PHYS1001B College Physics IB

Optics II Geometric Optics (Ch. 34)

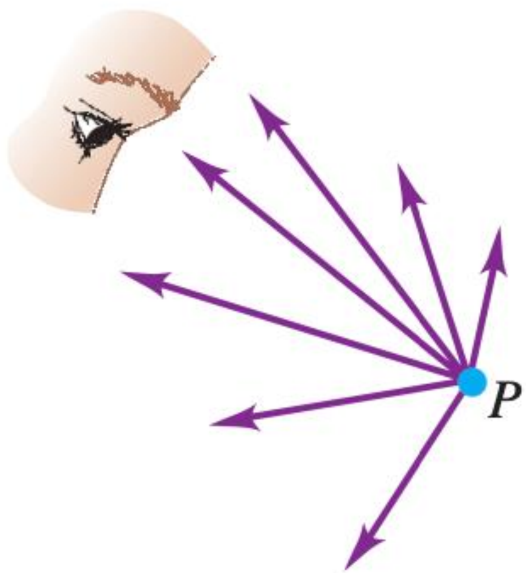
Introduction

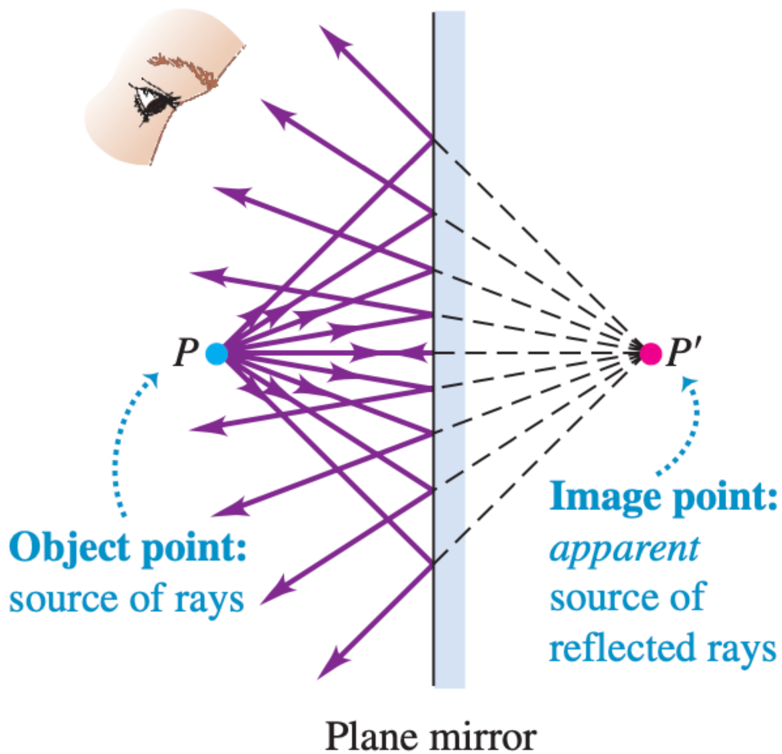
? How do magnifying lenses work? At what distance from the object being examined do they provide the sharpest view?

Outline

- 34-1 Reflection and Refraction at a Plane Surface
- 34-2 Reflection at a Spherical Surface
- 34-4 Thin Lenses
- 34-5 Cameras
- 34-6 The Eye

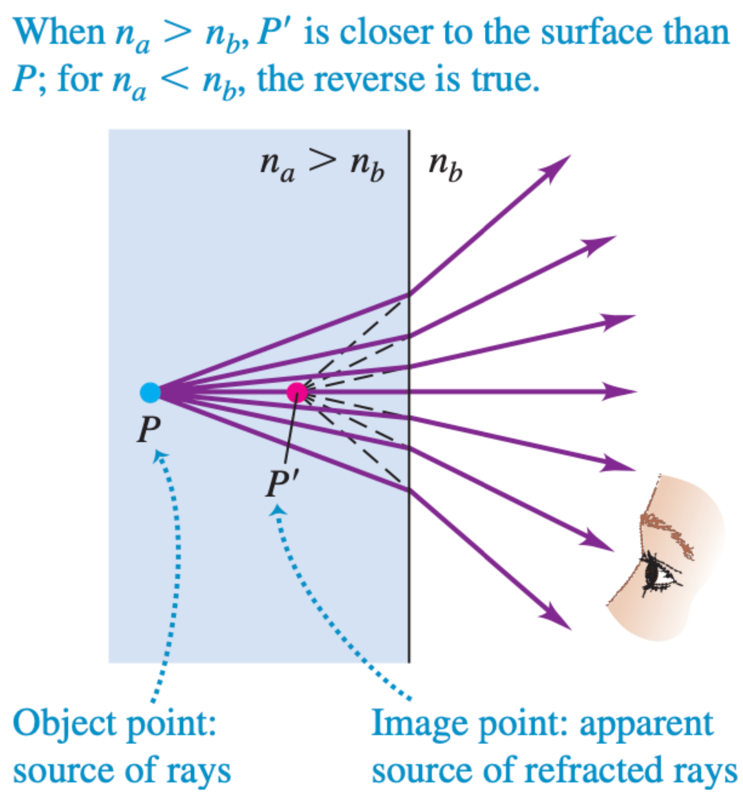
34-1 Reflection and Refraction at a Plane Surface





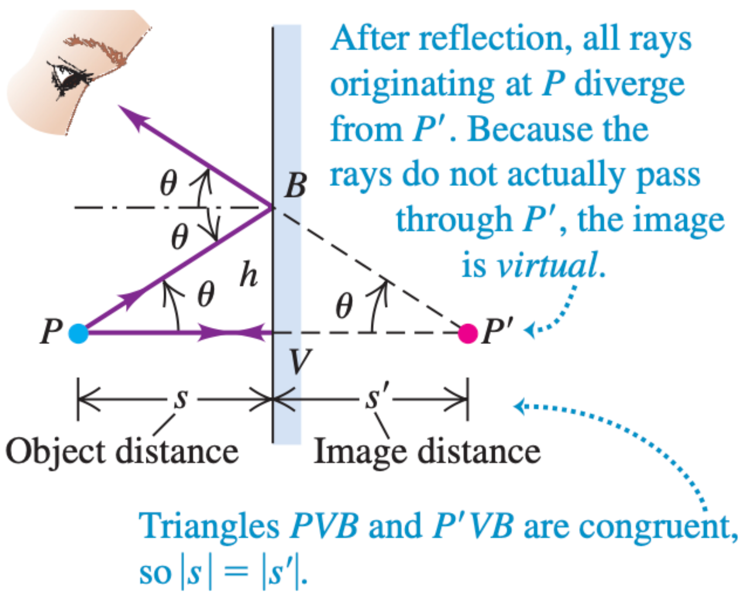
34-1 Reflection and Refraction at a Plane Surface

34.3 Light rays from the object at point P are refracted at the plane interface. The refracted rays entering the eye look as though they had come from image point P'.

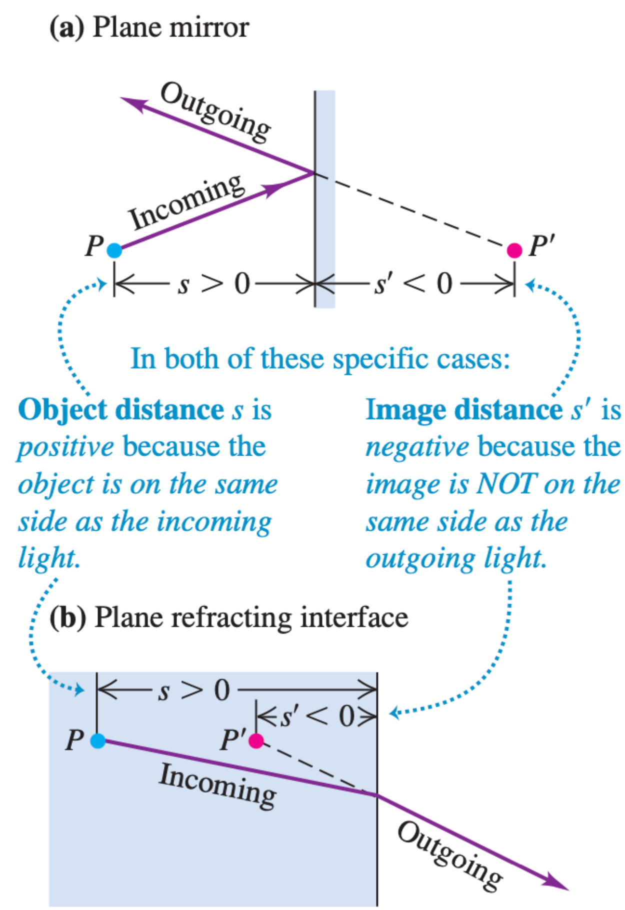


34-1 Reflection and Refraction at a Plane Surface

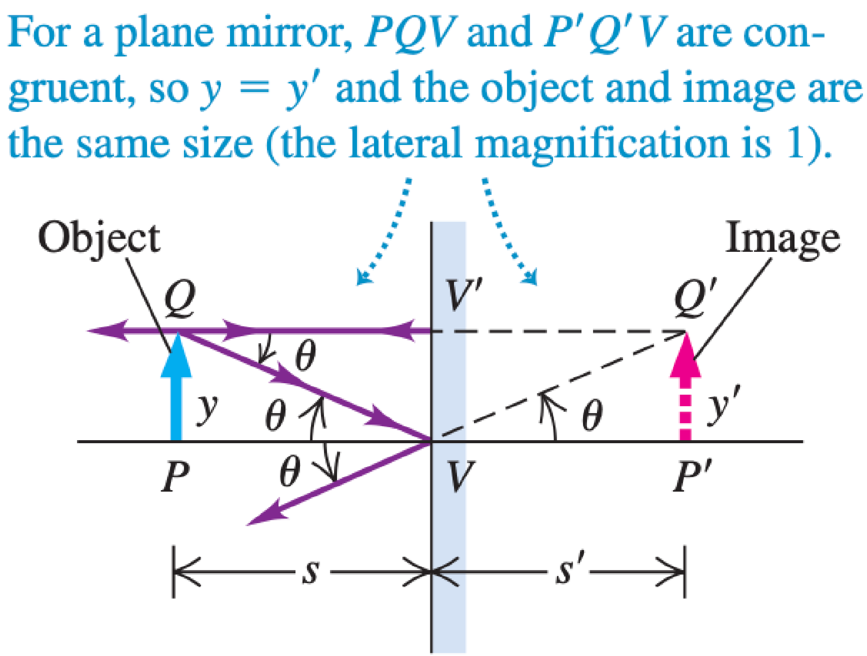
34.4 Construction for determining the location of the image formed by a plane mirror. The image point P' is as far behind the mirror as the object point P is in front of it.



34.5 For both of these situations, the object distance s is positive (rule 1) and the image distance s' is negative (rule 2).



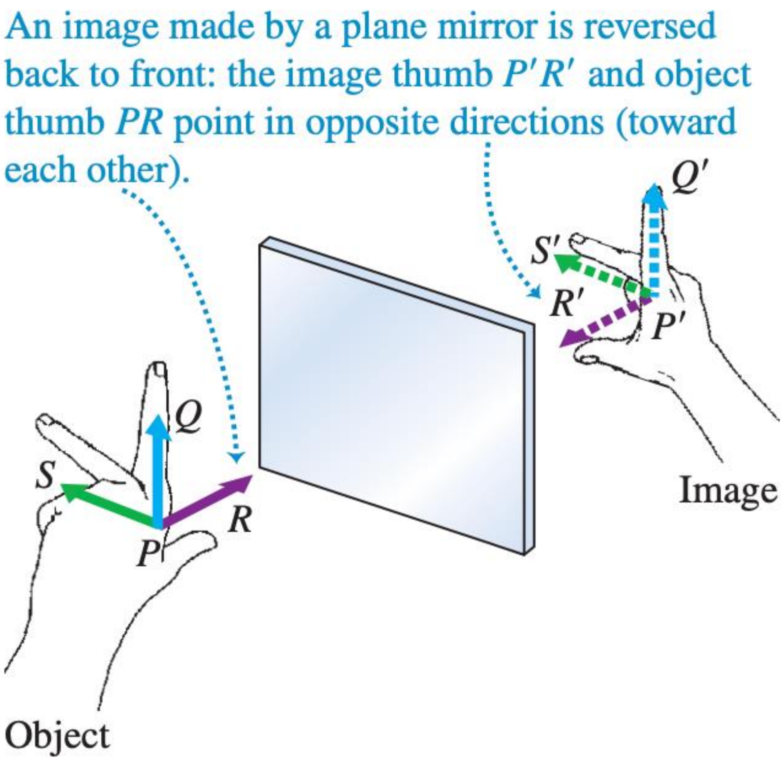
34-1 Reflection and Refraction at a Plane Surface



$$m = \frac{y'}{y} \qquad \text{(lateral magnification)}$$

m>0 erect
m<0 inverted

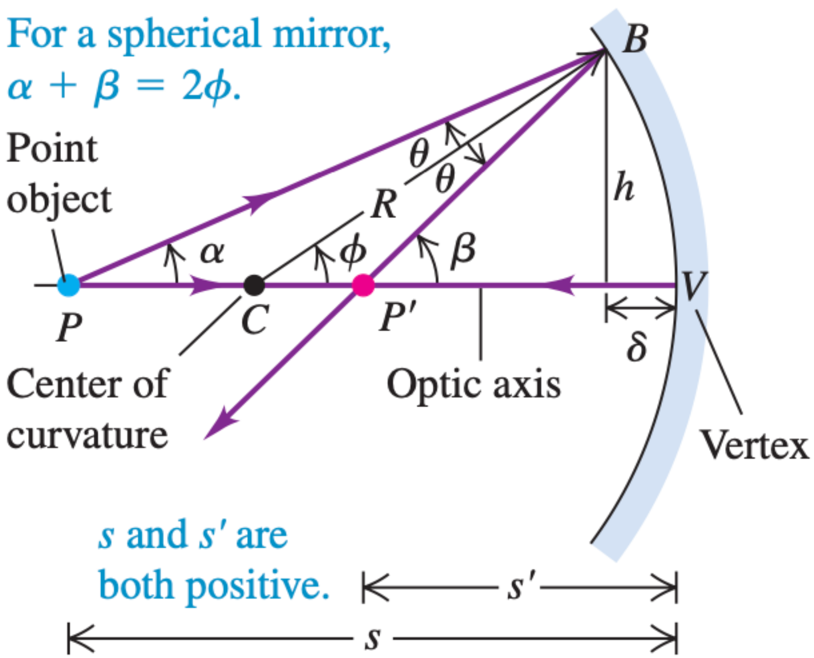
34-1 Reflection and Refraction at a Plane Surface



34.8 The image formed by a plane mirror is reversed; the image of a right hand is a left hand, and so on. (The hand is resting on a horizontal mirror.) Are images of the letters H and A reversed?

34-2 Reflection at a Spherical Surface

(a) Construction for finding the position P' of an image formed by a concave spherical mirror



$$\phi = \alpha + \theta \qquad \beta = \phi + \theta$$

$$\alpha + \beta = 2\phi$$

$$\tan\alpha = \frac{h}{s - \delta} \qquad \tan\beta = \frac{h}{s' - \delta} \qquad \tan\phi = \frac{h}{R - \delta}$$

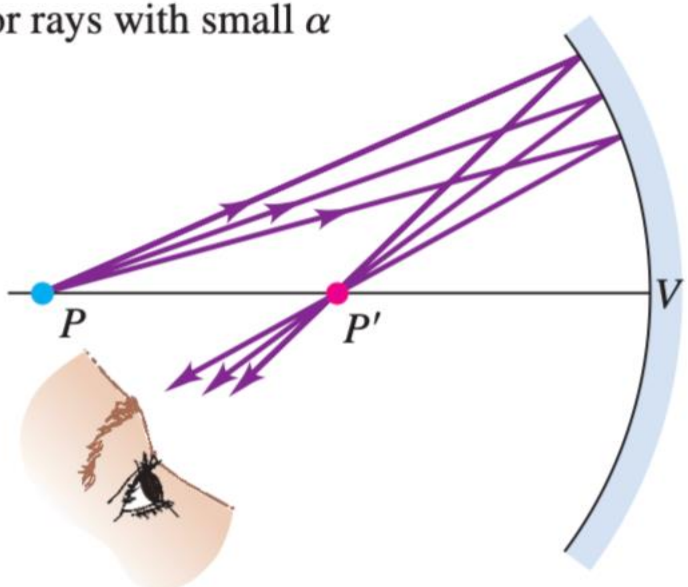
Small angle and delta

$$\alpha = \frac{h}{s} \qquad \beta = \frac{h}{s'} \qquad \phi = \frac{h}{R}$$

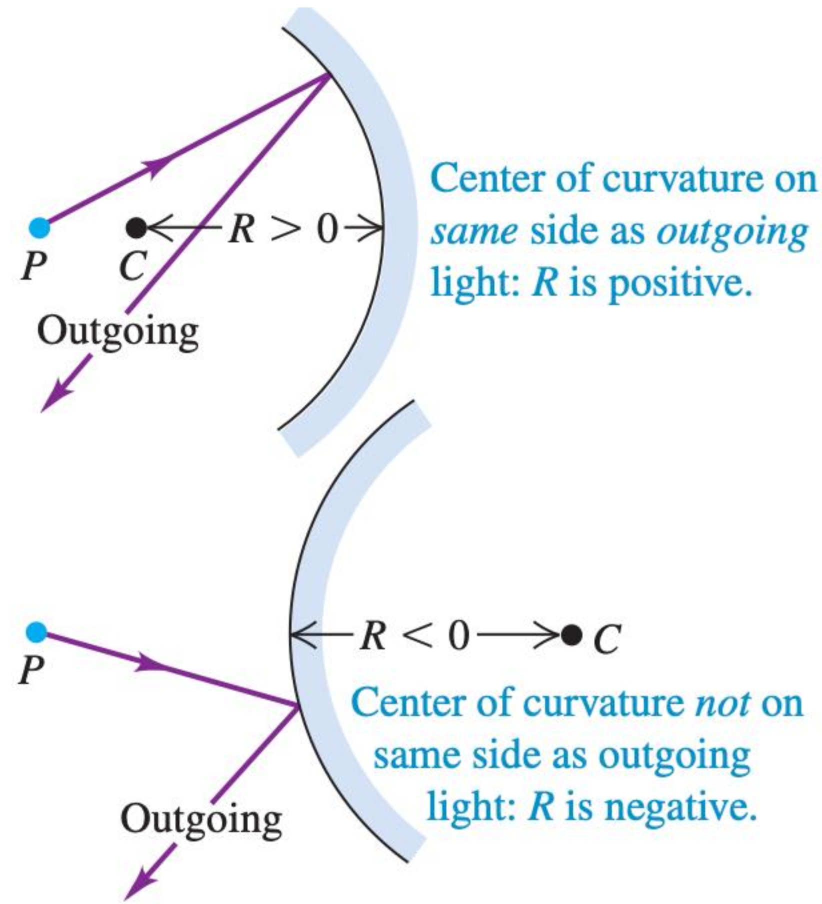
$$\frac{1}{s} + \frac{1}{s'} = \frac{2}{R} \qquad \text{(object–image relationship, spherical mirror)}$$

34-2 Reflection at a Spherical Surface

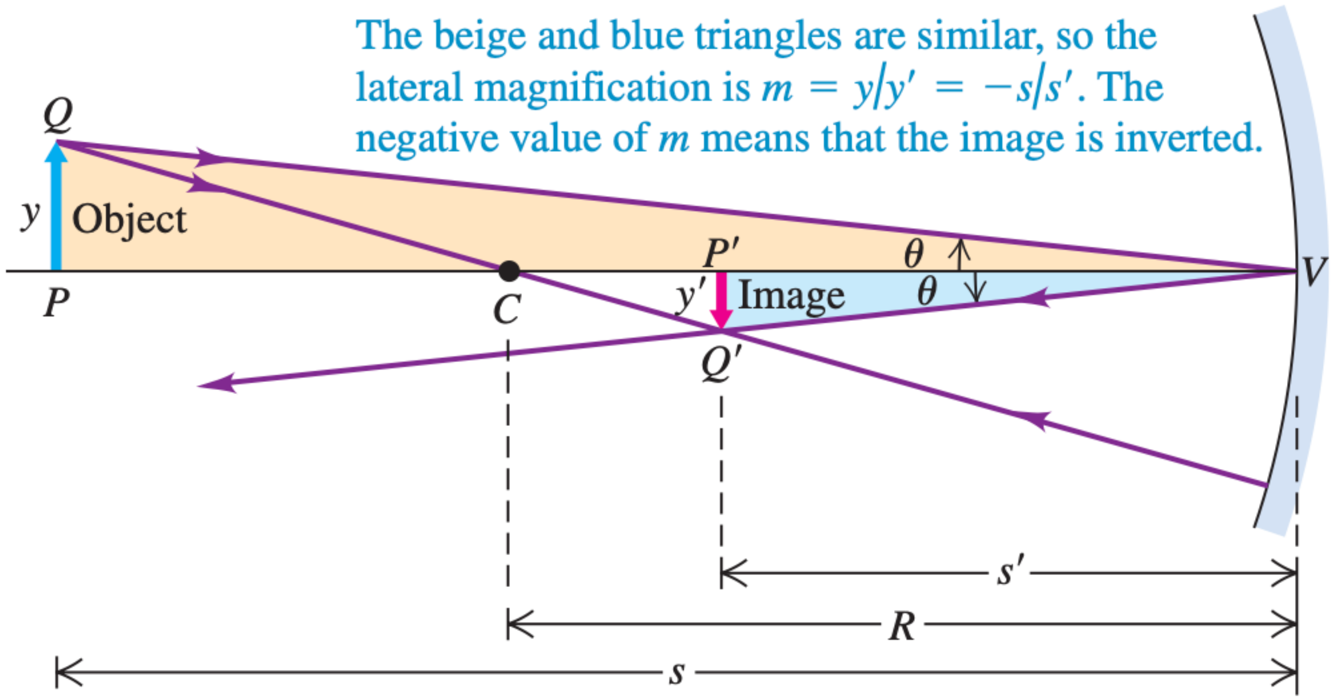
(b) The paraxial approximation, which holds for rays with small α



All rays from P that have a small angle α pass through P', forming a real image.



34-2 Reflection at a Spherical Surface



$$m = \frac{y'}{y} = -\frac{s'}{s} \qquad \text{(lateral magnification, spherical mirror)}$$

Sample Problem

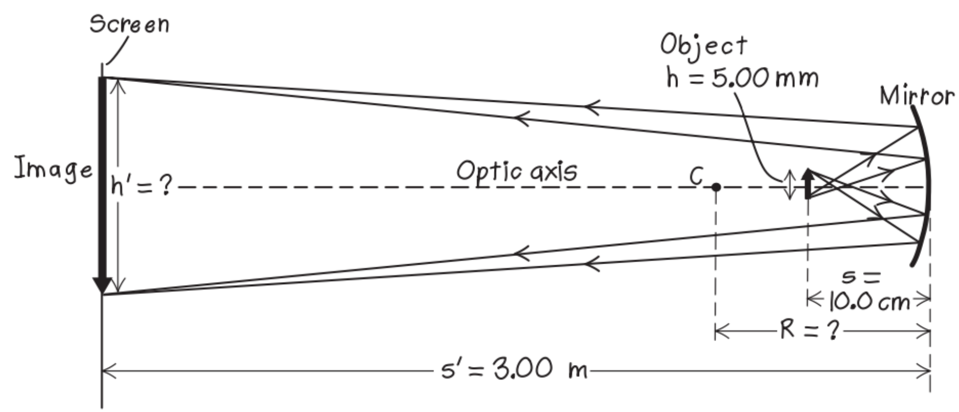
Example 34.1 **Image formation by a concave mirror I**

A concave mirror forms an image, on a wall 3.00 m in front of the mirror, of a headlamp filament 10.0 cm in front of the mirror. (a) What are the radius of curvature and focal length of the mirror? (b) What is the lateral magnification? What is the image height if the object height is 5.00 mm?

EXECUTE: (a) Both the object and the image are on the concave (reflective) side of the mirror, so both s and s' are positive; we have $s = 10.0$ cm and $s' = 300$ cm. We solve Eq. (34.4) for R:

$$\frac{1}{10.0\text{ cm}} + \frac{1}{300\text{ cm}} = \frac{2}{R}$$

$$R = 2\left(\frac{1}{10.0\text{ cm}} + \frac{1}{300\text{ cm}}\right)^{-1} = 19.4\text{ cm}$$



The focal length of the mirror is $f = R/2 = 9.7$ cm.

(b) From Eq. (34.7) the lateral magnification is

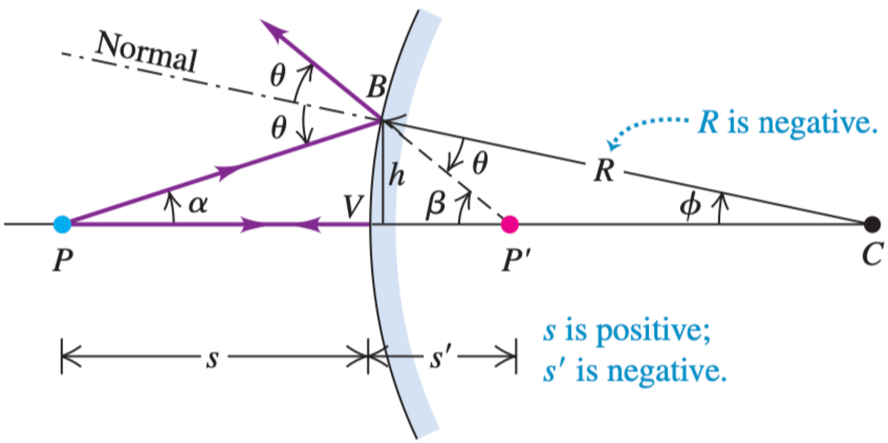
$$m = -\frac{s'}{s} = -\frac{300\text{ cm}}{10.0\text{ cm}} = -30.0$$

Because m is negative, the image is inverted. The height of the image is 30.0 times the height of the object, or $(30.0)(5.00\text{ mm}) = 150$ mm.

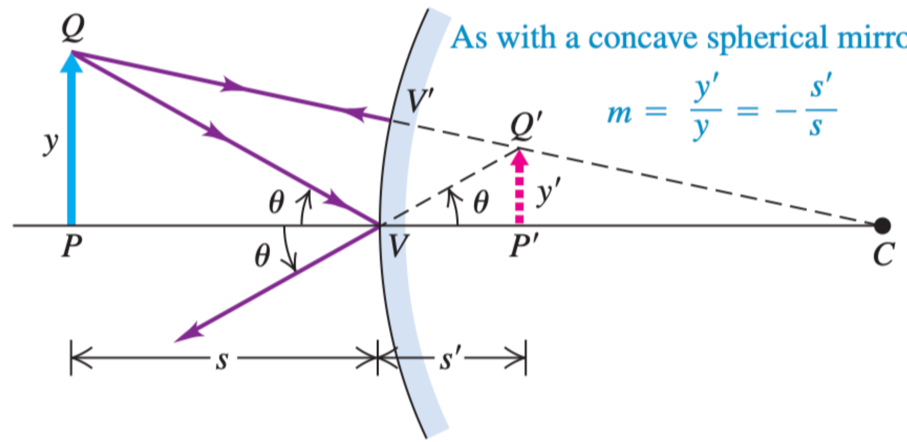
34-2 Reflection at a Spherical Surface

Image formation 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

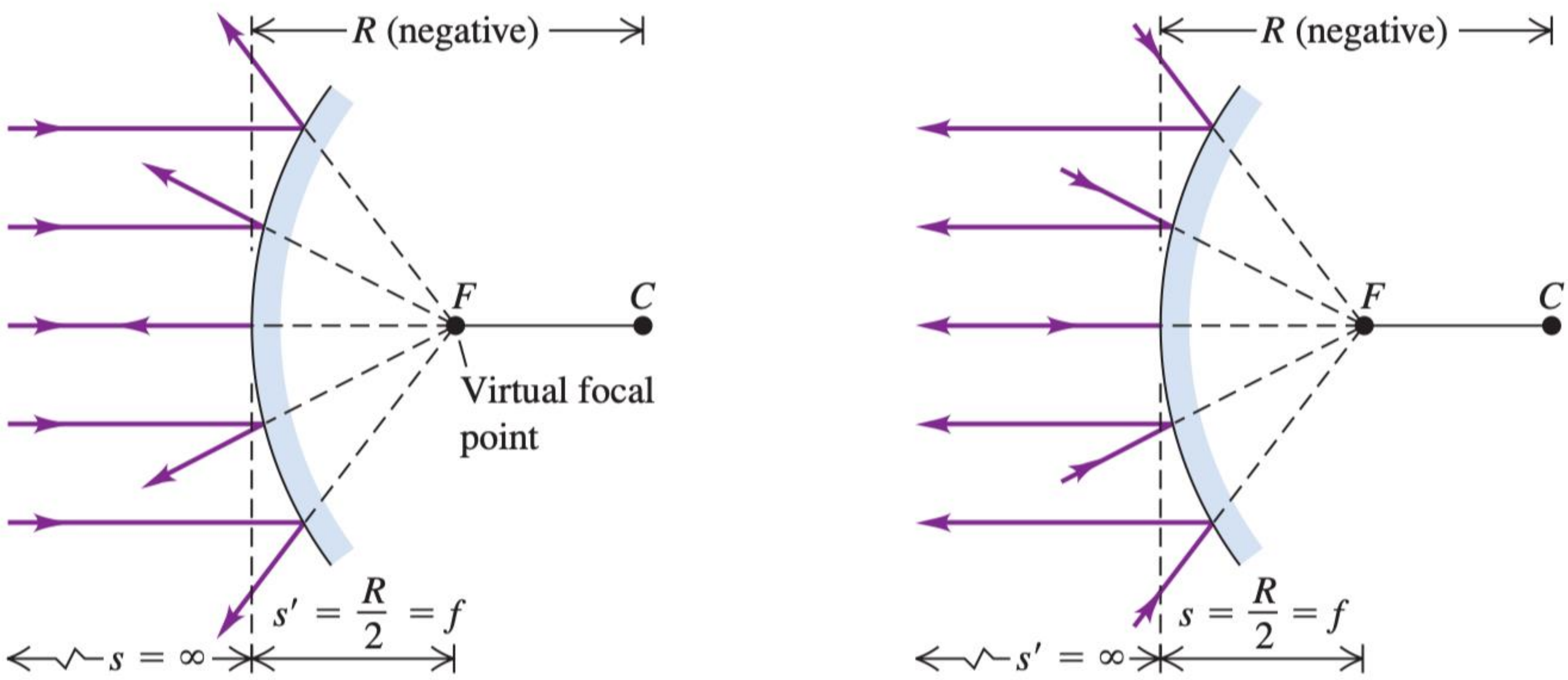


34-2 Reflection at a Spherical Surface

Focal point and focal length

(a) Paraxial rays incident on a convex spherical mirror diverge from a virtual focal point.

(b) Rays aimed at the virtual focal point are parallel to the axis after reflection.

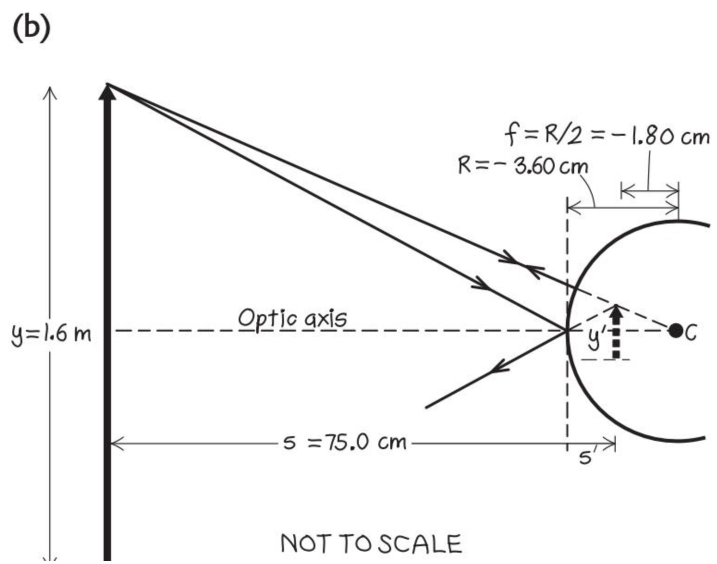


Sample Problem

Example 34.3 Santa's image problem

Santa checks himself for soot, using his reflection in a silvered Christmas tree ornament 0.750 m away (Fig. 34.18a). The diameter of the ornament is 7.20 cm. Standard reference texts state that he is a "right jolly old elf," so we estimate his height to be 1.6 m. Where and how tall is the image of Santa formed by the ornament? Is it erect or inverted?

(a) The ornament forms a virtual, reduced, erect image of Santa. **(b)** Our sketch of two of the rays forming the image.



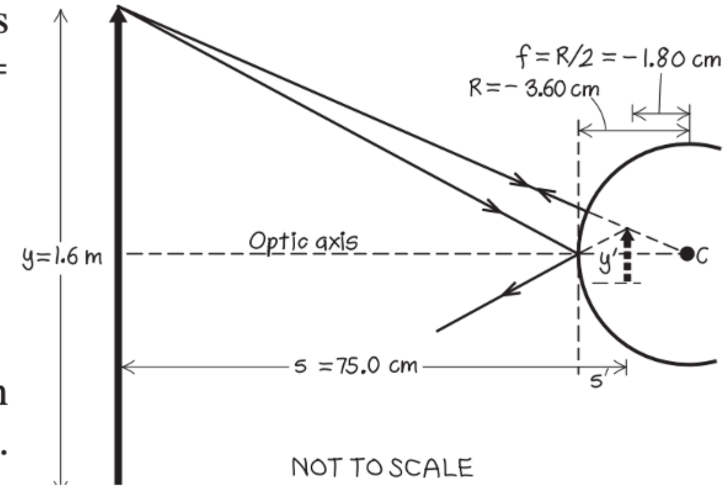
Sample Problem

EXECUTE: The radius of the mirror (half the diameter) is $R = -(7.20\text{ cm})/2 = -3.60\text{ cm}$, and the focal length is $f = R/2 = -1.80\text{ cm}$. From Eq. (34.6),

$$\frac{1}{s'} = \frac{1}{f} - \frac{1}{s} = \frac{1}{-1.80\text{ cm}} - \frac{1}{75.0\text{ cm}}$$

$$s' = -1.76\text{ cm}$$

Because s' is negative, the image is behind the mirror—that is, on the side opposite to the outgoing light (Fig. 34.18b)—and it is virtual.



The image is about halfway between the front surface of the ornament and its center.

From Eq. (34.7), the lateral magnification and the image height are

$$m = \frac{y'}{y} = -\frac{s'}{s} = -\frac{-1.76\text{ cm}}{75.0\text{ cm}} = 0.0234$$

$$y' = my = (0.0234)(1.6\text{ m}) = 3.8 \times 10^{-2}\text{m} = 3.8\text{ cm}$$

Sample Problem

Example 34.4 **Concave mirror with various object distances**

A concave mirror has a radius of curvature with absolute value 20 cm. Find graphically the image of an object in the form of an arrow perpendicular to the axis of the mirror at object distances of (a) 30 cm, (b) 20 cm, (c) 10 cm, and (d) 5 cm. Check the construction by *computing* the size and lateral magnification of each image.

Sample Problem

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

Measurements of the figures, with appropriate scaling, give the following approximate image distances: (a) 15 cm; (b) 20 cm; (c) ∞ or $-\infty$ (because the outgoing rays are parallel and do not converge at any finite distance); (d) -10 cm. To *compute* these distances, we solve Eq. (34.6) for s' and insert $f = 10\ \text{cm}$:

$$\text{(a)}\ \frac{1}{30\ \text{cm}} + \frac{1}{s'} = \frac{1}{10\ \text{cm}} \qquad s' = 15\ \text{cm}$$

$$\text{(b)}\ \frac{1}{20\ \text{cm}} + \frac{1}{s'} = \frac{1}{10\ \text{cm}} \qquad s' = 20\ \text{cm}$$

$$\text{(c)}\ \frac{1}{10\ \text{cm}} + \frac{1}{s'} = \frac{1}{10\ \text{cm}} \qquad s' = \infty\ (\text{or } -\infty)$$

$$\text{(d)}\ \frac{1}{5\ \text{cm}} + \frac{1}{s'} = \frac{1}{10\ \text{cm}} \qquad s' = -10\ \text{cm}$$

The signs of s' tell us that the image is real in cases (a) and (b) and virtual in case (d).

Sample Problem

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

The lateral magnifications measured from the figures are approximately (a) $-\frac{1}{2}$; (b) -1; (c) ∞ or $-\infty$; (d) $+2$. From Eq. (34.7),

$$\text{(a) } m = -\frac{15 \text{ cm}}{30 \text{ cm}} = -\frac{1}{2}$$

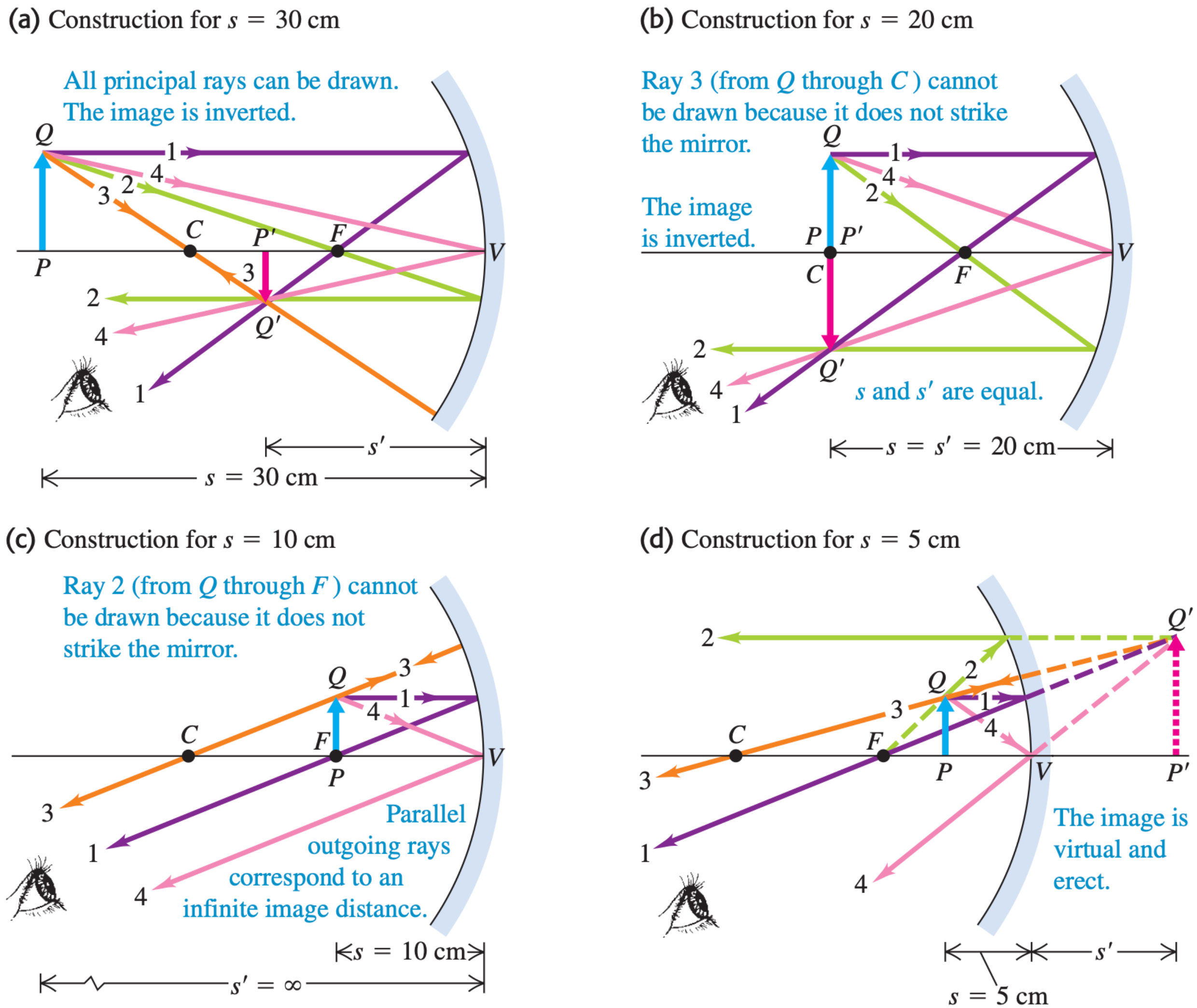
$$\text{(b) } m = -\frac{20 \text{ cm}}{20 \text{ cm}} = -1$$

$$\text{(c) } m = -\frac{\infty \text{ cm}}{10 \text{ cm}} = -\infty \ (\text{or } +\infty)$$

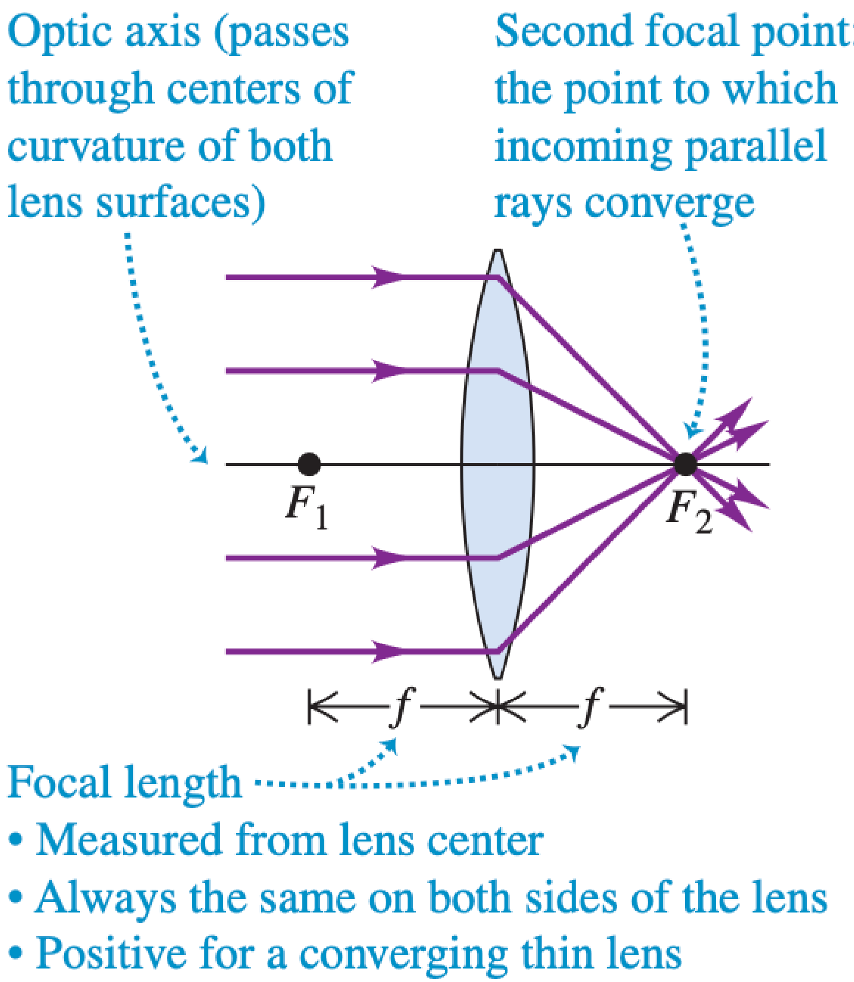
$$\text{(d) } m = -\frac{-10 \text{ cm}}{5 \text{ cm}} = +2$$

The signs of m tell us that the image is inverted in cases (a) and (b) and erect in case (d).

Sample Problem

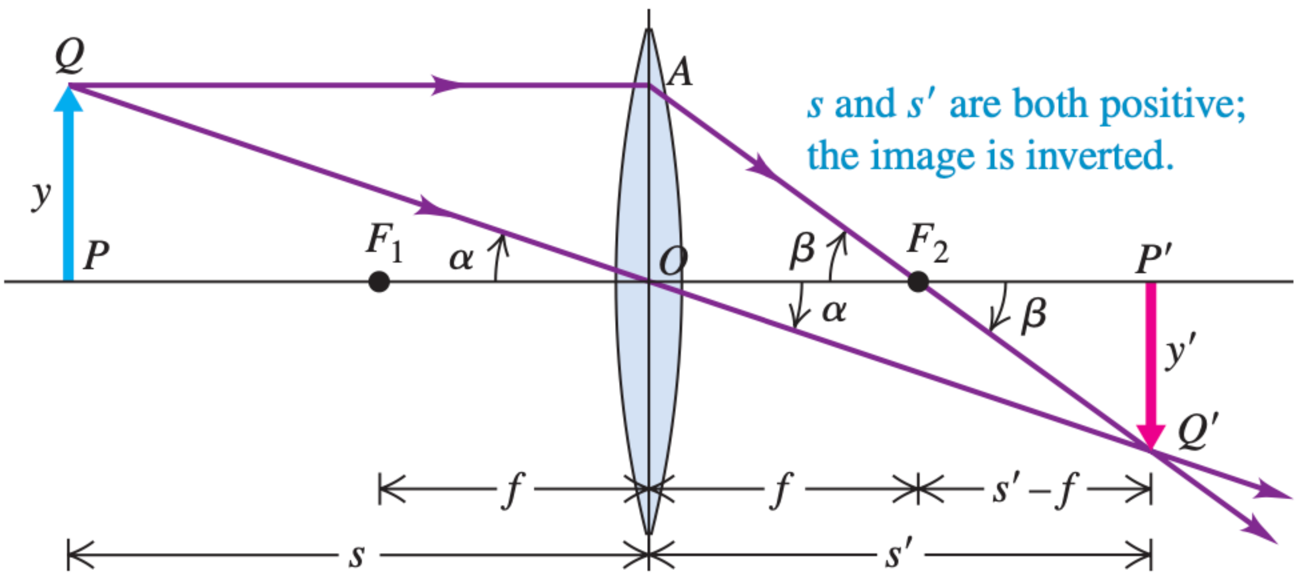


34-4 Thin Lenses



34-4 Thin Lenses

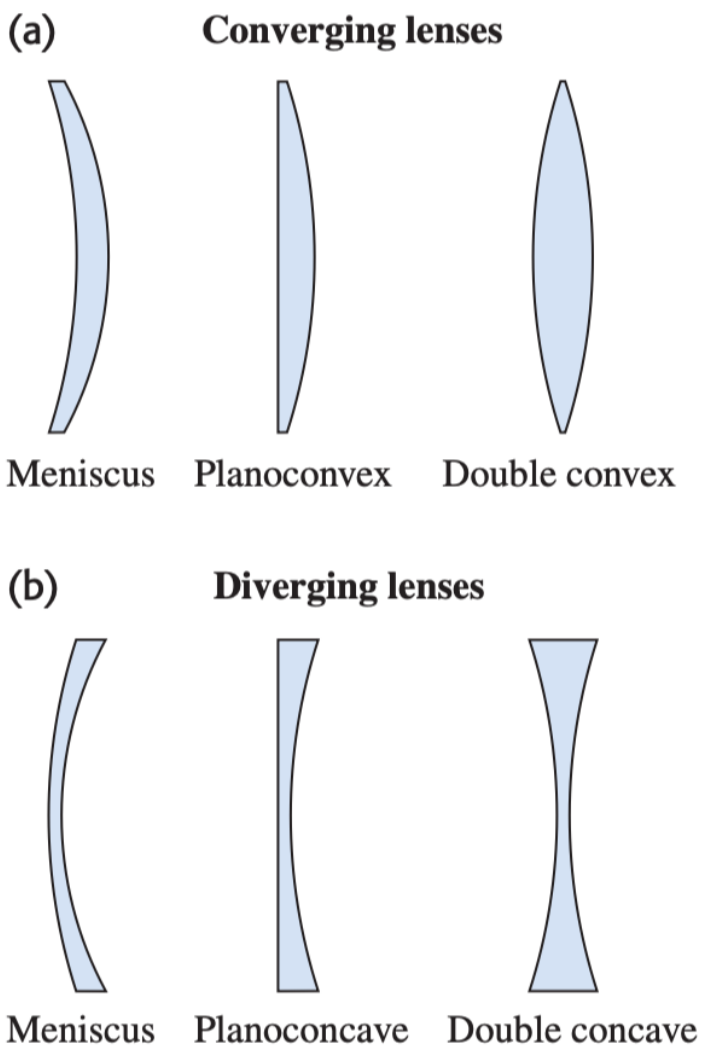
Image of an Extended Object: Converging Lens



$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f} \qquad \text{(object–image relationship, thin lens)}$$

$$m = -\frac{s'}{s} \qquad \text{(lateral magnification, thin lens)}$$

34-4 Thin Lenses



The Lensmaker's Equation

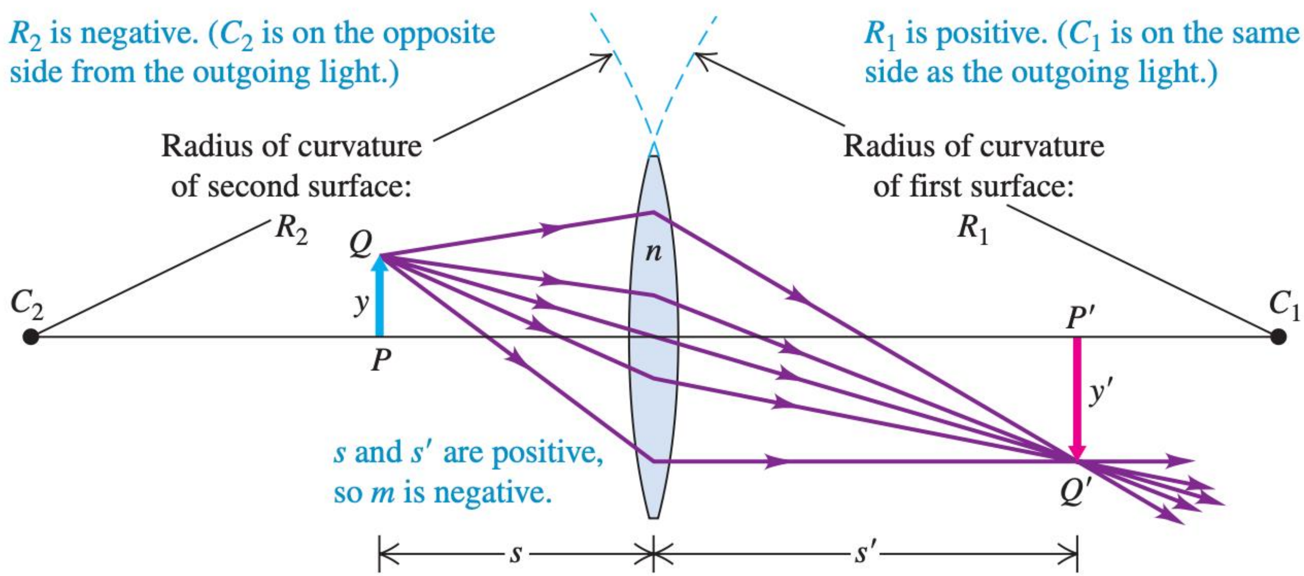
$$\frac{1}{f} = (n - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

the focal length f of a lens in terms of its index of refraction n and the radii of curvature R_1 and R_2 of its surfaces

Sample Problem

Example 34.8 Determining the focal length of a lens

(a) Suppose the absolute values of the radii of curvature of the lens surfaces in Fig. 34.35 are both equal to 10 cm and the index of refraction of the glass is $n = 1.52$. What is the focal length f of the lens? (b) Suppose the lens in Fig. 34.31 also has $n = 1.52$ and the absolute values of the radii of curvature of its lens surfaces are also both equal to 10 cm. What is the focal length of this lens?



Sample Problem

EXECUTE: (a) The lens in Fig. 34.35 is *double convex:* The center of curvature of the first surface (C_1) is on the outgoing side of the lens, so R_1 is positive, and the center of curvature of the second surface (C_2) is on the *incoming* side, so R_2 is negative. Hence $R_1 = +10$ cm and $R_2 = -10$ cm. Then from Eq. (34.19),

$$\frac{1}{f} = (1.52 - 1)\left(\frac{1}{+10\text{ cm}} - \frac{1}{-10\text{ cm}}\right)$$

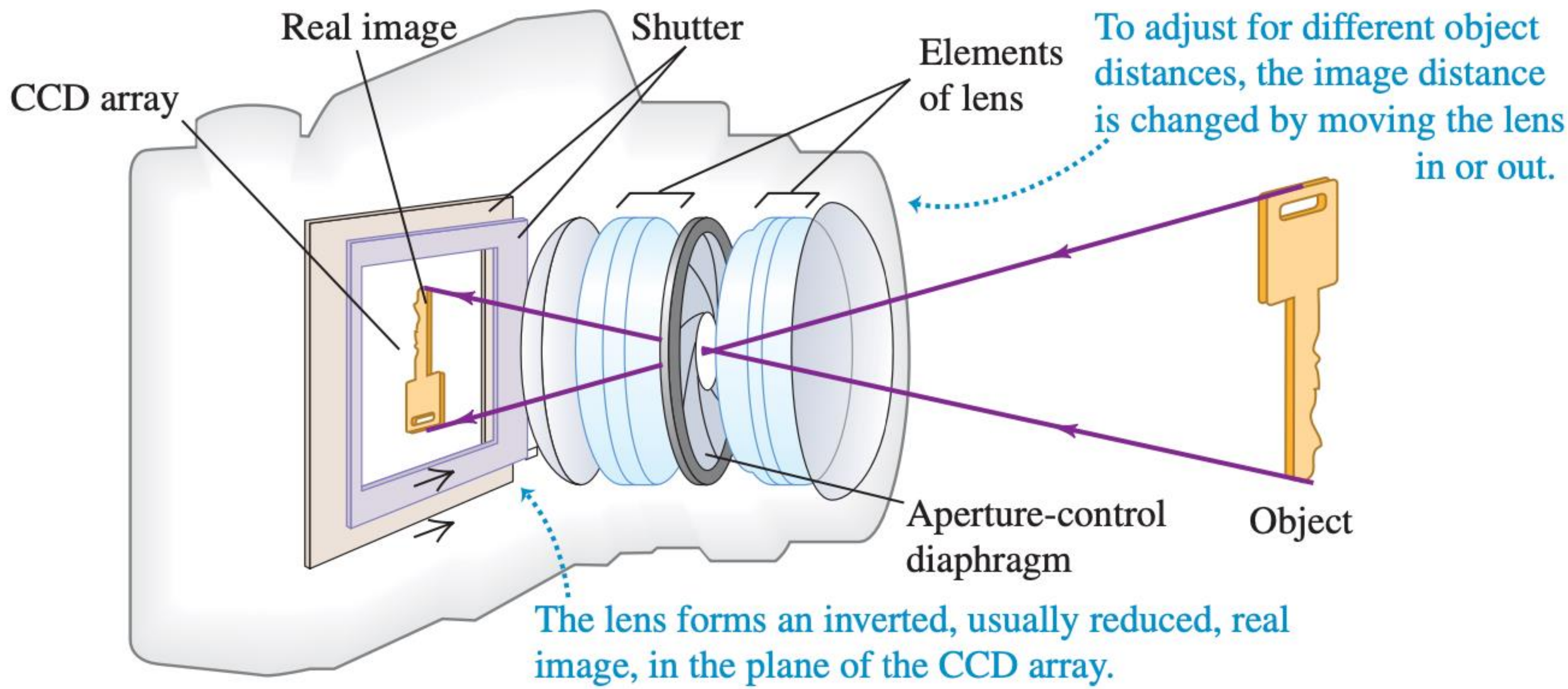
$$f = 9.6\text{ cm}$$

(b) The lens in Fig. 34.31 is *double concave:* The center of curvature of the first surface is on the *incoming* side, so R_1 is negative, and the center of curvature of the second surface is on the outgoing side, so R_2 is positive. Hence in this case $R_1 = -10$ cm and $R_2 = +10$ cm. Again using Eq. (34.19),

$$\frac{1}{f} = (1.52 - 1)\left(\frac{1}{-10\text{ cm}} - \frac{1}{+10\text{ cm}}\right)$$

$$f = -9.6\text{ cm}$$

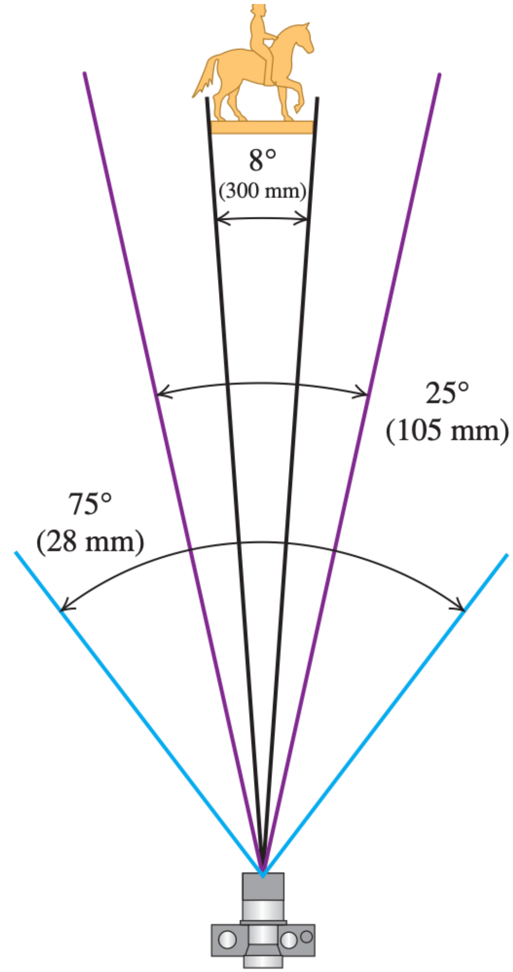
34-5 Cameras



Real image
Shutter
Elements of lens
To adjust for different object distances, the image distance is changed by moving the lens in or out.
CCD array
Aperture-control diaphragm
Object
The lens forms an inverted, usually reduced, real image, in the plane of the CCD array.

34-5 Cameras

(a) f = 28 mm (b) f = 105 mm (c) f = 300 mm



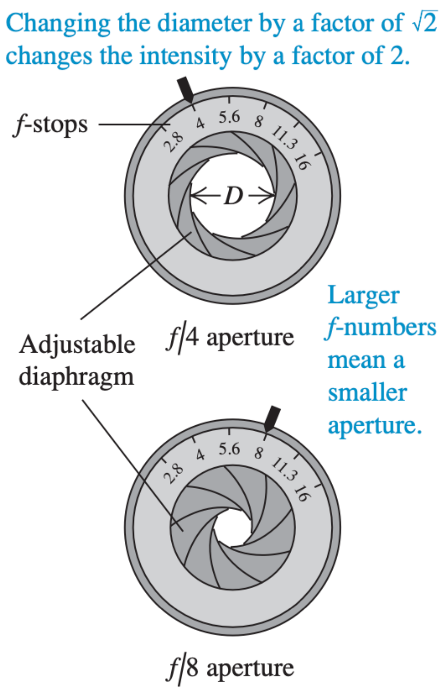
- long focal length, called a *telephoto* lens, gives a small angle of view and a large image of a distant object
- a lens of short focal length gives a small image and a wide angle of view and is called a *wide-angle* lens.

34-5 Cameras

- For the film to record the image properly, the total light energy per unit area reaching the film (the "exposure") must fall within certain limits.

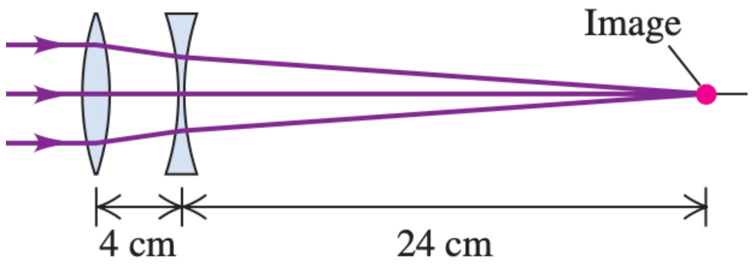
- This is controlled by the *shutter* and the *lens aperture*. The shutter controls the time interval during which light enters the lens.

$$f\text{-number} = \frac{\text{Focal length}}{\text{Aperture diameter}} = \frac{f}{D}$$

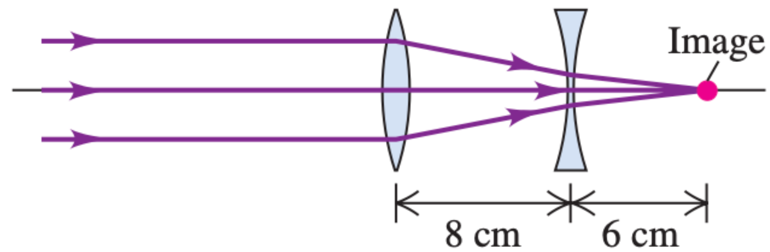


34-5 Cameras

(a) Zoom lens set for long focal length



(b) Zoom lens set for short focal length



(c) A practical zoom lens

Sample Problem

Example 34.12 **Photographic exposures**

A common telephoto lens for a 35-mm camera has a focal length of 200 mm; its f-stops range from $f/2.8$ to $f/22$. (a) What is the corresponding range of aperture diameters? (b) What is the corresponding range of image intensities on the film?

EXECUTE: (a) From Eq. (34.20), the diameter ranges from

$$D = \frac{f}{f\text{-number}} = \frac{200\ \text{mm}}{2.8} = 71\ \text{mm}$$

to

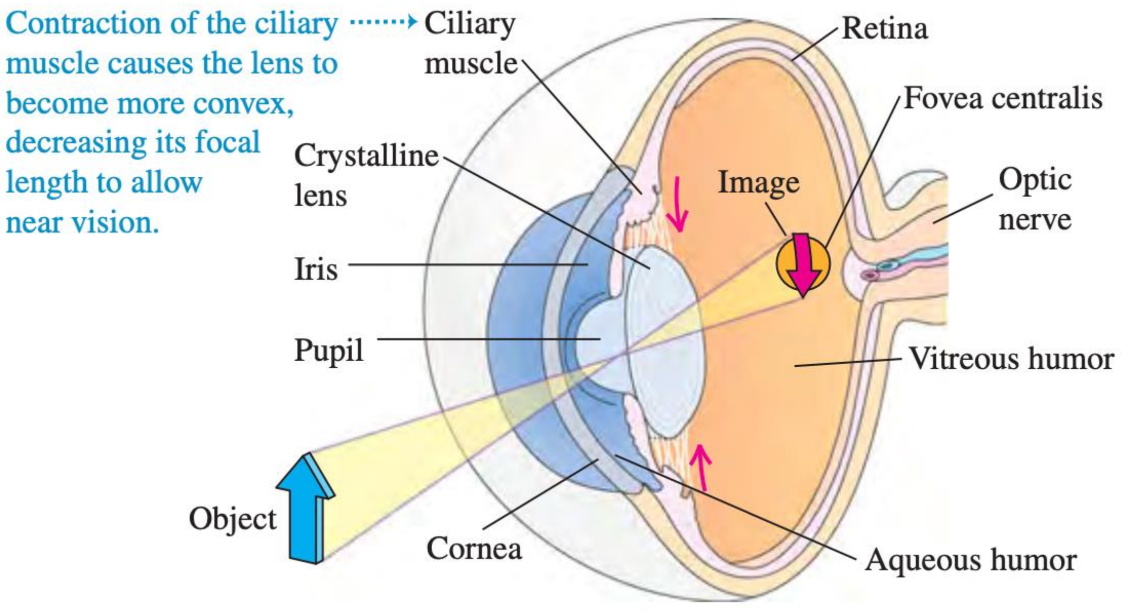
$$D = \frac{200\ \text{mm}}{22} = 9.1\ \text{mm}$$

(b) Because the intensity is proportional to D^2, the ratio of the intensity at $f/2.8$ to the intensity at $f/22$ is

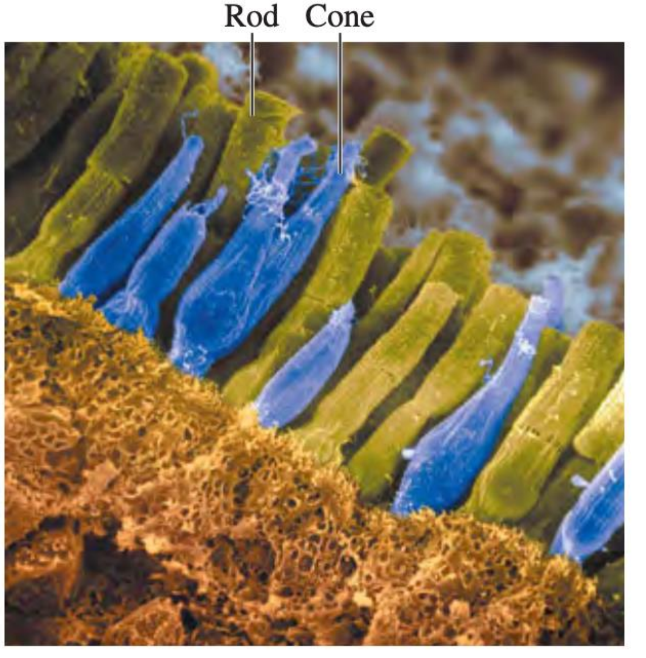
$$\left(\frac{71\ \text{mm}}{9.1\ \text{mm}}\right)^2 = \left(\frac{22}{2.8}\right)^2 = 62 \qquad (\text{about } 2^6)$$

34-6 The Eye

(a) Diagram of the eye

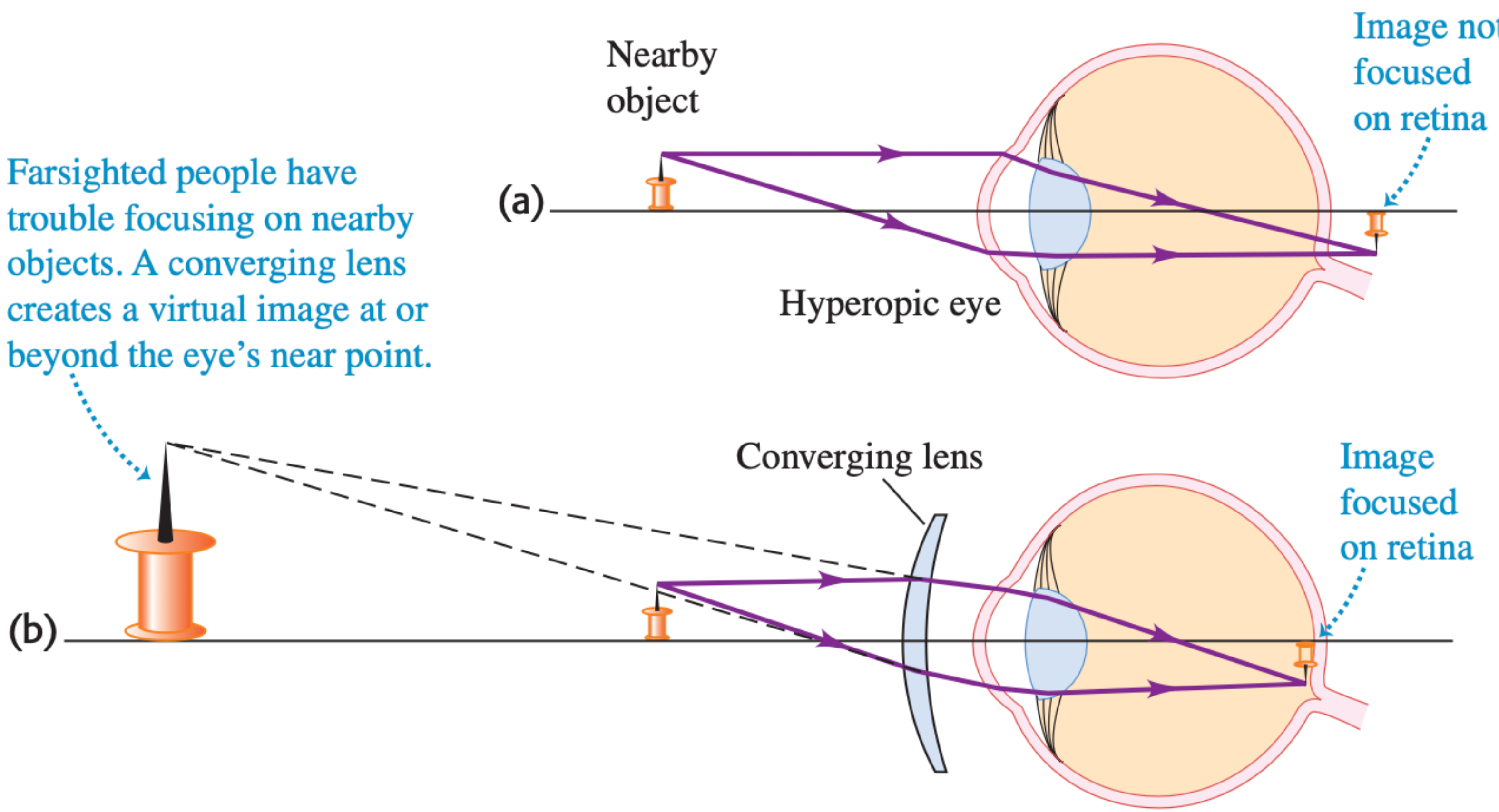


(b) Scanning electron micrograph showing retinal rods and cones in different colors



34-6 The Eye

Hyperopic (farsighted) eye



34-6 The Eye

Myopic (nearsighted) eye