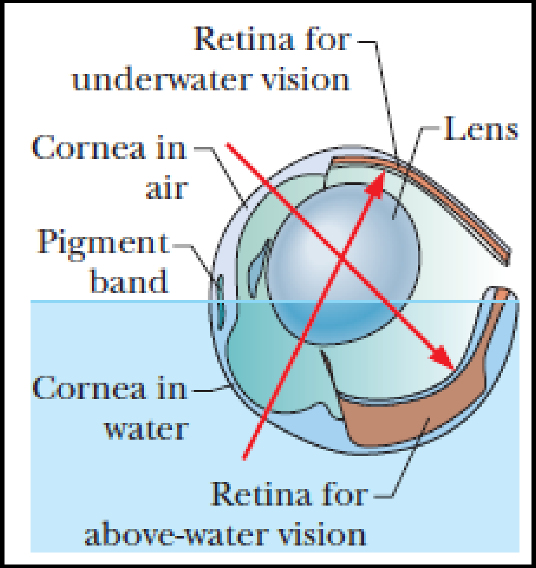
14 Images – Geometrical Optics

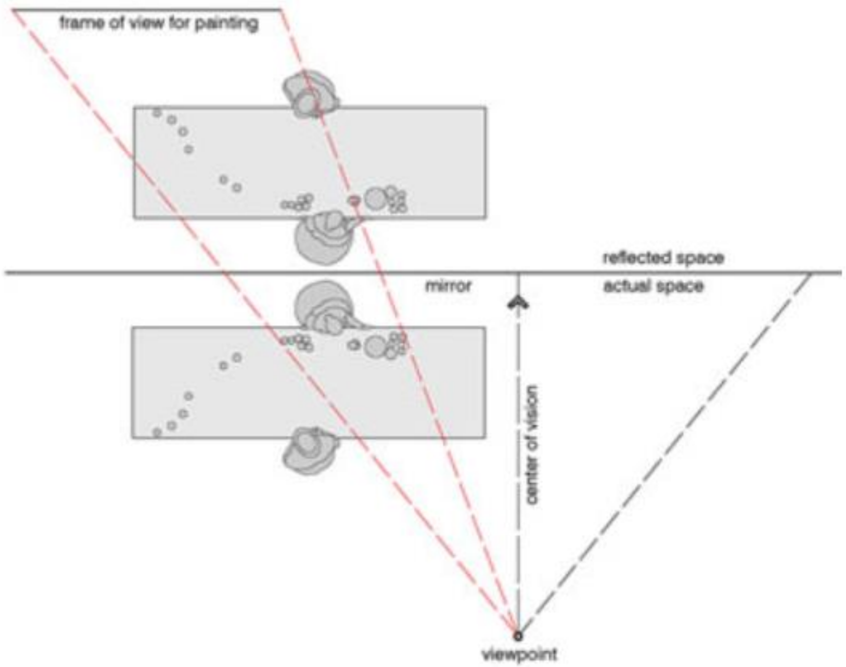
Anableps – 4 eyed fish



How can its eyes function in both air and water?

What's wrong about it?

Manet's Bar at the Folies-Bergère: One Scholar's Perspective



Arrangement of the bar and its reflected image, viewed from above, showing the "offset" viewpoint. Computer-generated diagram by Malcolm Park, with the assistance of Darren McKimm. Courtesy of Malcolm Park

+ Enlarge

Photograph showing a reconstruction of the bar arrangement as seen from the offset viewpoint, 2000. Photograph by Greg Callan Courtesy of Malcolm Park

+ Enlarge

Sections

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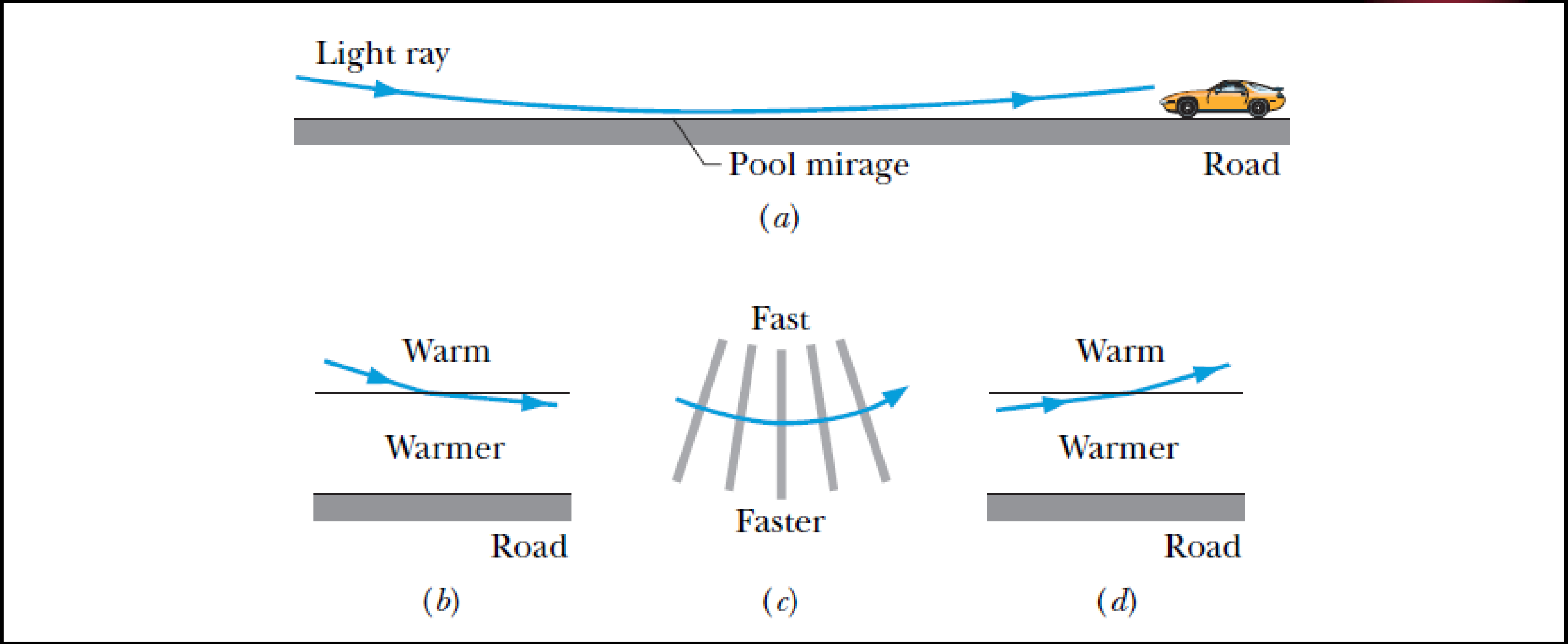
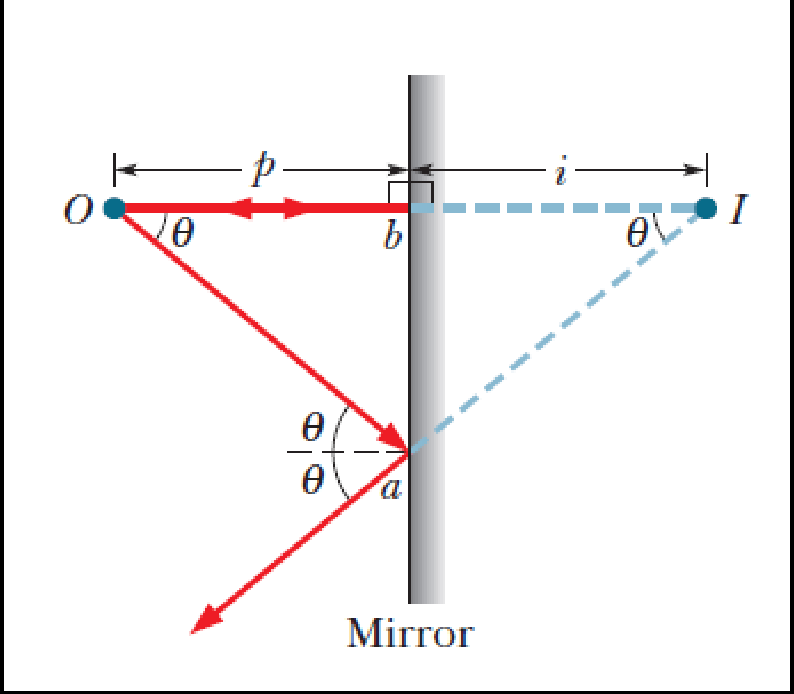
14.1 VIRTUAL IMAGE and REAL IMAGE

An Example of Virtual Image, A Common Mirage:



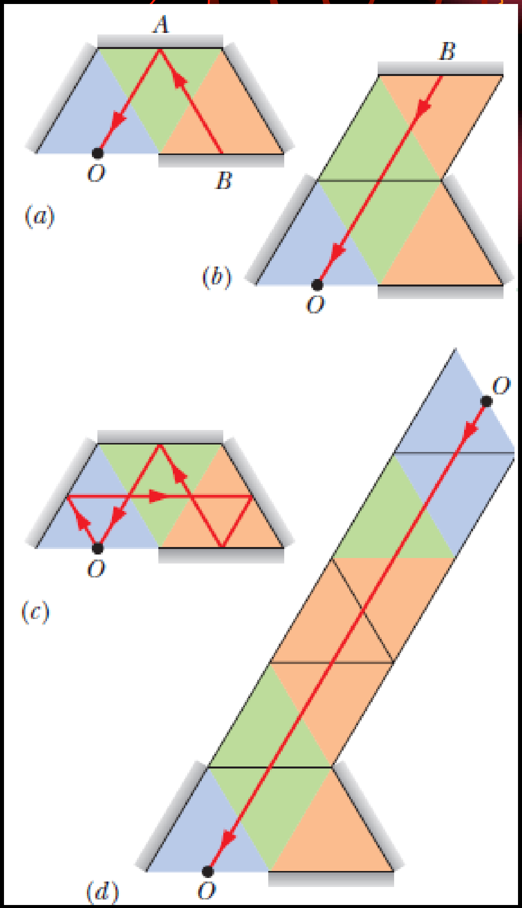
14.2 Plane Mirrors



$$Ib = Ob,$$

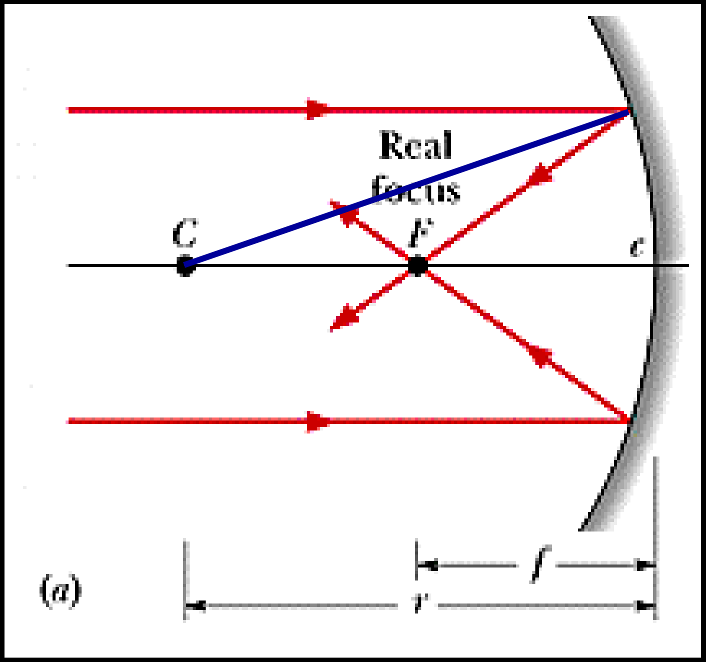
$$i = -p \qquad \text{(plane mirror).}$$

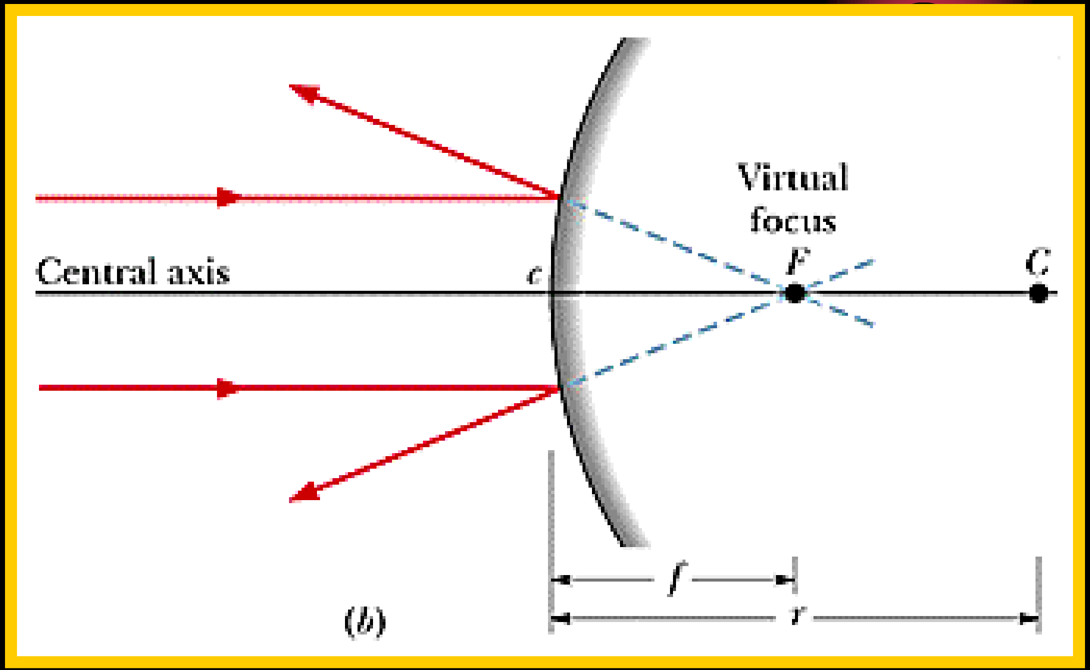
Mirror Maze



14.3 Concave and Convex Spherical Mirrors

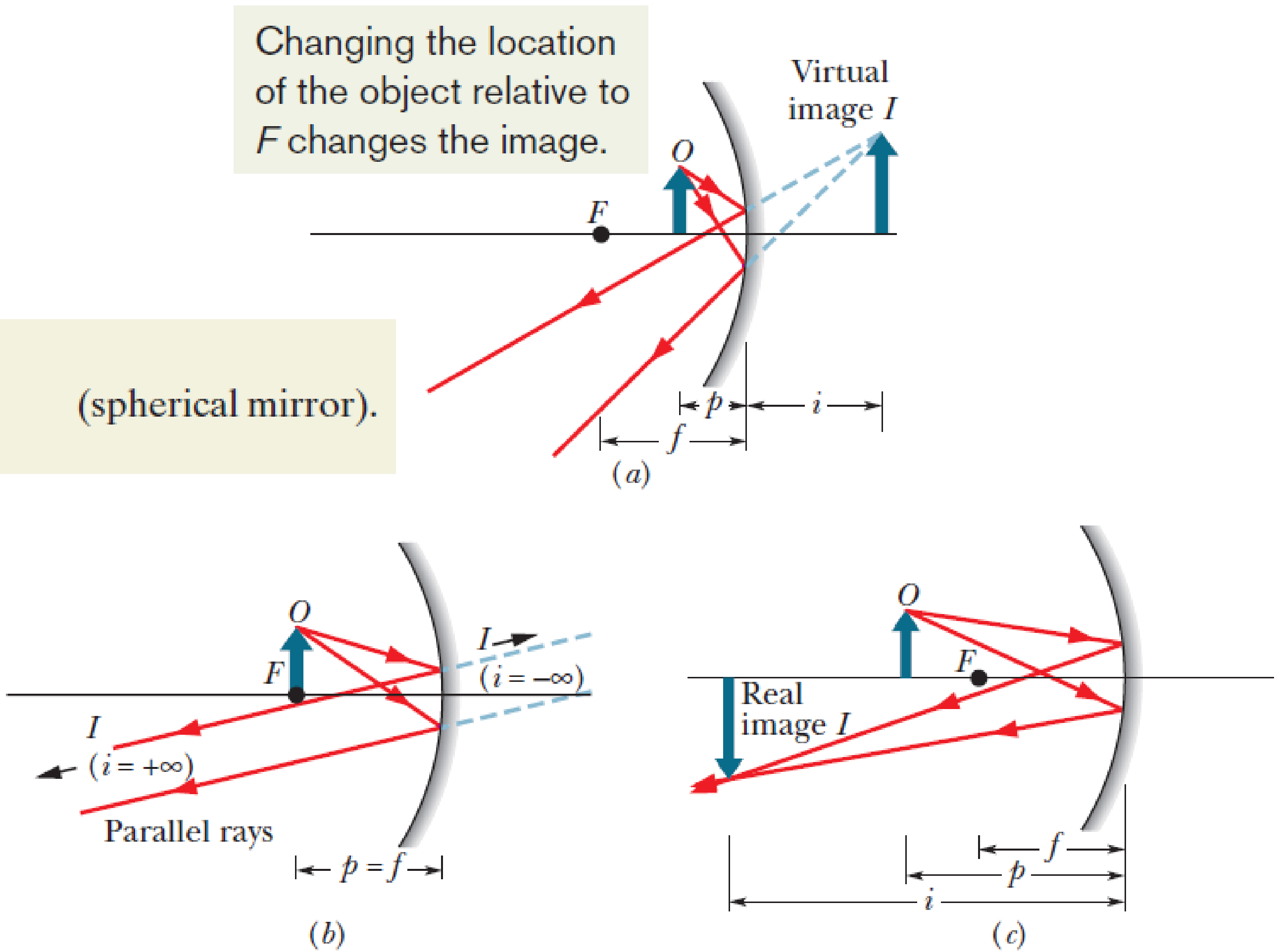
Focal length *f* and radius of curvature *r*





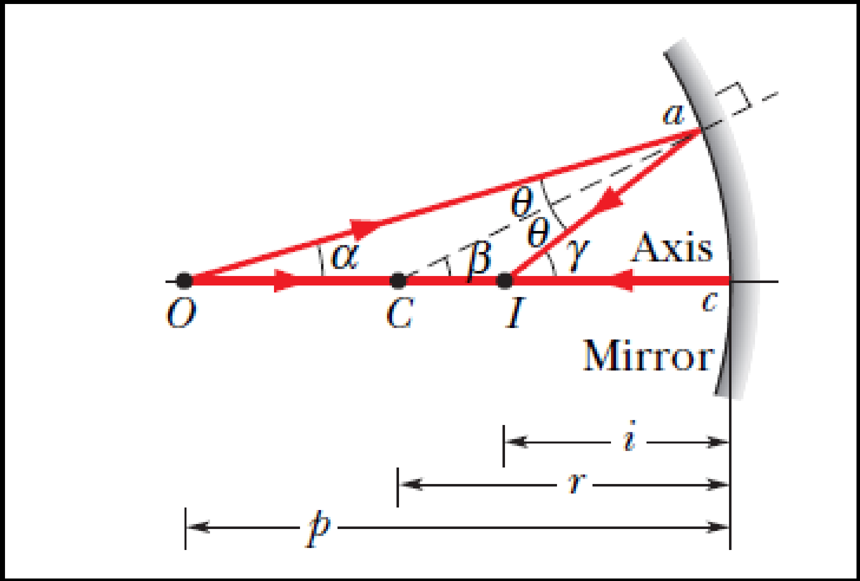
$$f = r/2$$

14.4 Images from Spherical Mirrors



$$\frac{1}{p} + \frac{1}{i} = \frac{1}{f} \qquad \text{(spherical mirror).}$$

The Spherical Mirror Formula



$$\beta = \alpha + \theta \quad \text{and} \quad \gamma = \alpha + 2\theta.$$

$$\alpha + \gamma = 2\beta.$$

$$\alpha \approx \frac{\widehat{ac}}{cO} = \frac{\widehat{ac}}{p}, \qquad \beta = \frac{\widehat{ac}}{cC} = \frac{\widehat{ac}}{r},$$

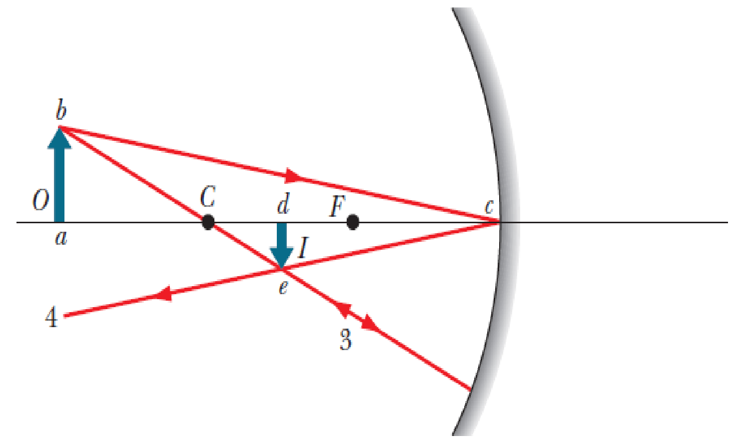
$$\gamma \approx \frac{\widehat{ac}}{cI} = \frac{\widehat{ac}}{i},$$

$$\frac{1}{p} + \frac{1}{i} = \frac{1}{f} \qquad \text{(spherical mirror).}$$

lateral magnification *m*

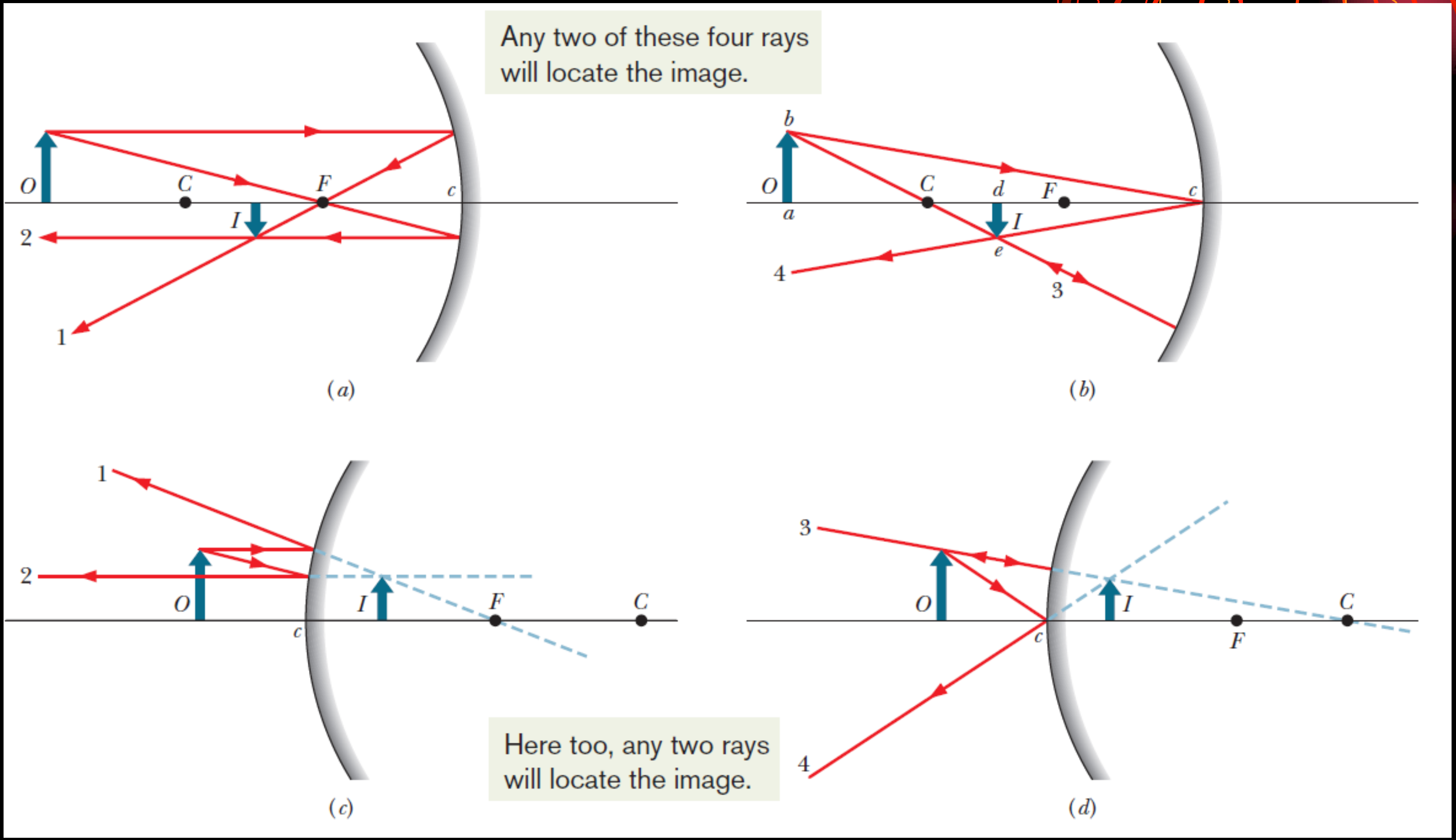
$$|m| = \frac{h'}{h} \quad \text{(lateral magnification).}$$

$$= -\frac{i}{p} \quad \text{(lateral magnification).}$$



(b)

Locating Images by drawing (4) rays



Example: Image produced by a spherical mirror

A tarantula of height h sits cautiously before a spherical mirror whose focal length has absolute value $|f| = 40$ cm. The image of the tarantula produced by the mirror has the same orientation as the tarantula and has height $h' = 0.20h$.

(a) Is the image real or virtual, and is it on the same side of the mirror as the tarantula or the opposite side?

(b) Is the mirror concave or convex, and what is its focal length f, sign included?

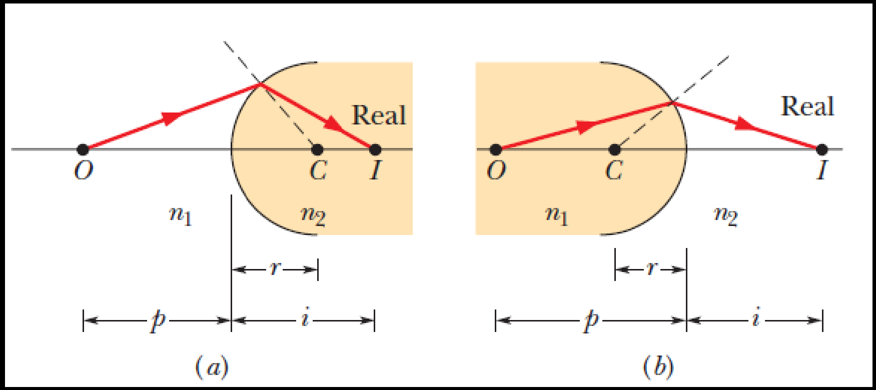
$$|m| = \frac{h'}{h} = 0.20.$$

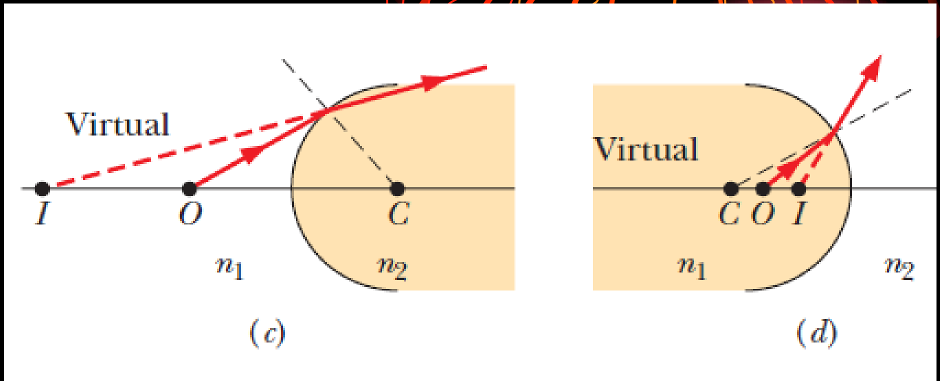
$$i = -0.20p,$$

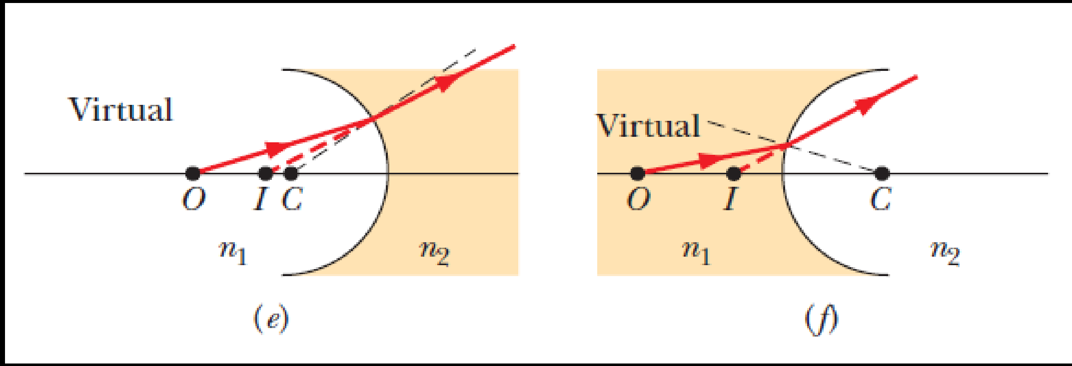
$$\frac{1}{f} = \frac{1}{i} + \frac{1}{p} = \frac{1}{-0.20p} + \frac{1}{p} = \frac{1}{p}(-5 + 1),$$

$$f = -40 \text{ cm}.$$

14.5 Spherical Refracting Surfaces





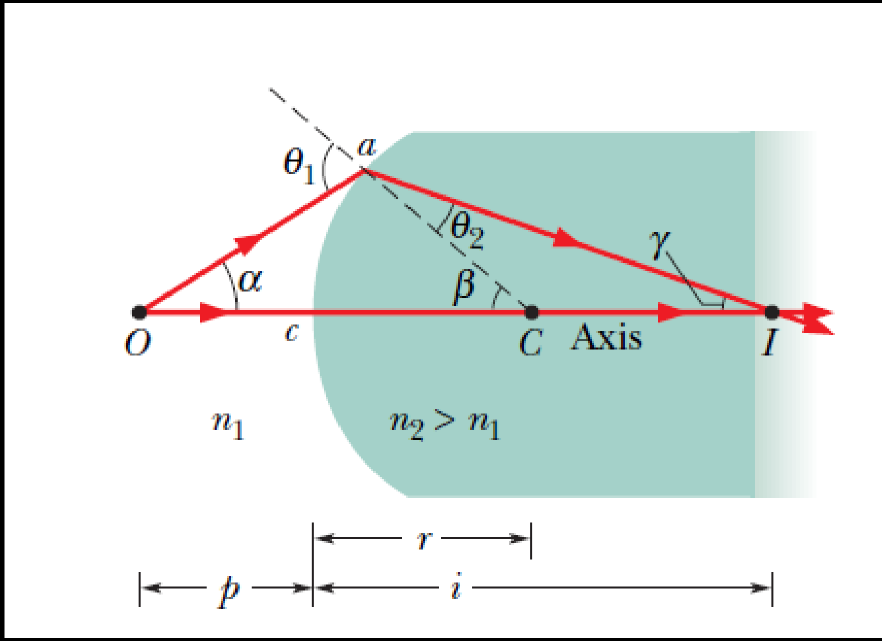


$$\frac{n_1}{p} + \frac{n_2}{i} = \frac{n_2 - n_1}{r}.$$

- Real images form on the side of a refracting surface that is opposite the object, and virtual images form on the same side as the object.

- When the object faces a convex refracting surface, the radius of curvature *r* is positive. When it faces a concave surface, *r* is negative.

The Refracting Surface formula



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

$$n_1\theta_1 \approx n_2\theta_2.$$

$$\theta_1 = \alpha + \beta \quad \text{and} \quad \beta = \theta_2 + \gamma.$$

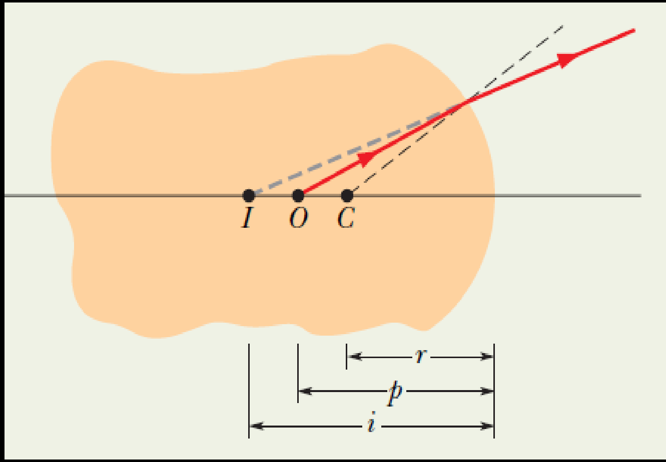
$$n_1\alpha + n_2\gamma = (n_2 - n_1)\beta.$$

$$\alpha \approx \frac{\widehat{ac}}{p}; \qquad \beta = \frac{\widehat{ac}}{r}; \qquad \gamma \approx \frac{\widehat{ac}}{i}.$$

$$\frac{n_1}{p} + \frac{n_2}{i} = \frac{n_2 - n_1}{r}.$$

Image produced by a Refracting Surface

A Jurassic mosquito is discovered embedded in a chunk of amber, which has index of refraction 1.6. One surface of the amber is spherically convex with radius of curvature 3.0 mm (Fig. 34-13). The mosquito's head happens to be on the central axis of that surface and, when viewed along the axis, appears to be buried 5.0 mm into the amber. How deep is it really?

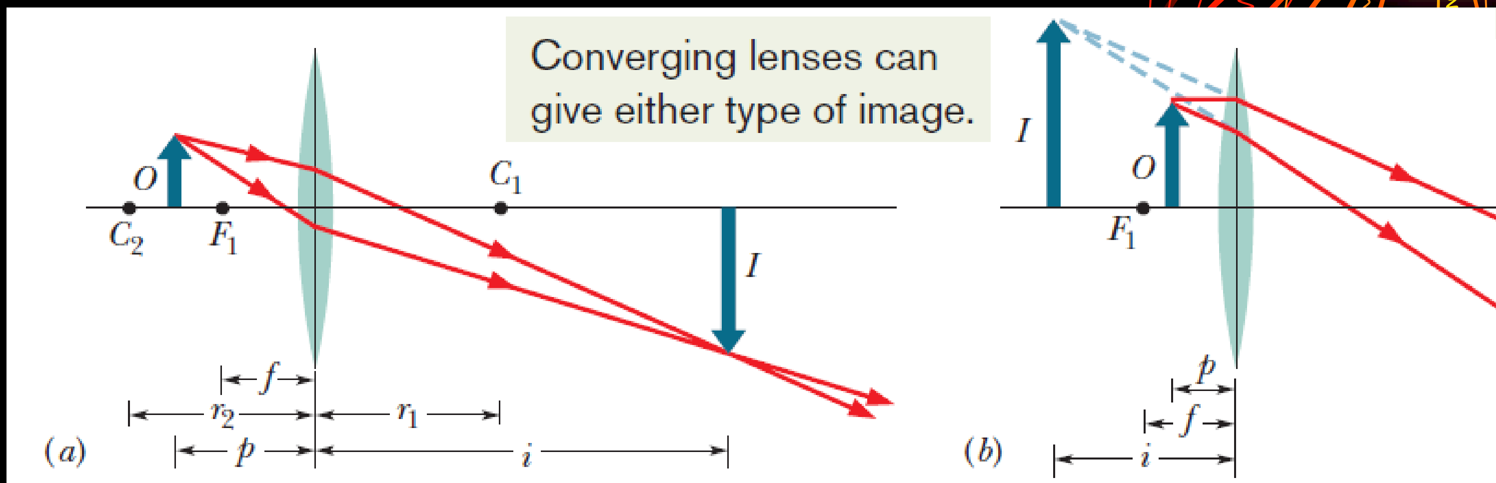


$$\frac{n_1}{p} + \frac{n_2}{i} = \frac{n_2 - n_1}{r},$$

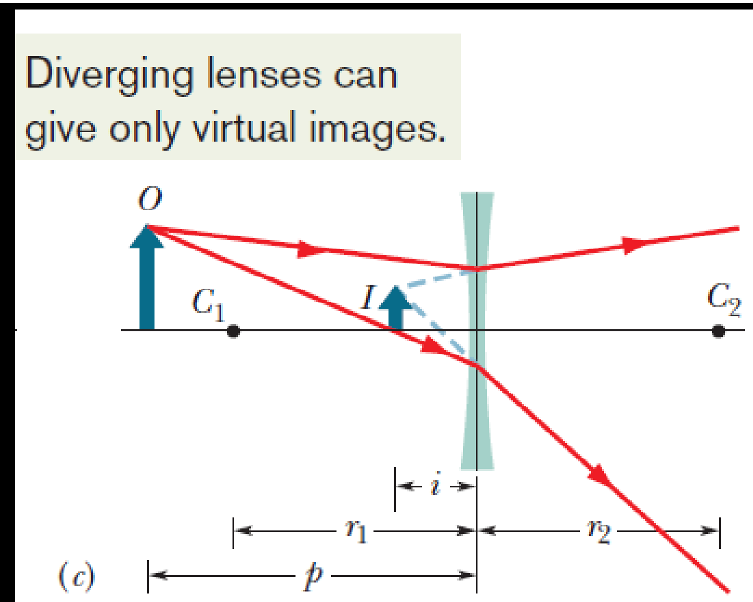
$$\frac{1.6}{p} + \frac{1.0}{-5.0\ \text{mm}} = \frac{1.0 - 1.6}{-3.0\ \text{mm}}$$

$$p = 4.0\ \text{mm}. \qquad \text{(Answer)}$$

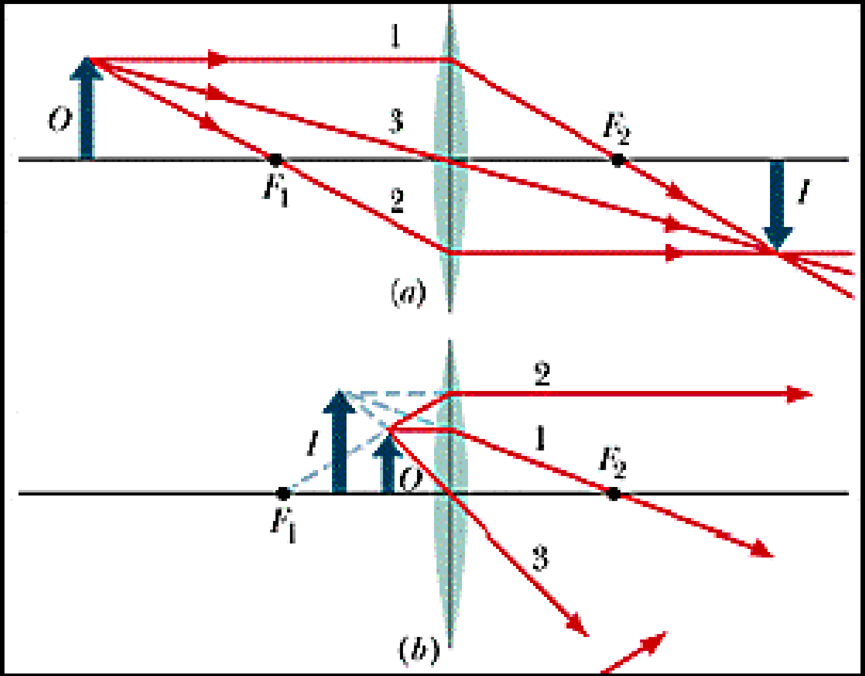
14.6 Thin Lenses

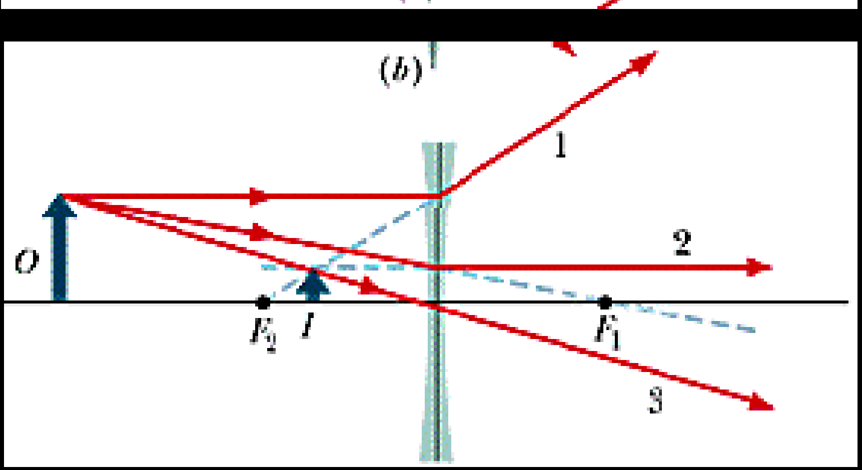


- converging and diverging lens

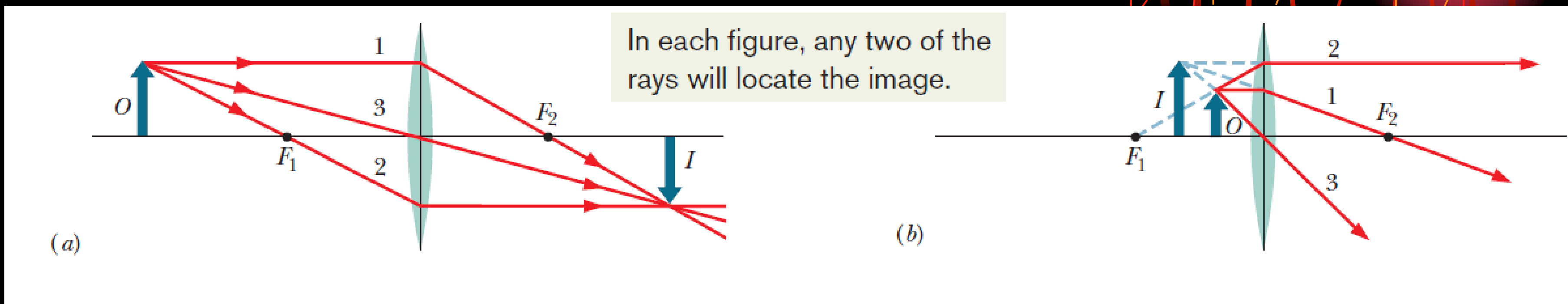


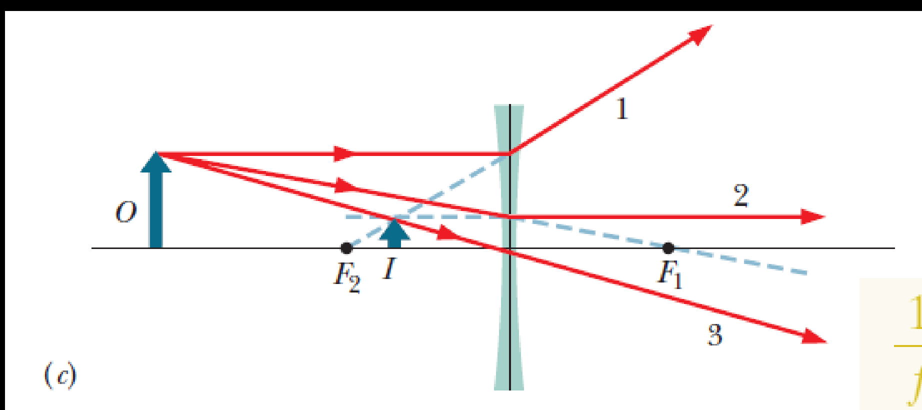
Convex Lens and Concave Lens





Locating Images by Drawing Rays



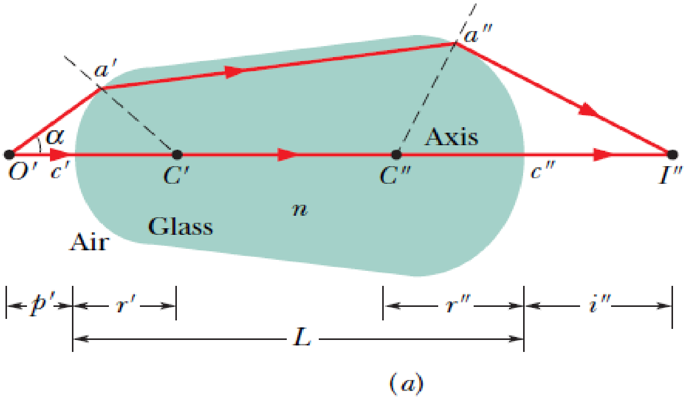


$$\frac{1}{f} = \frac{1}{p} + \frac{1}{i} \qquad \text{(thin lens),}$$

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

the lens maker's equation

The Thin Lens Formulas



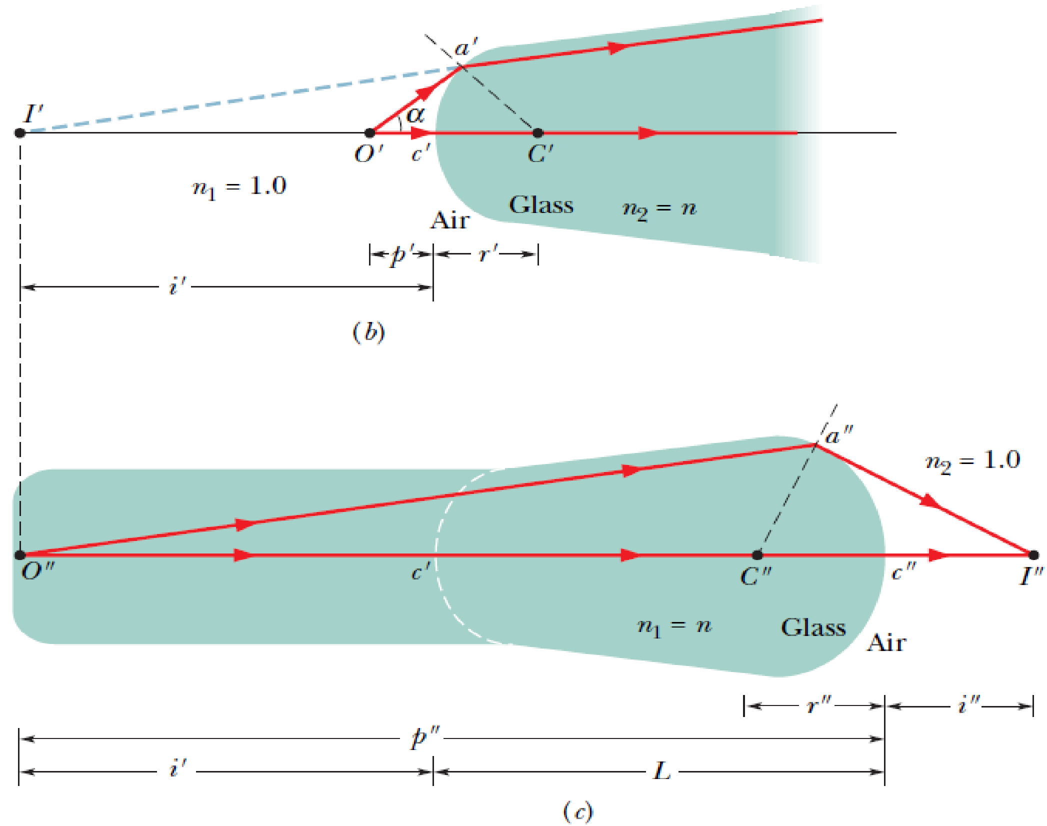


Fig. 34-24 (*a*) Two rays from point object O' form a real image I'' after refracting through two spherical surfaces of a lens. The object faces a convex surface at the left side of the lens and a concave surface at the right side. The ray traveling through points a' and a'' is actually close to the central axis through the lens. (*b*) The left side and (*c*) the right side of the lens in (*a*), shown separately.

$$\frac{n_1}{p} + \frac{n_2}{i} = \frac{n_2 - n_1}{r}.$$

+

$$\frac{1}{p'} - \frac{n}{i'} = \frac{n-1}{r'}.$$

+

$$p'' = i' + L.$$

$$\frac{n}{i' + L} + \frac{1}{i''} = \frac{1-n}{r''}.$$

+

$$\frac{n}{i'} + \frac{1}{i''} = -\frac{n-1}{r''}.$$

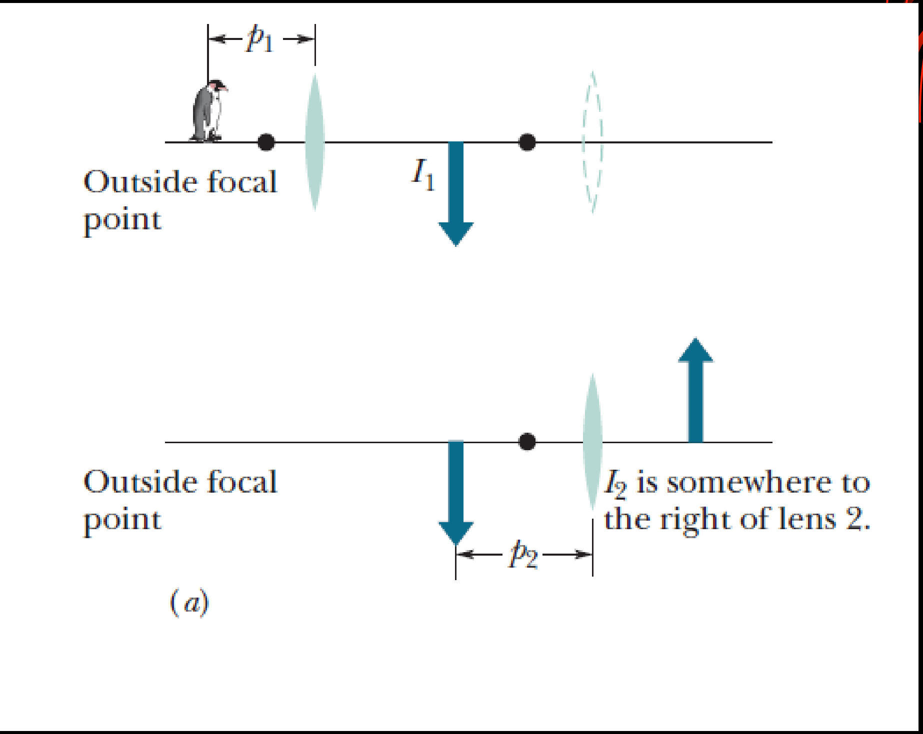
+

$$\frac{1}{p'} + \frac{1}{i''} = (n-1)\left(\frac{1}{r'} - \frac{1}{r''}\right).$$

$\Rightarrow$

$$\frac{1}{p} + \frac{1}{i} = (n-1)\left(\frac{1}{r'} - \frac{1}{r''}\right),$$

Two Lens System



Total magnification: $M = m_1 m_2.$

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

Image produced by a thin symmetric lens

A praying mantis preys along the central axis of a thin symmetric lens, 20 cm from the lens. The lateral magnification of the mantis provided by the lens is $m = -0.25$, and the index of refraction of the lens material is 1.65.

$$i = -mp = 0.25p.$$

$$i = (0.25)(20\text{ cm}) = 5.0\text{ cm}.$$

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{i} = \frac{1}{20\text{ cm}} + \frac{1}{5.0\text{ cm}},$$

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

$$\frac{1}{4.0\text{ cm}} = (1.65 - 1)\frac{2}{r},$$

$$r = (0.65)(2)(4.0\text{ cm}) = 5.2\text{ cm}.$$