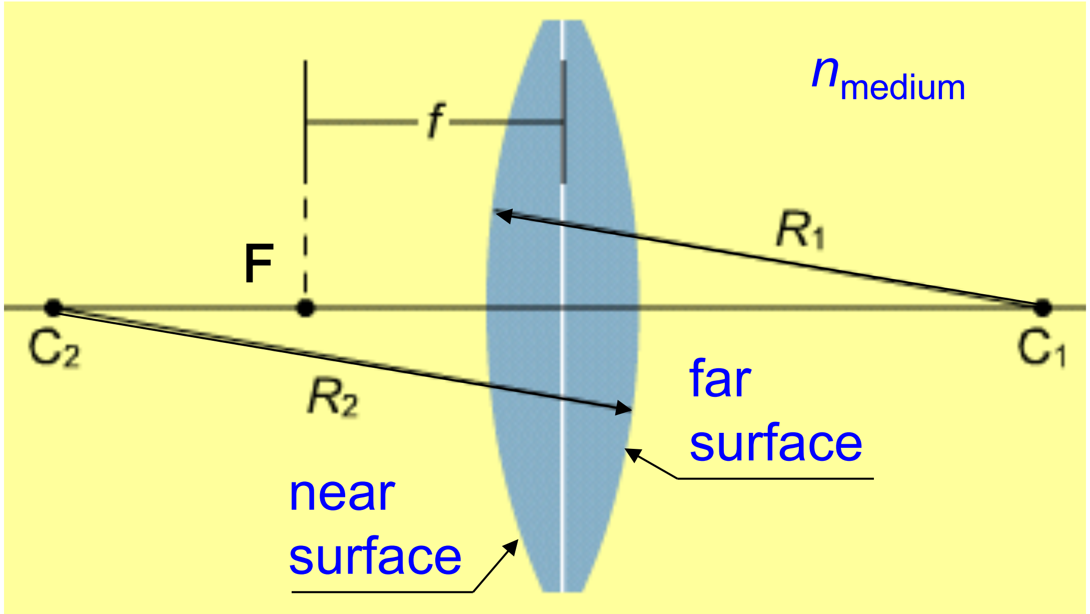
- Pick up the focal point, hence the focal length in question.
- Mark the near surface S_1, and far surface S_2.
- Based on the curve of these two surfaces, mark the center C_1 for S_1 and C_2 for S_2.
- Mark R_1 for S_1 and R_2 for S_2.
- Now decide on the sign of R_1 and R_2, based on its center on far side (+) or near side (-).

The lens maker's formula (lens in a medium)



$$\frac{1}{f} = \left(\frac{n_{lens}}{n_{medium}} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Example: prove for a thin lens, the focal length on both side of the lens is the same.



$$\frac{1}{f} = \left(\frac{n_{lens}}{n_{medium}} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

More examples

A thin lens has a focal lens of f_a = 5 mm in air. The index of refraction of the lens material is 1.53. If this lens is placed in water (n = 1.33), what will the lens' focal length in water?

One more example

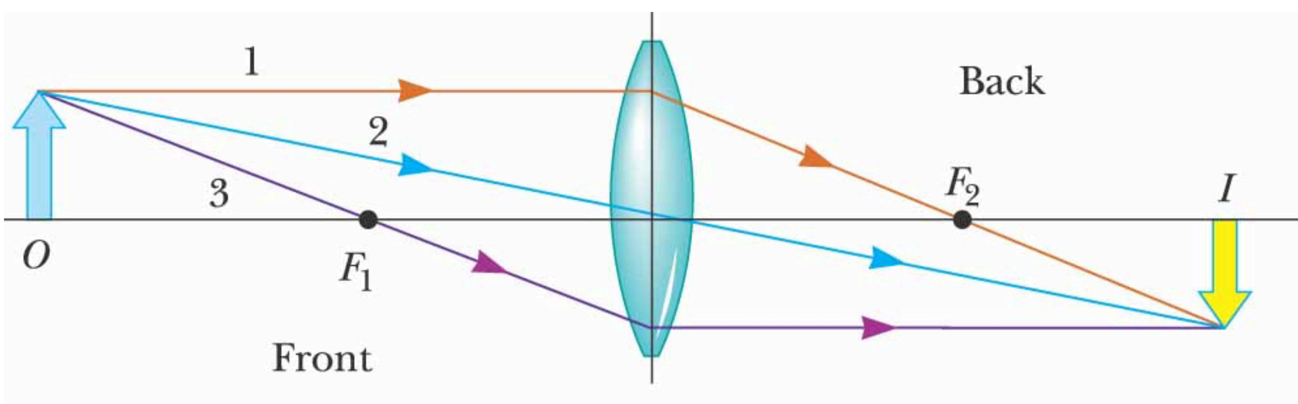
A thin lens has a near surface with a radius of curvature of −5.00 cm and a far surface with a radius of curvature of +7.00 cm. (a) Is the lens converging or diverging? (b) What is the focal length of the lens if the index of refraction of the material is 1.74?

Notes on Focal Length and Focal Point of a Thin Lens

- Because light can travel in either direction through a lens, each lens has two focal points
  - One focal point is for light passing in one direction through the lens and the other is for light traveling in the opposite direction
- However, there is only one focal length
- Each focal point is located the same distance from the lens

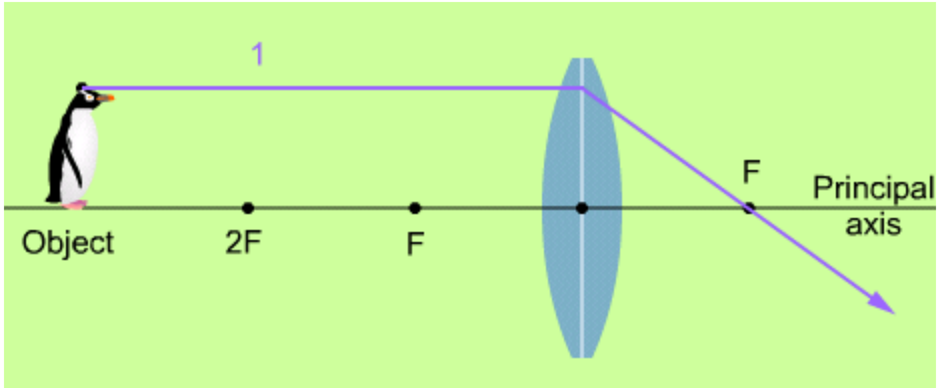
Ray Diagrams for Thin Lenses – converging

- Ray diagrams are convenient for locating the images formed by thin lenses or systems of lenses
- For a converging lens, the following three rays are drawn:
  - Ray 1 is drawn parallel to the principal axis and then passes through the focal point on the back side of the lens
  - Ray 2 is drawn through the center of the lens and continues in a straight line
  - Ray 3 is drawn through the focal point on the front of the lens (or as if coming from the focal point if $p < f$) and emerges from the lens parallel to the principal axis

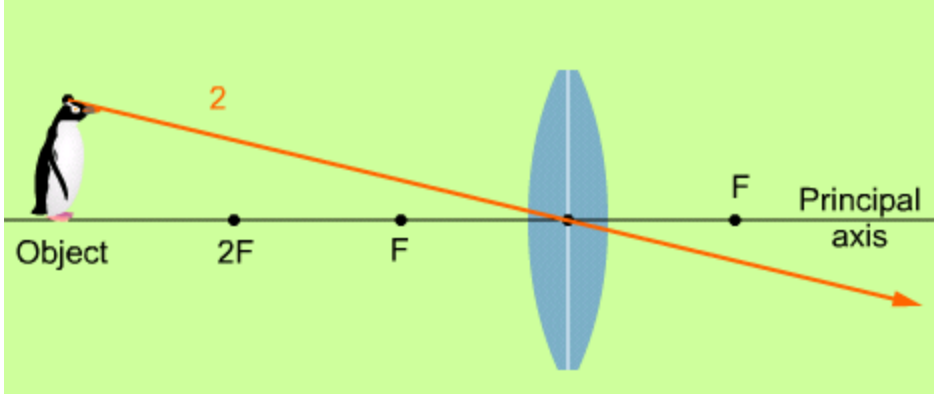


- The image is real
- The image is inverted
- The image is on the back side of the lens

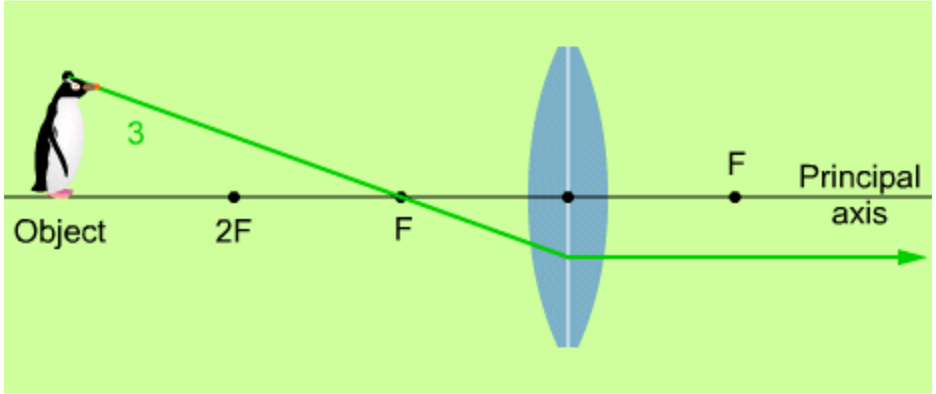
The 3-ray diagram again



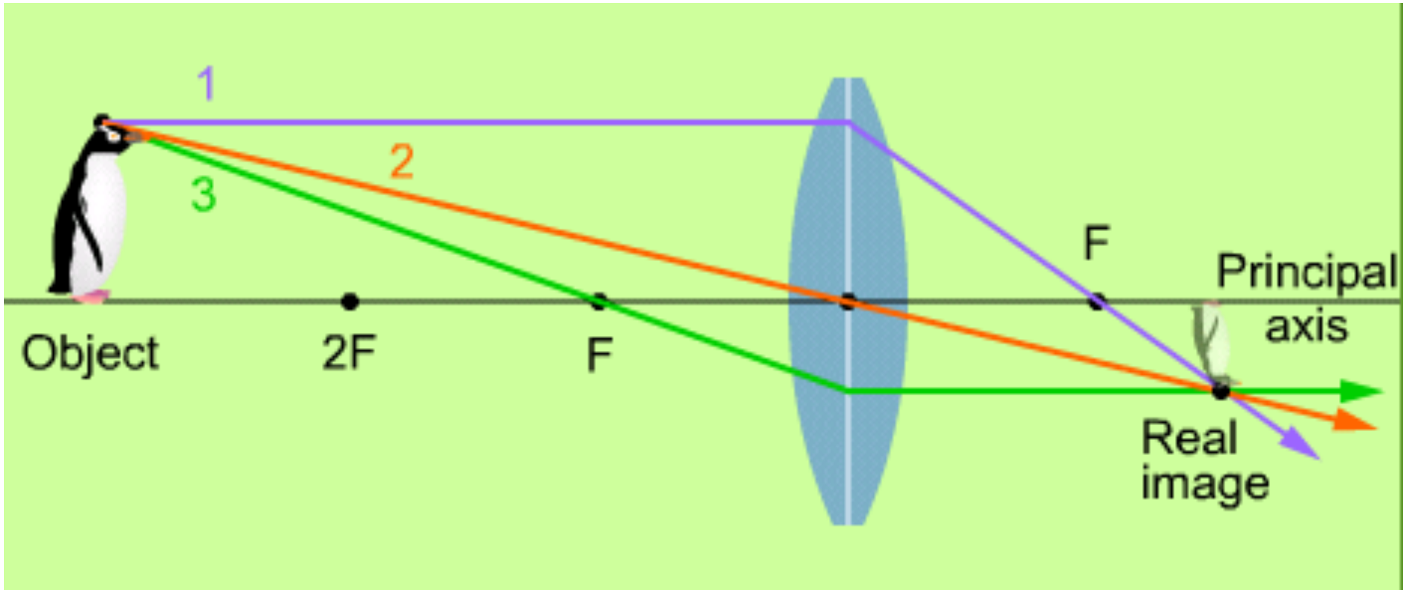
Ray 1:
Parallel to axis, then passes through far focal point

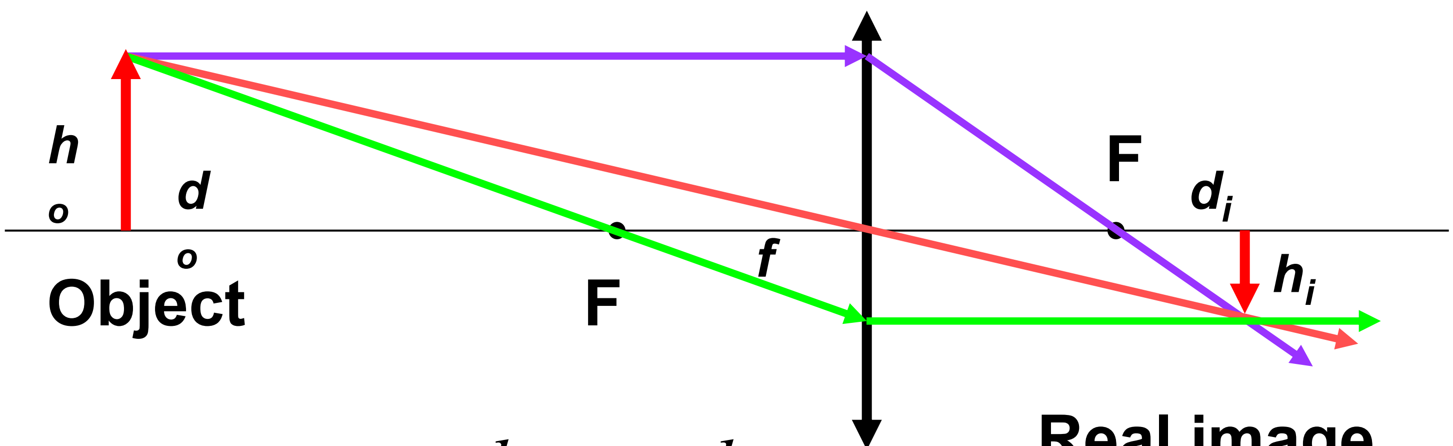


Ray 2:
Passes unchanged through center of lens



Ray 3:
Passes through near focal point, then parallel to axis

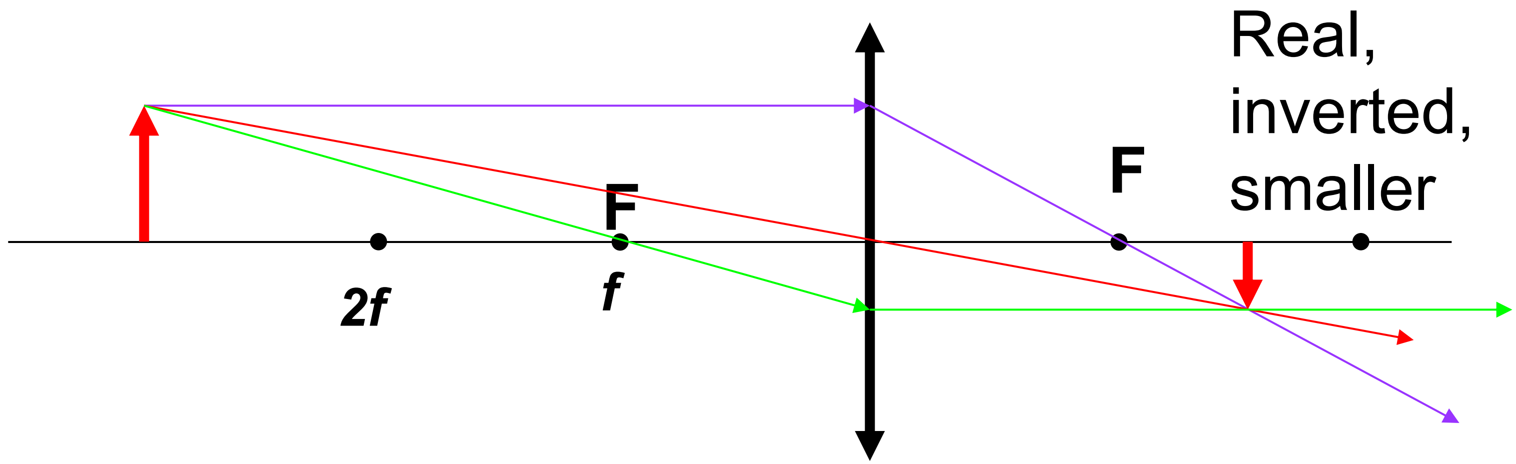


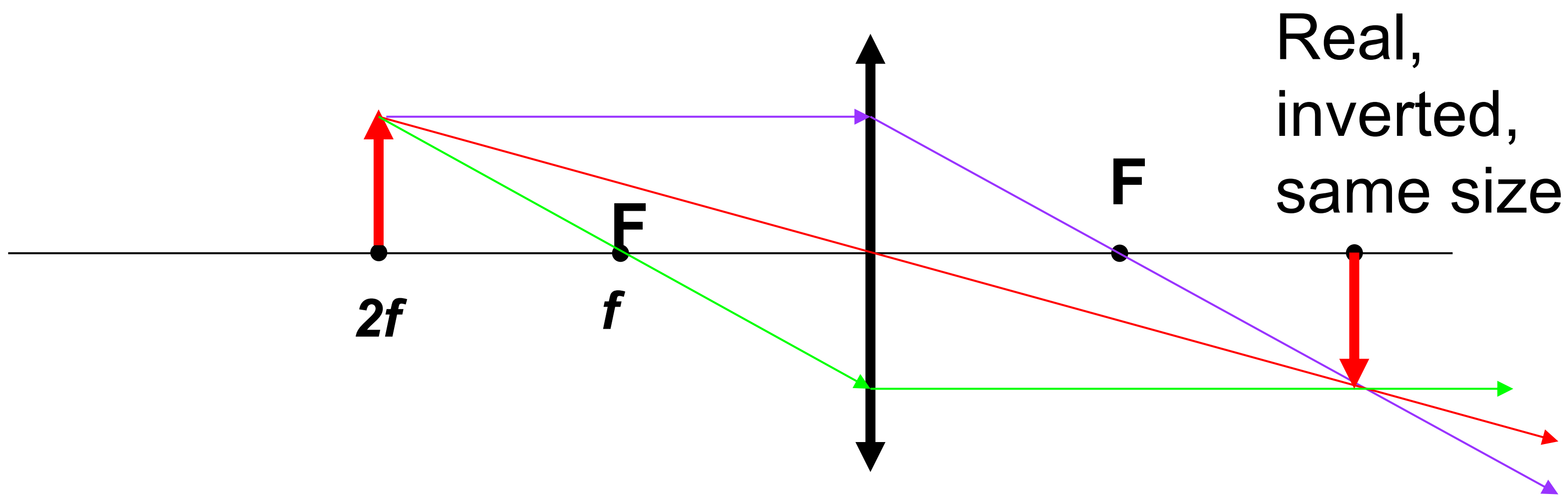


Real image, inverted, smaller

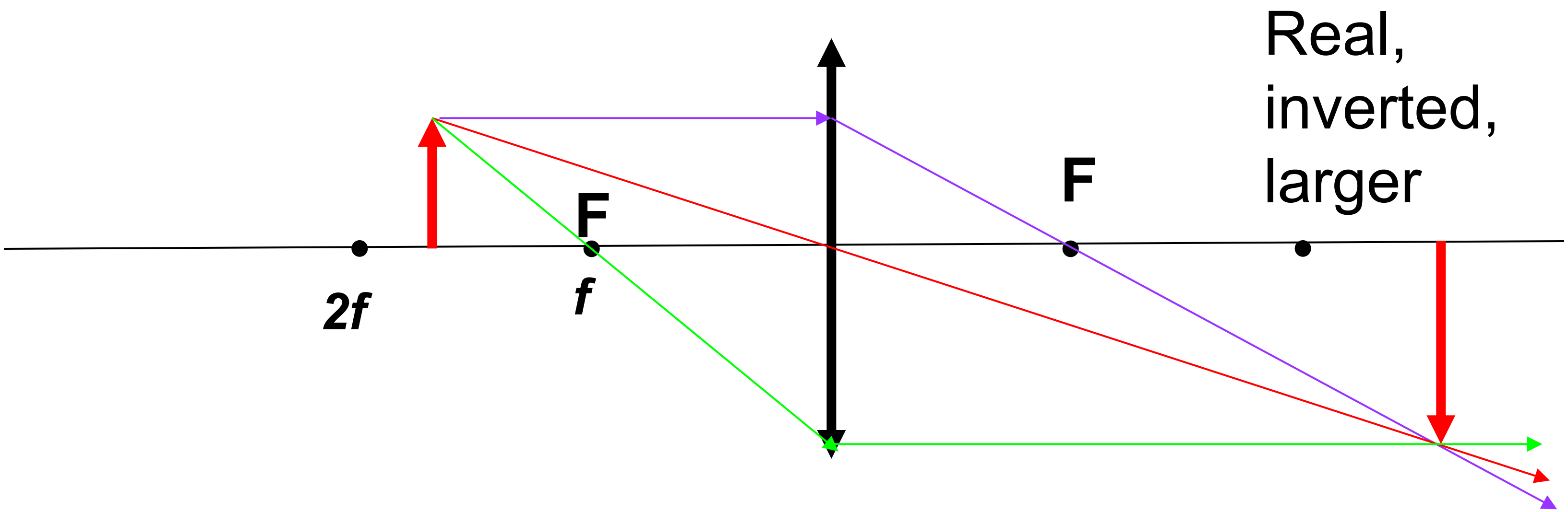
$$\text{magnification}: \quad m \equiv \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

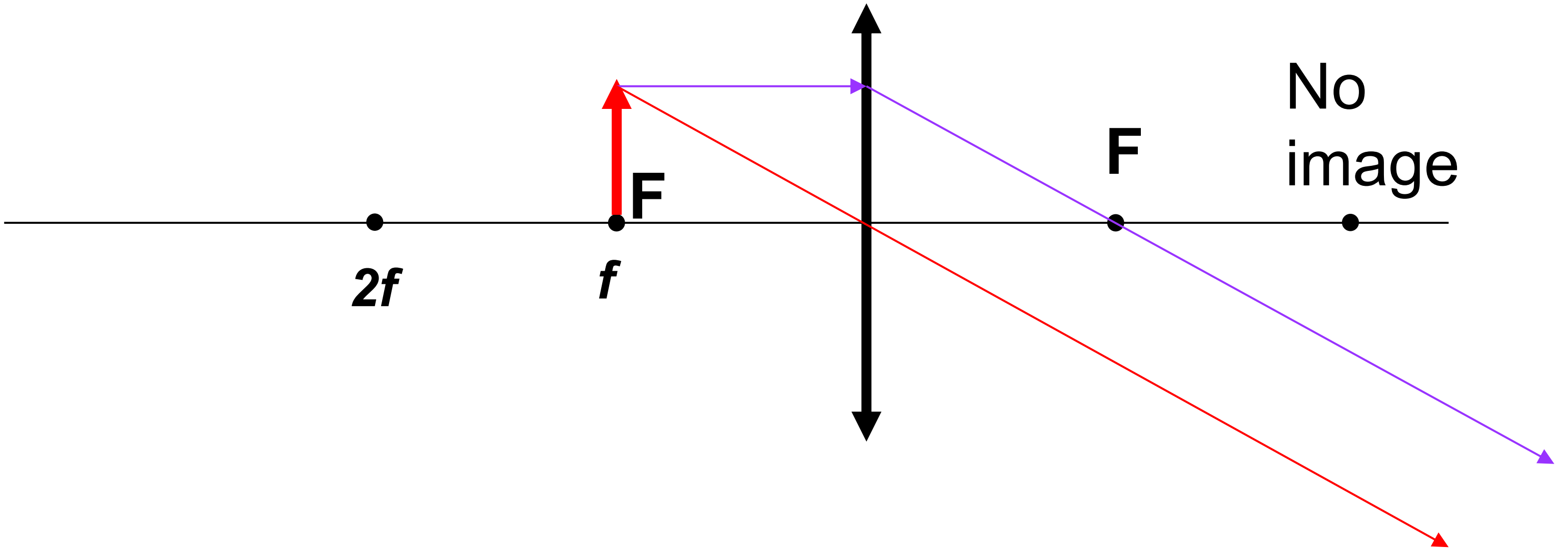
Object distance, 5 cases: 1 -- 2



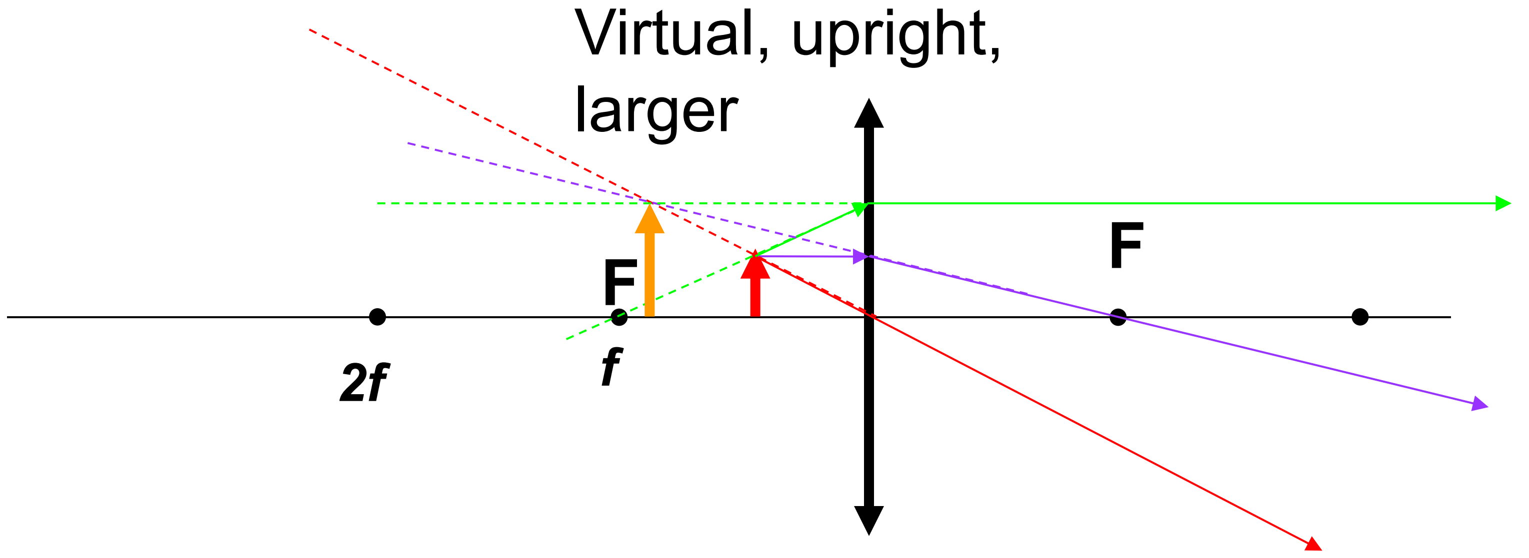


Object distance, 5 cases: 3 -- 4





Object distance, 5 cases: 5

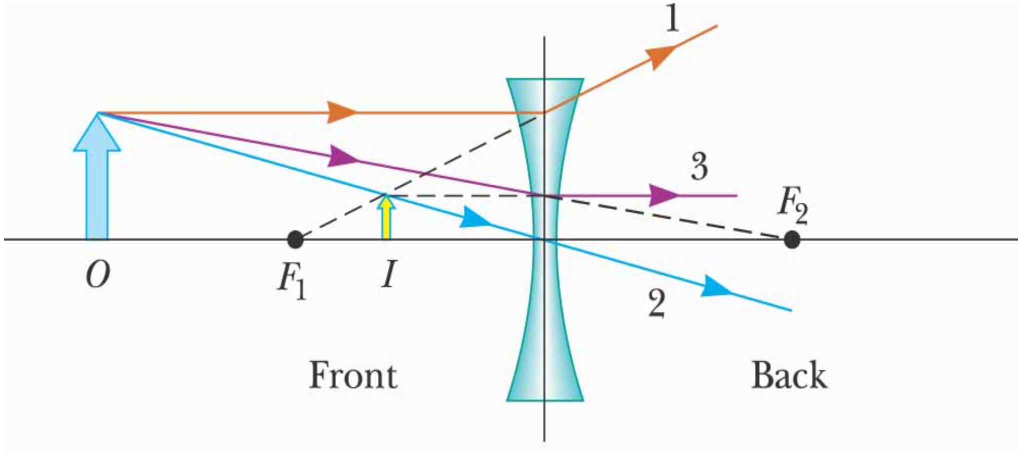


Like in the converging mirror case, there are 5 possible object locations that produce different images.

While in the diverging lens case, like in the diverging mirror case, no matter where the object is placed, you always get a virtual, upright and smaller image.

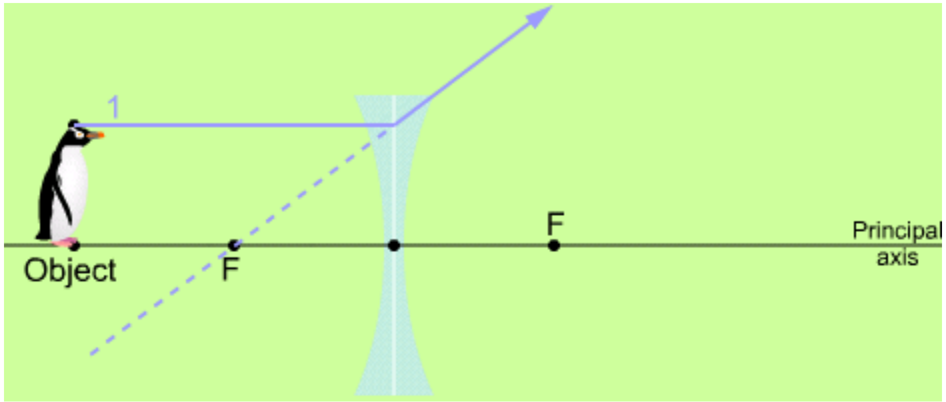
Ray Diagrams for Thin Lenses – Diverging

- For a diverging lens, the following three rays are drawn:
  - Ray 1 is drawn parallel to the principal axis and emerges directed away from the focal point on the front side of the lens
  - Ray 2 is drawn through the center of the lens and continues in a straight line
  - Ray 3 is drawn in the direction toward the focal point on the back side of the lens and emerges from the lens parallel to the principal axis

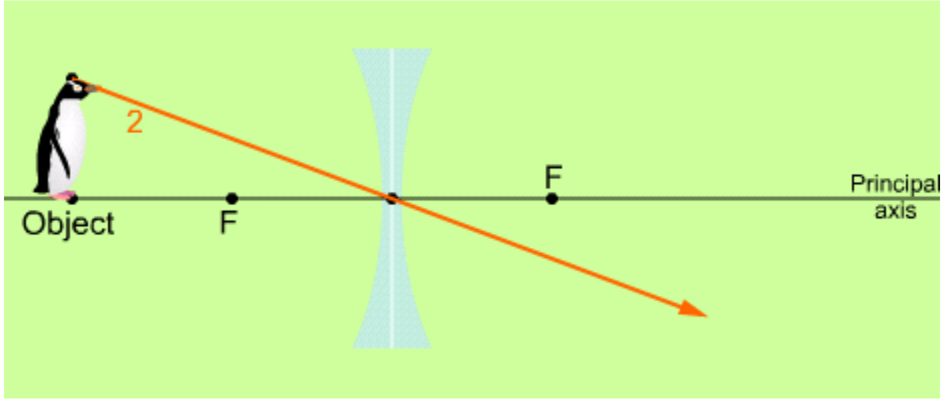


1. The image is virtual
2. The image is upright
3. The image is smaller
4. The image is on the front side of the lens

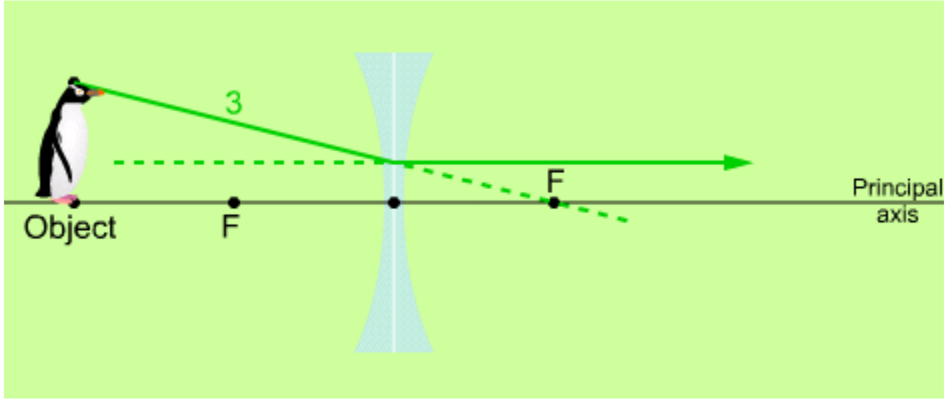
The 3-ray diagram again



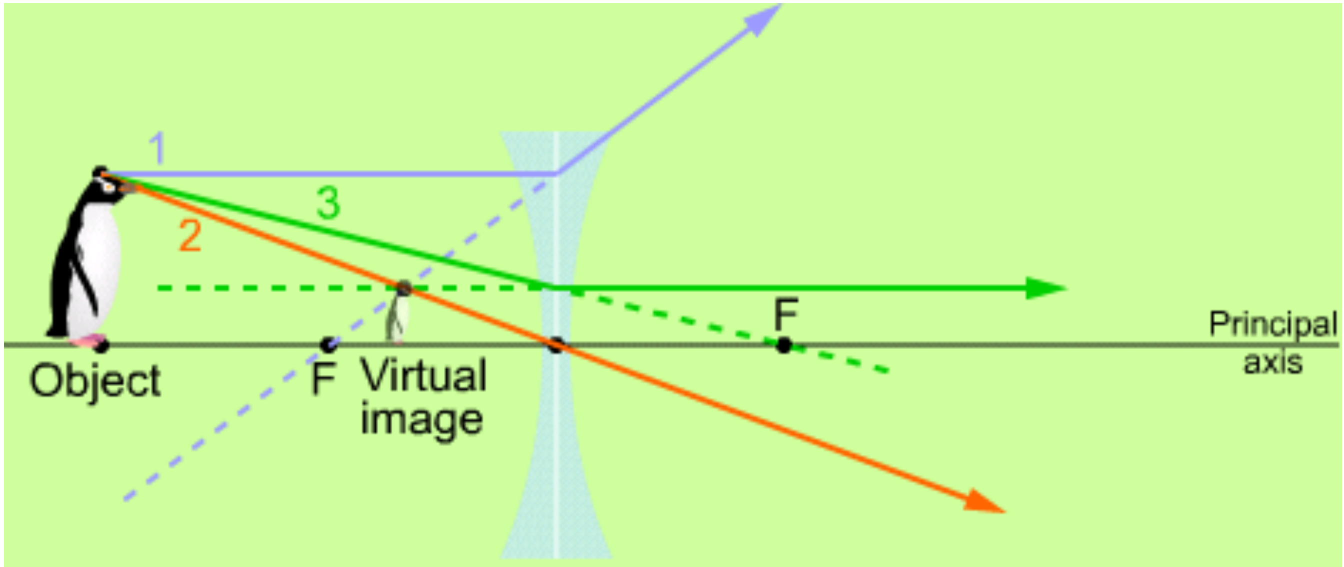
Ray 1
Parallel to axis, virtual ray passes through near focal point

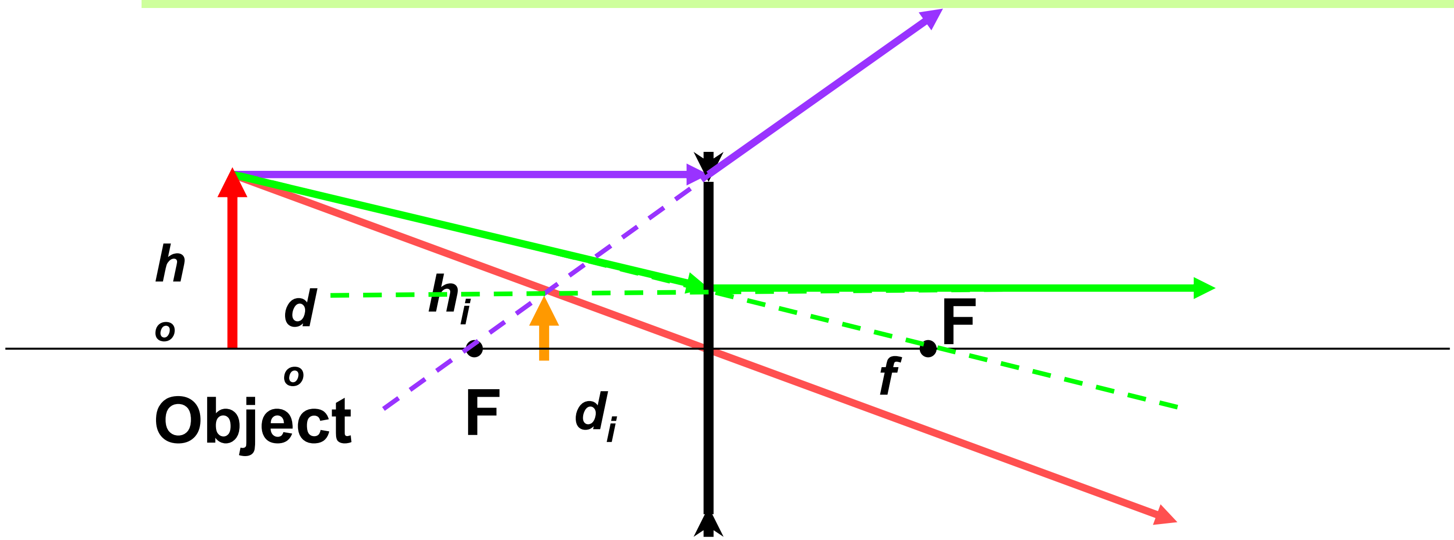


Ray 2
Straight through center of lens



Ray 3
Virtual ray through far focal point, virtual ray parallel to axis

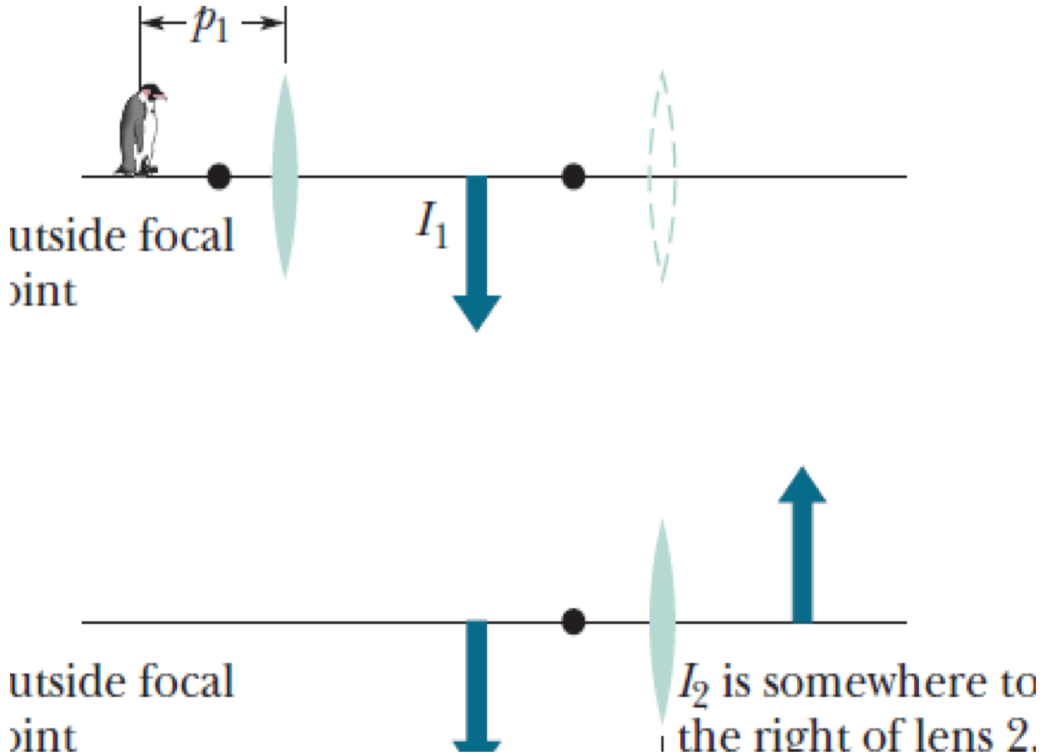




Virtual image, upright, smaller

34.7: Thin Lenses, Two Lens System, where the calculation helps

Step 1
Neglecting lens 2, locate the image I_1 produced by lens 1.
Determine whether the image is on the left or right side of the lens, whether it is real or virtual, and whether it has the same orientation as the object. Find the lateral magnification m_1.



Step 2
Neglecting lens 1, treat I_1 as though it is the object for lens 2. Locate the image I_2 produced by the second lens.
If I_1 lies to the right of lens 2 (past lens 2), treat it as the object for lens 2, but take the object distance p_2 as a negative number when locating the final image position, I_2.
Find the lateral magnification m_2.

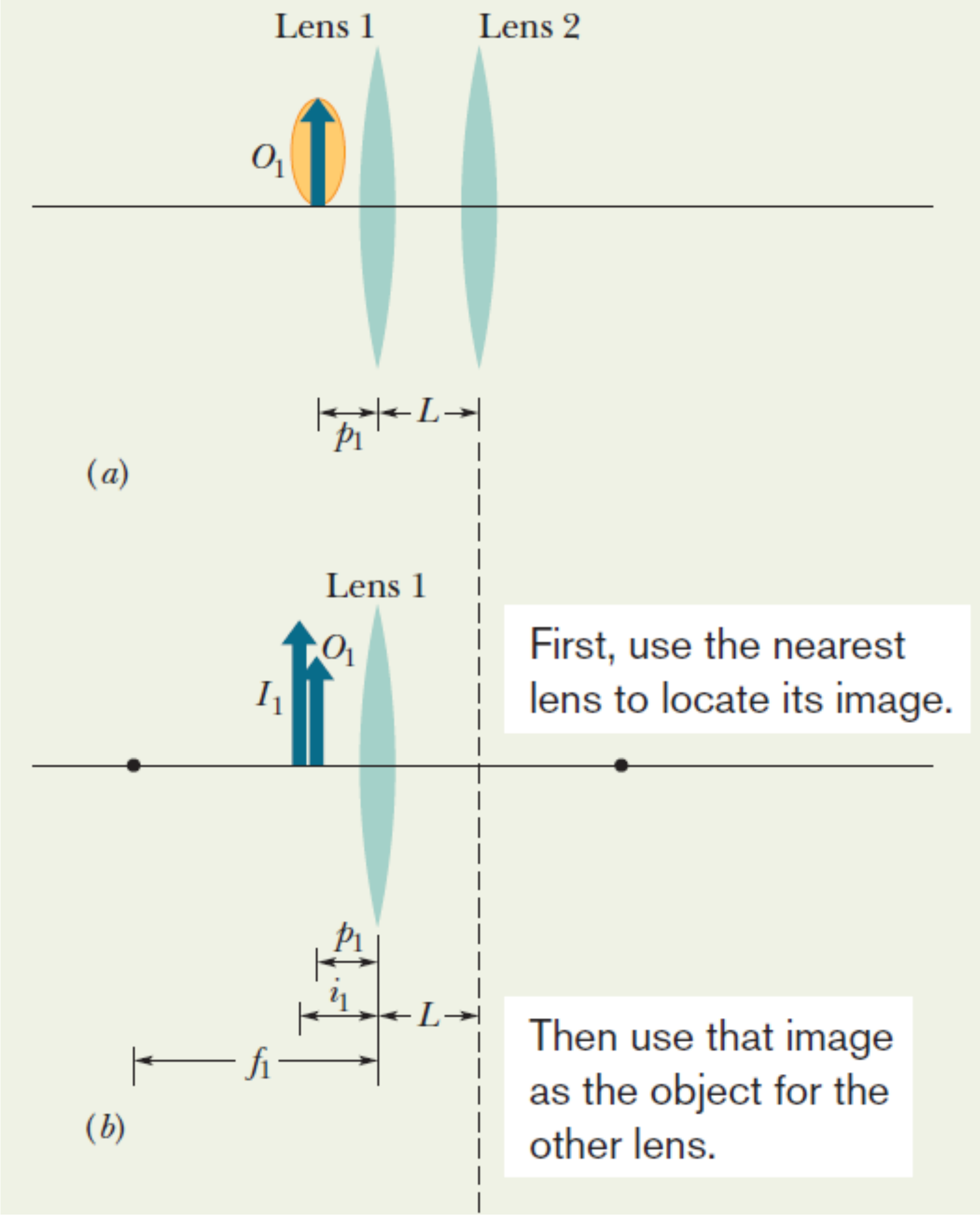
Total magnification is: $M = m_1 m_2.$

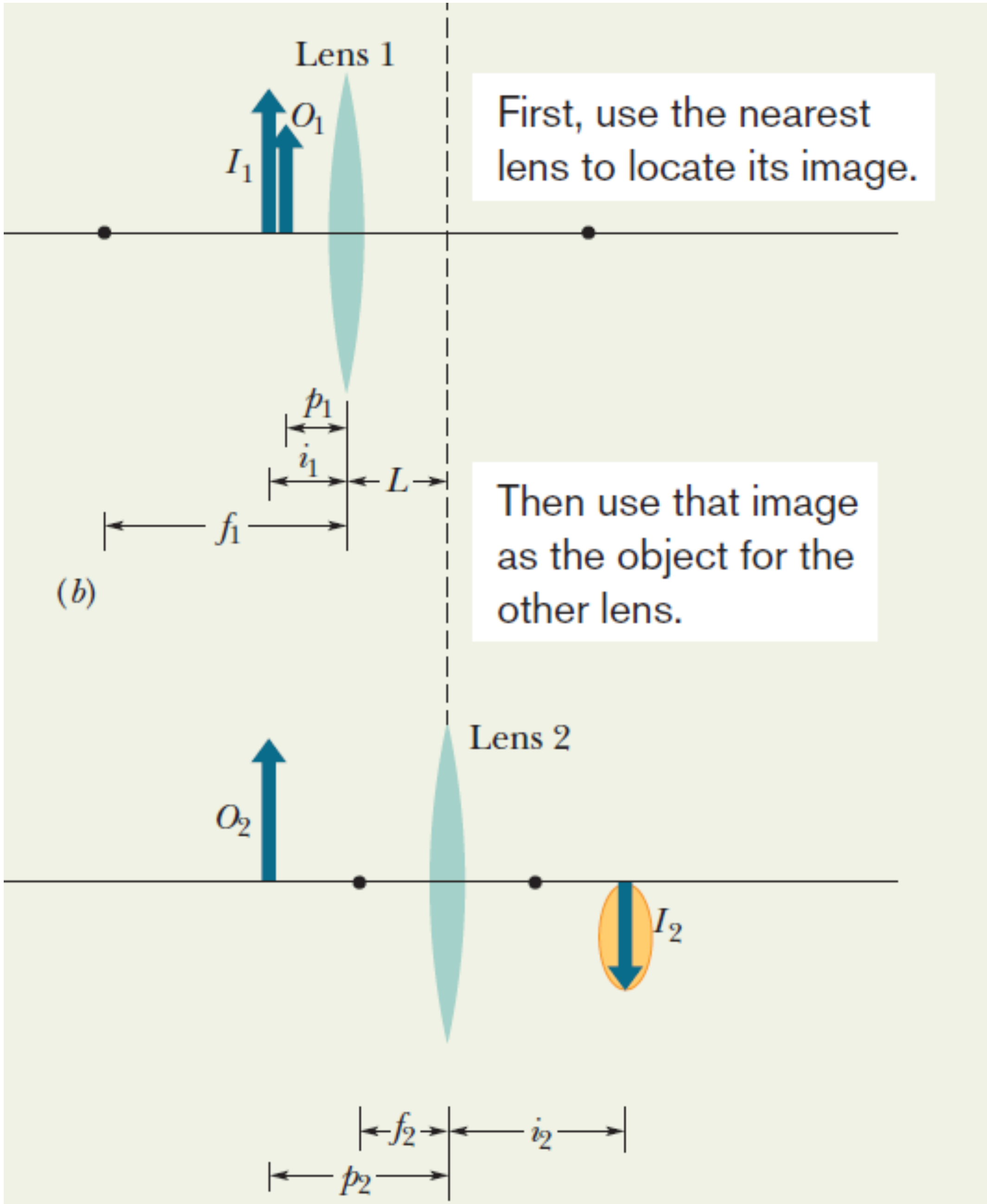
If M is positive, the final image has same the orientation as the object.

Example, Image produced by a system of two thin lenses:

Figure 34-18*a* shows a jalapeño seed O_1 that is placed in front of two thin symmetrical coaxial lenses 1 and 2, with focal lengths $f_1 = +24$ cm and $f_2 = +9.0$ cm, respectively, and with lens separation $L = 10$ cm. The seed is 6.0 cm from lens 1. Where does the system of two lenses produce an image of the seed?

Fig. 34-18


Lens 1
Lens 2
O_1
p_1
L
(a)
Lens 1
O_1
I_1
First, use the nearest lens to locate its image.
p_1
i_1
L
f_1
(b)
Then use that image as the object for the other lens.

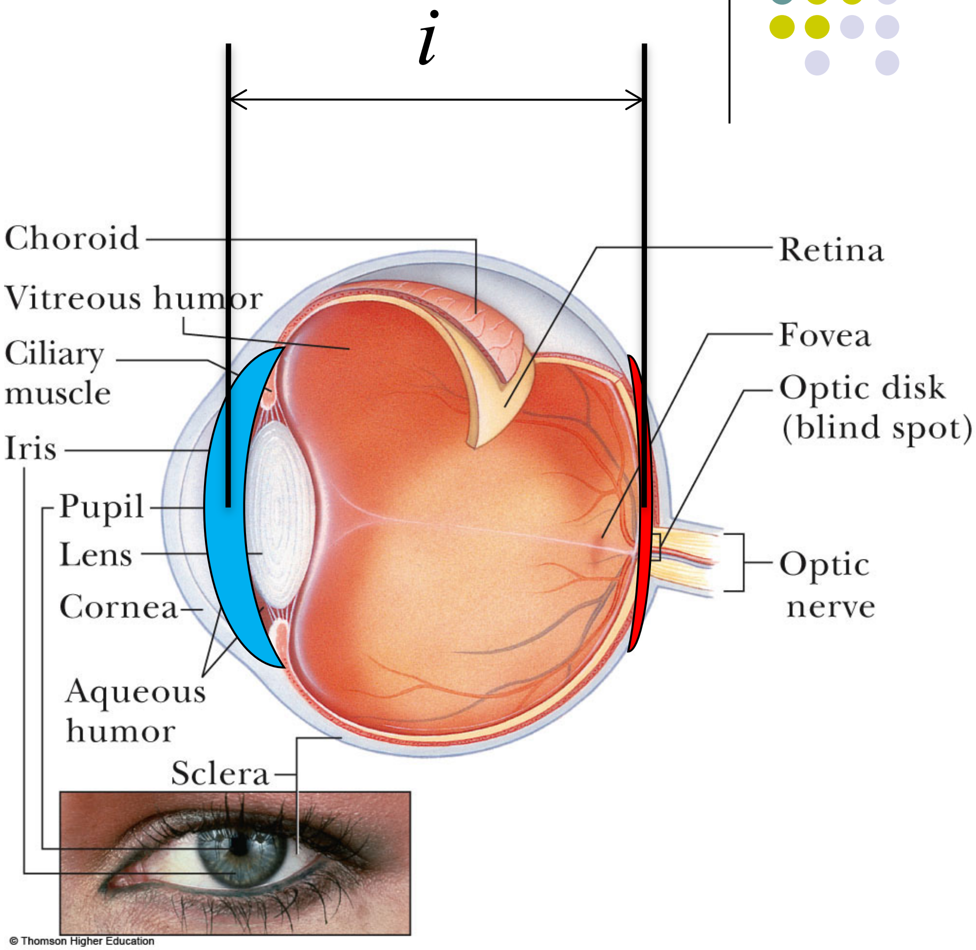


Lens 1
O_1
I_1
First, use the nearest lens to locate its image.
p_1
i_1
L
f_1
(b)
Then use that image as the object for the other lens.
Lens 2
O_2
I_2
f_2
i_2
p_2
(c)

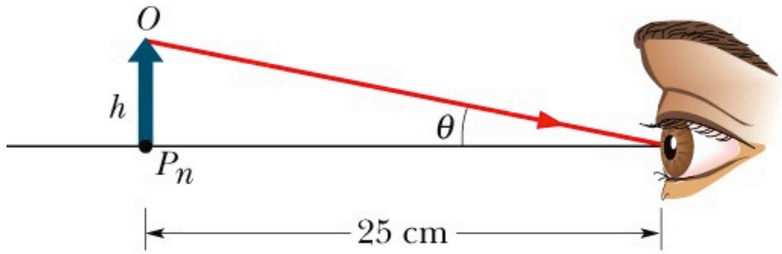
Fig. 34-18

The Eye

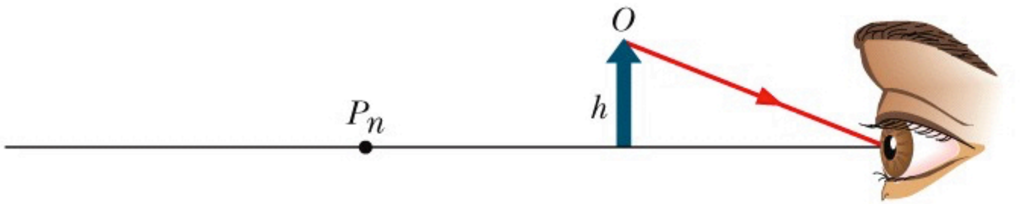
- The normal eye focuses light and produces a sharp image.
- The image distance is unknown but fixed. The focal length changes in a range.
- The near point corresponds to the shortest focal length, the far point, which is infinity for an healthy eye, a finite distance for near-sighted, corresponds to the longest focal length.



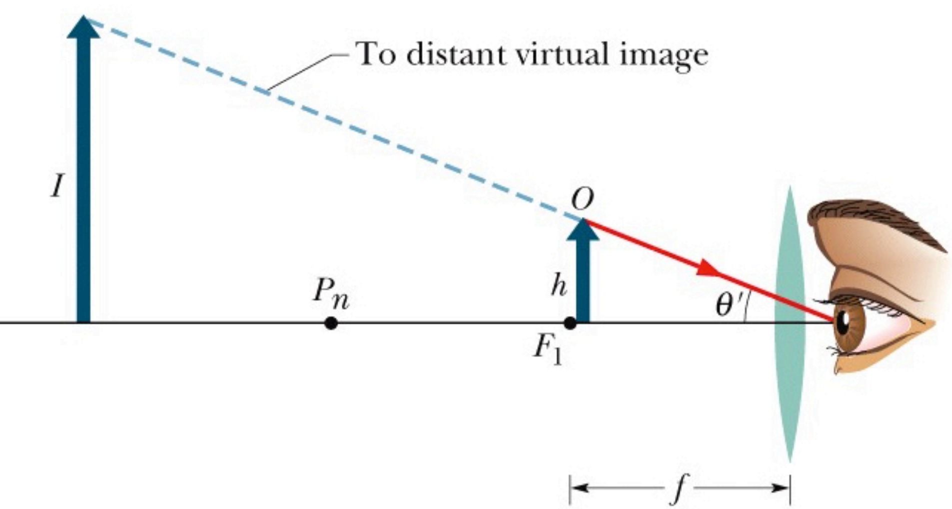
Simple Magnifying Lens



Object at near point P_n, the angle θ corresponds to the ability the eye can distinguish the height of the object.

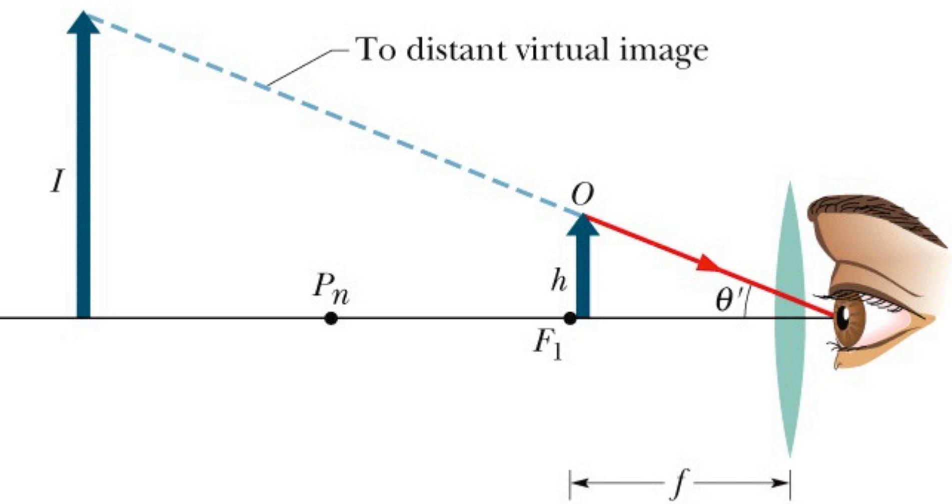


When object is between the near point and the eye, image is no longer on the retina, the eye sees a blurred image.



When object is too small (to have an opening angle of θ at the near point P_n), a magnifying lens is placed before the eye so that the image of the object by this lens has an opening angle of $\theta' > \theta$: magnified.

Simple Magnifying Lens

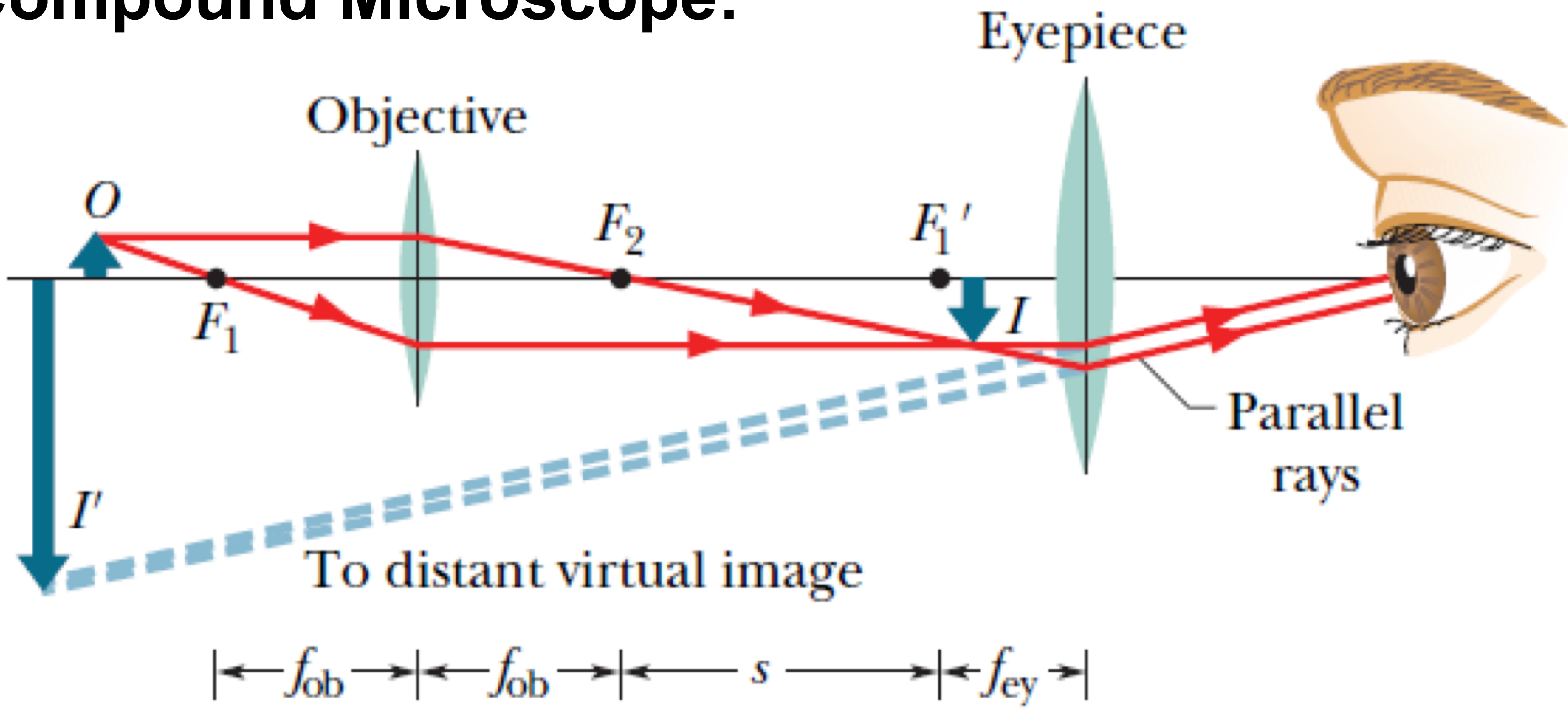


The angular magnification (not the lateral magnification) of a simple magnifying lens is

$$M_\theta = \frac{\theta'}{\theta} \cong \frac{25\text{ cm}}{f}$$

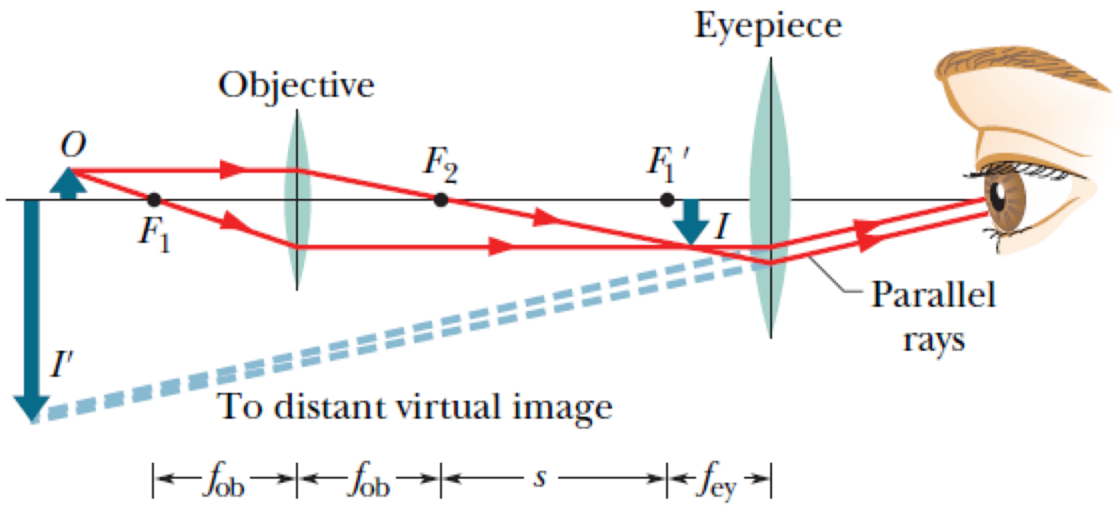
where f is the focal length of the lens and 25 cm is a reference value for the near point value.

Compound Microscope:



A compound microscope is made of two focusing lenses (called the objective and the eyepiece). The focal lengths f_{ob} and f_{ey} are small compared with the distance s between the two lenses. The two lenses are configured in such a way that the object, placed just outside of the focal point F_1 of the objective produces an magified real image just inside the focal point F_1' of the eyepiece. When looking through the eyepiece, that real image forms a much magnified virtual image to the eye.

Compound Microscope:

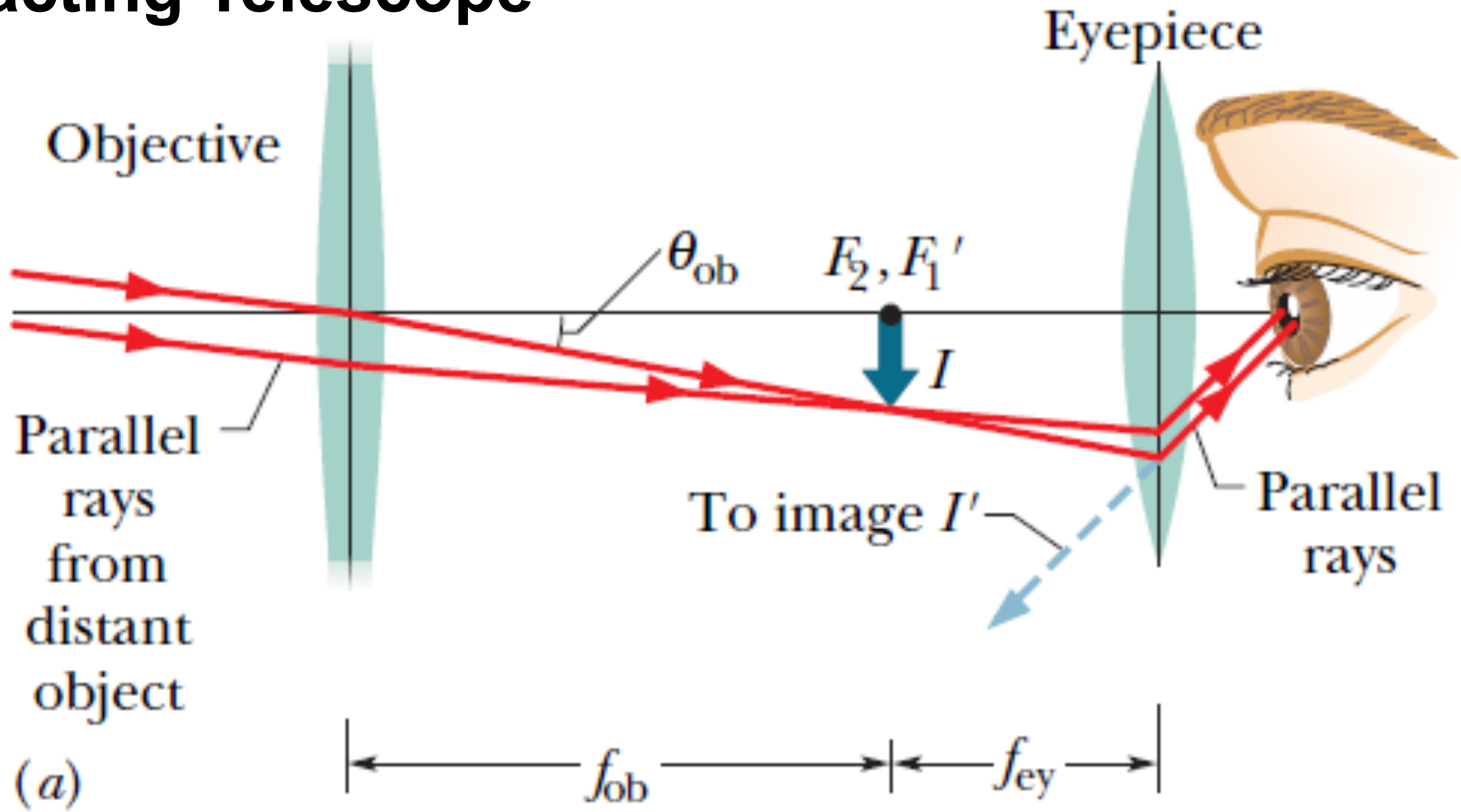


If the lateral magnification produced by the objective is m, and the total magnification of the microscope is M, then

$$m = -\frac{i}{p} \cong -\frac{s}{f_{\text{object lens}}}$$

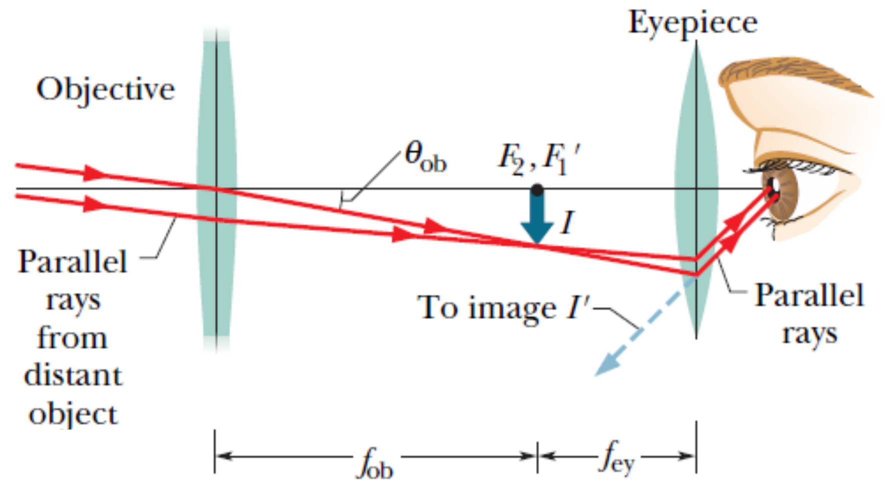
$$M = mM_\theta \cong -\frac{s}{f_{\text{object lens}}}\frac{25\text{ cm}}{f_{\text{eyepiece}}}$$

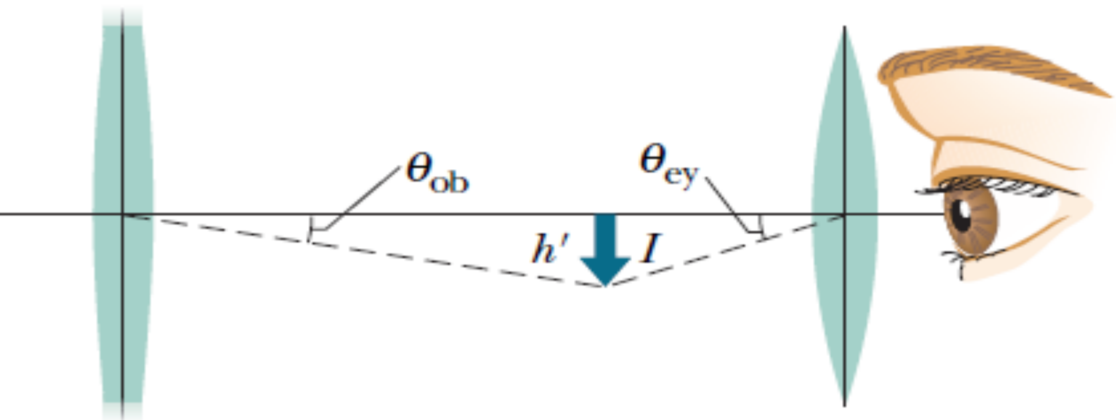
Refracting Telescope



A refracting telescope is also made of two focusing lenses (called the objective and the eyepiece). The objective focal length is longer than that of the eyepiece: $f_{ob} > f_{ey}$. The two lenses are configured in such the distance between them is the sum of the two focal lengths: $s = f_{ob} + f_{ey}$. Object far away from the objective forms a real image just inside the focal point if the eyepiece. When looking through the eyepiece, that real image forms a much magnified virtual image to the eye.

Refracting Telescope





The angular magnification m_θ of the telescope is θ_{ey}/θ_{ob}. For rays close to the central axis, we can write $\theta_{ob} \approx h/f_{ob}$ *and* $\theta_{ey} \approx h/f_{ey}$, which gives

$$M_\theta \cong -\frac{f_{\text{objective}}}{f_{\text{eyepiece}}}$$