A paraxial ray

A. moves in a parabolic path.
B. is a ray that has been reflected from parabolic mirror.
C. is a ray that moves nearly parallel to the optical axis. ✔
D. is a ray that moves exactly parallel to the optical axis.

A virtual image is

A. the cause of optical illusions.
✔ B. a point from which rays appear to diverge.
C. an image that only seems to exist.
D. the image that is left in space after you remove a viewing screen.

The focal length of a converging lens is

A. the distance at which an image is formed.
B. the distance at which an object must be placed to form an image.
✔ C. the distance at which parallel light rays are focused.
D. the distance from the front surface to the back surface.

EXAMPLE A goldfish in a bowl

QUESTION:

A goldfish lives in a spherical fish bowl 50 cm in diameter. If the fish is 10 cm from the near edge of the bowl, where does the fish appear when viewed from the outside?

MODEL Model the fish as a point source and consider the paraxial rays that refract from the water into the air. The thin glass wall has little effect and will be ignored.

EXAMPLE A goldfish in a bowl

VISUALIZE **FIGURE 23.46** shows the rays refracting *away* from the normal as they move from the water into the air. We expect to find a virtual image at a distance less than 10 cm.

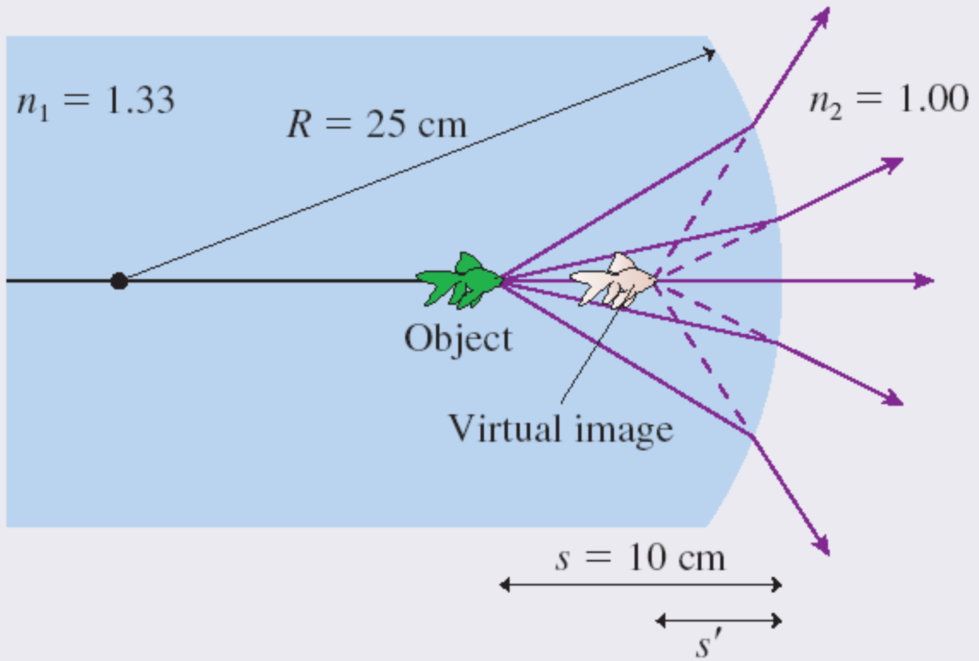


FIGURE 23.46 The curved surface of a fish bowl produces a virtual image of the fish.

EXAMPLE A goldfish in a bowl

SOLVE The object is in the water, so $n_1 = 1.33$ and $n_2 = 1.00$. The inner surface is concave (you can remember "concave" because it's like looking into a cave), so $R = -25$ cm. The object distance is $s = 10$ cm. Thus Equation 23.21 is

$$\frac{1.33}{10\text{ cm}} + \frac{1.00}{s'} = \frac{1.00 - 1.33}{-25\text{ cm}} = \frac{0.33}{25\text{ cm}}$$

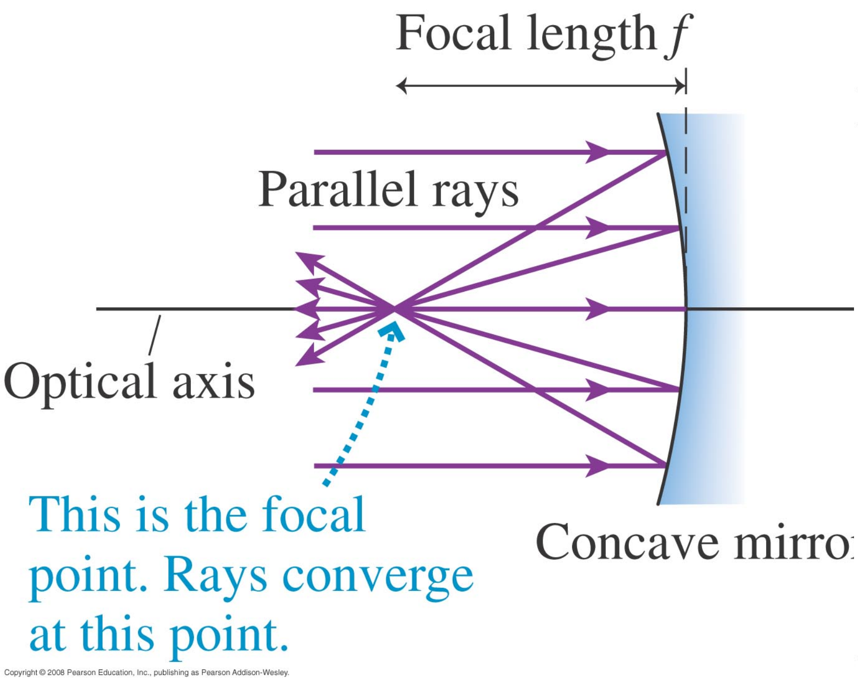
Solving for the image distance s' gives

$$\frac{1.00}{s'} = \frac{0.33}{25\text{ cm}} - \frac{1.33}{10\text{ cm}} = -0.12\text{ cm}^{-1}$$

$$s' = \frac{1.00}{-0.12\text{ cm}^{-1}} = -8.3\text{ cm}$$

ASSESS The image is virtual, located to the left of the boundary. A person looking into the bowl will see a fish that appears to be 8.3 cm from the edge of the bowl.

Mirrors


Focal length f
Parallel rays
Optical axis
This is the focal point. Rays converge at this point.
Concave mirro
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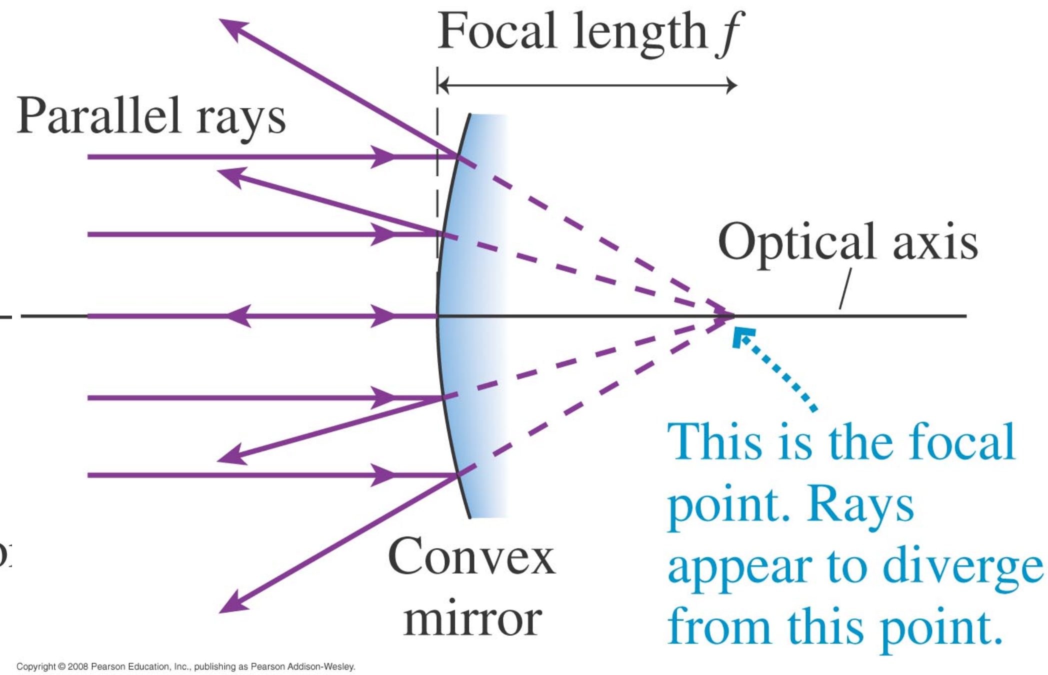
Focal length f
Parallel rays
Optical axis
Convex mirror
This is the focal point. Rays appear to diverge from this point.
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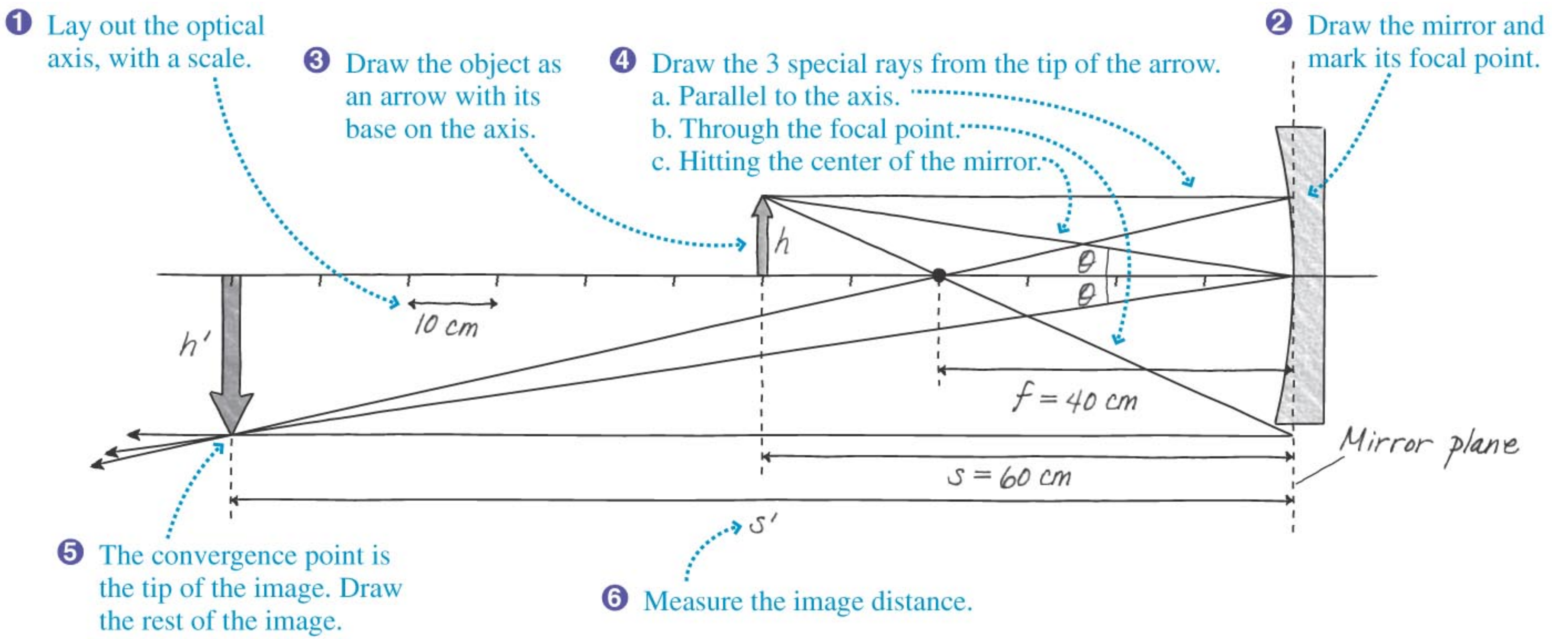
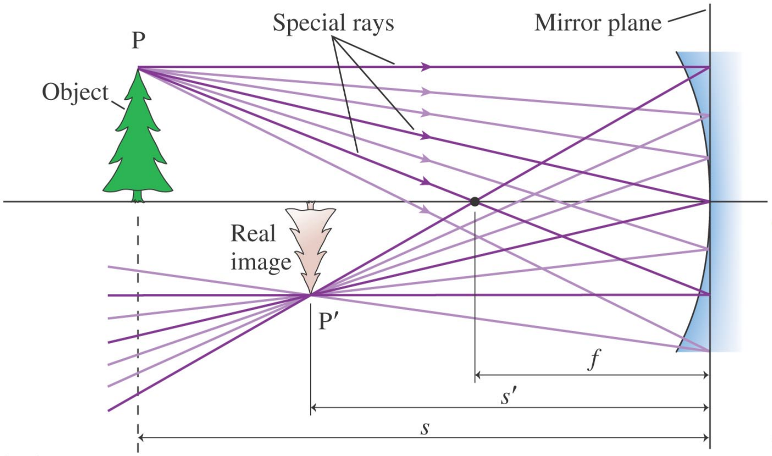
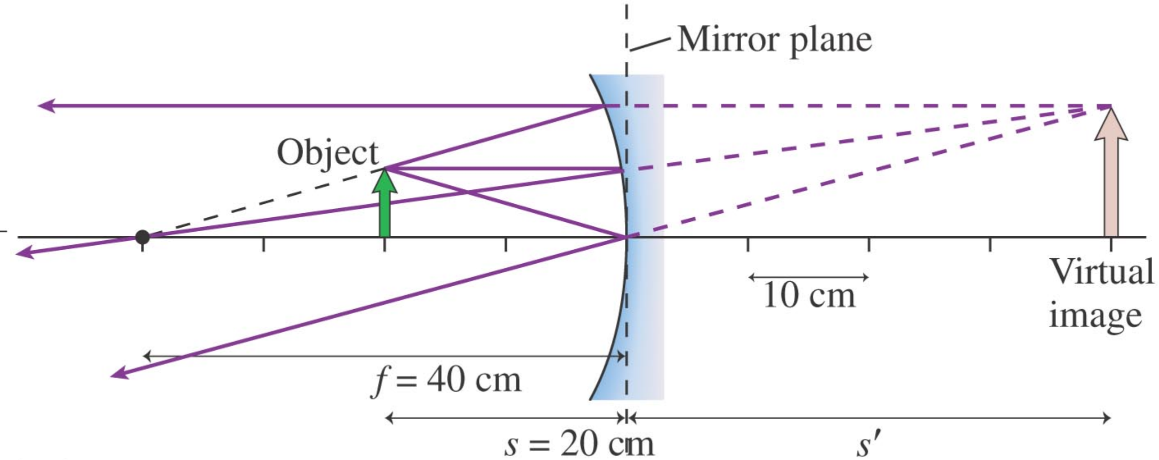
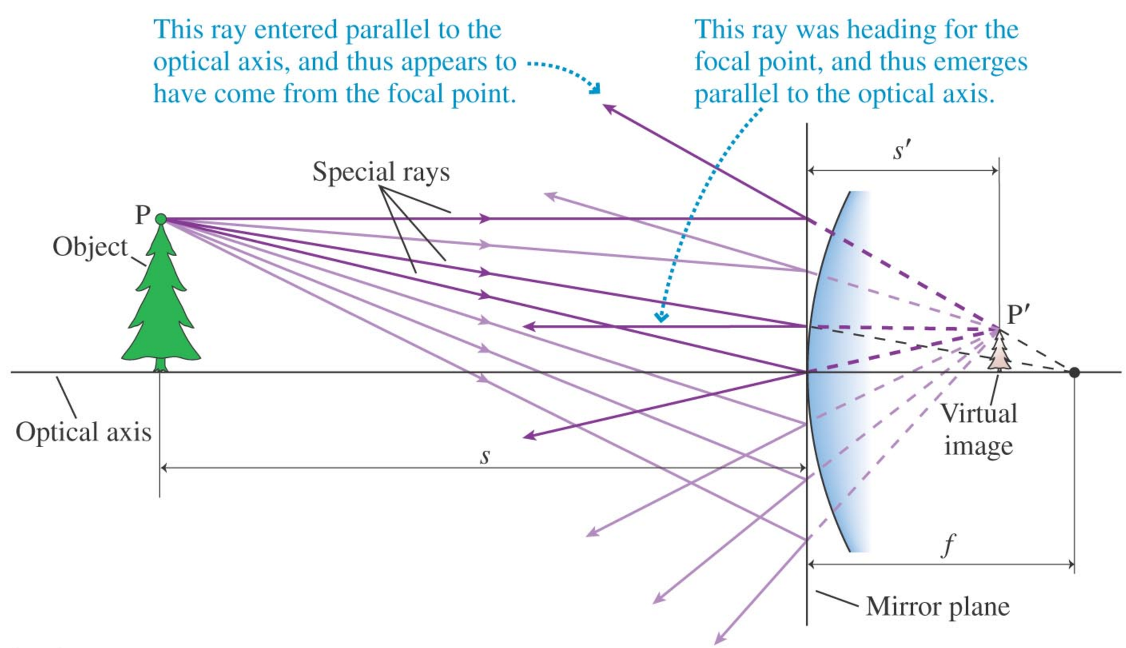
Ray Diagram: A Mirror



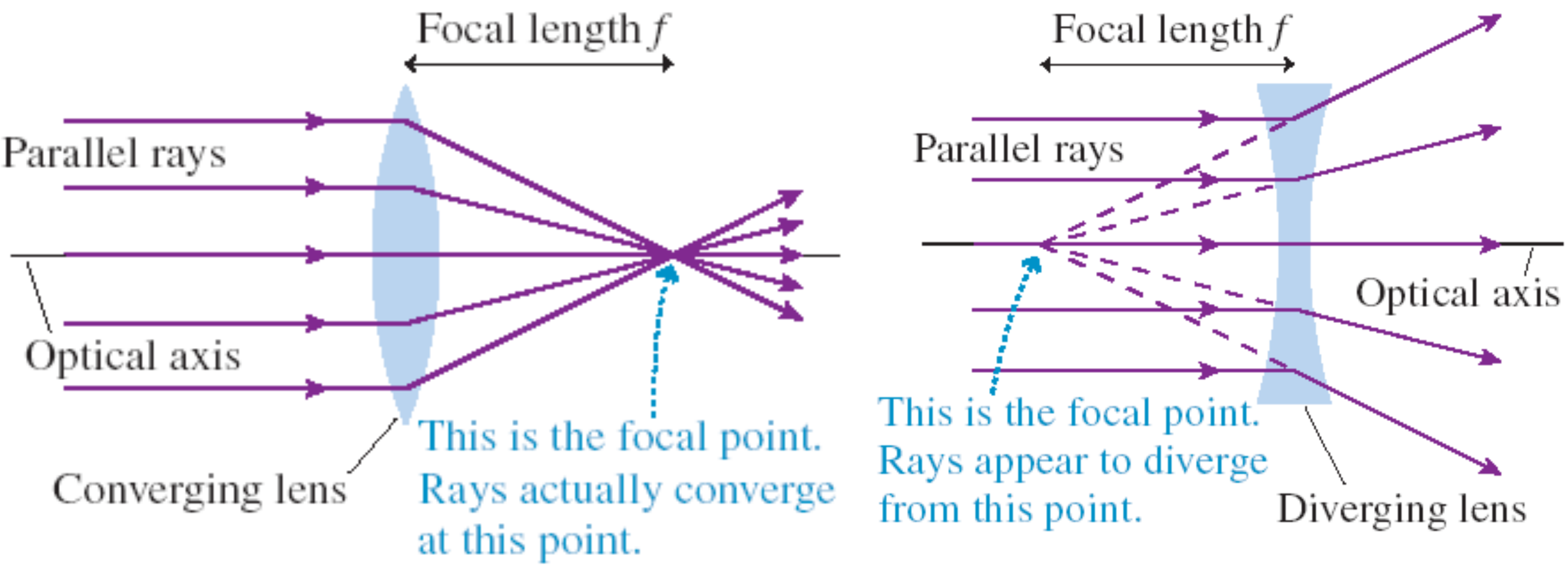
Imaging Formation by a Mirror



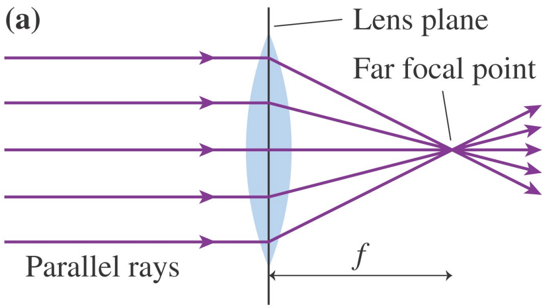




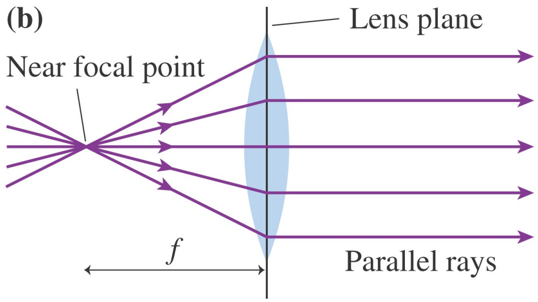
Thin Lens: Focal Point & Length



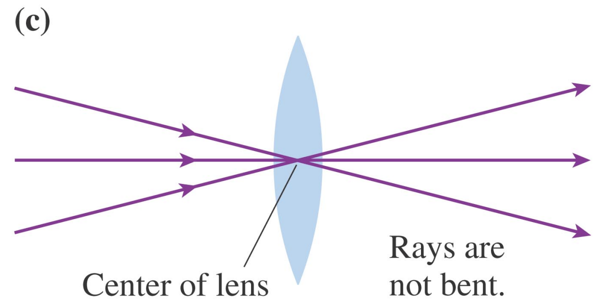
Major Rays



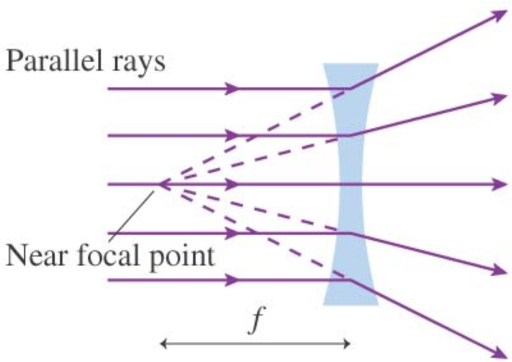
Any ray initially parallel to the optical axis will refract through the focal point on the far side of the lens.



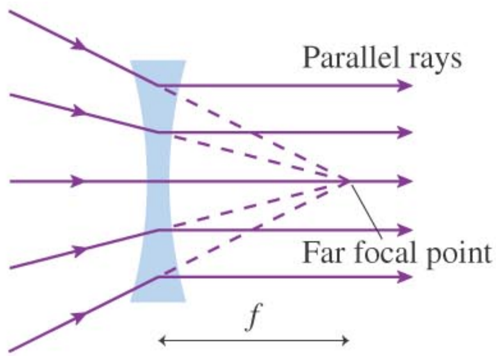
Any ray passing through the near focal point emerges from the lens parallel to the optical axis.



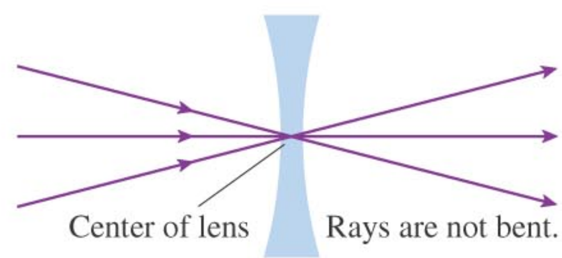
Any ray directed at the center of the lens passes through in a straight line.



Any ray initially parallel to the optical axis diverges along a line through the near focal point.



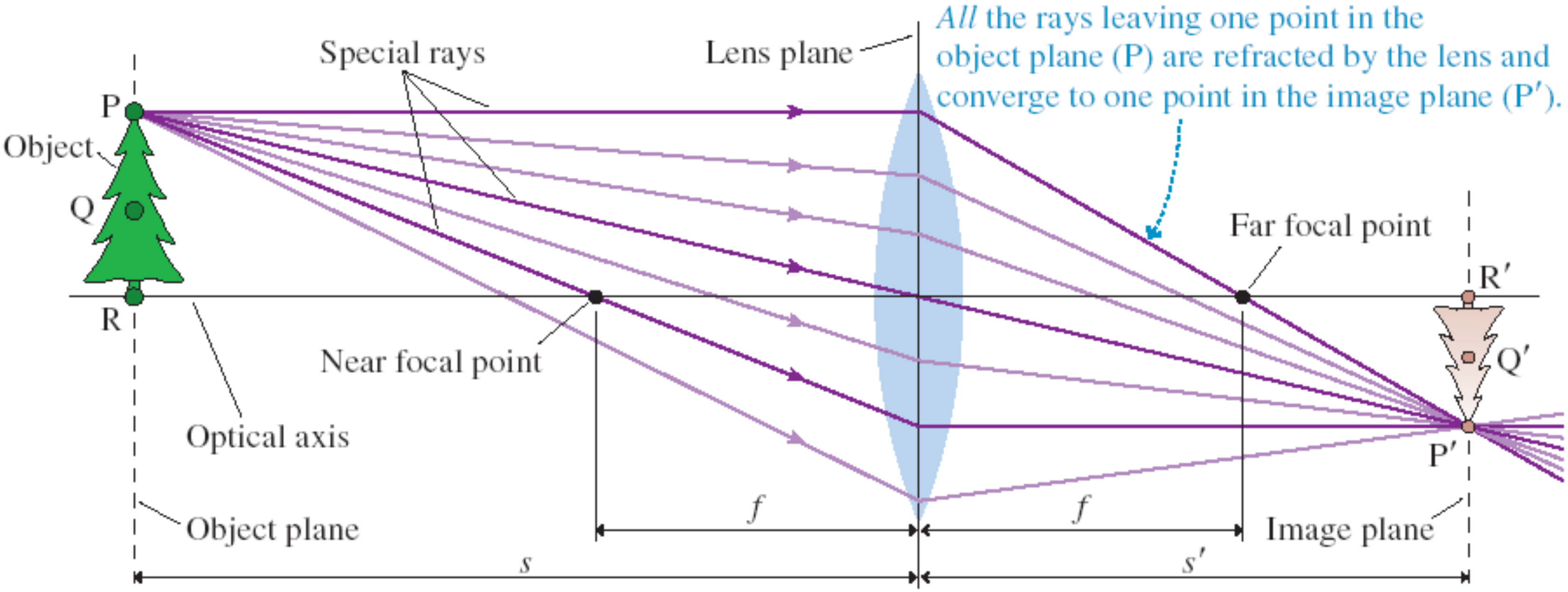
Any ray directed along a line toward the far focal point emerges from the lens parallel to the optical axis.



Any ray directed at the center of the lens passes through in a straight line.

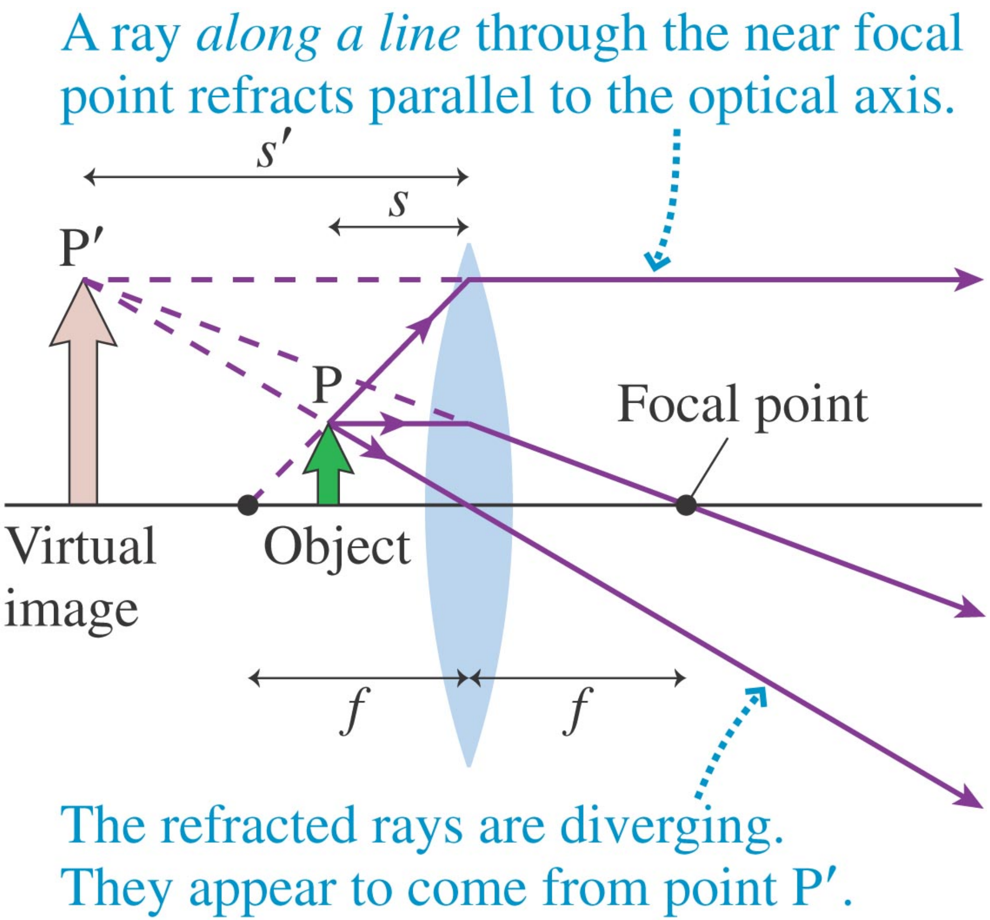
Thin Lenses: Ray Tracing

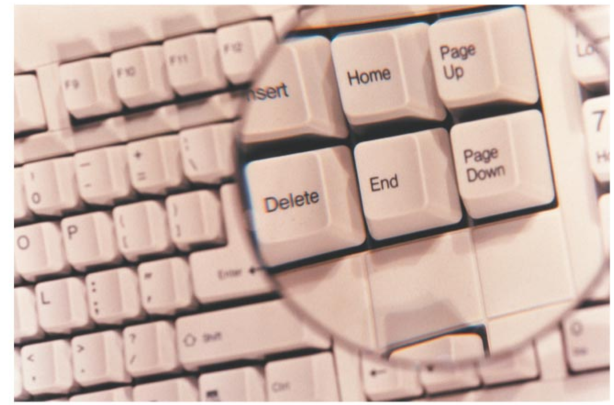
FIGURE 23.36 Rays from an object point P are refracted by the lens and converge to a real image at point P′.

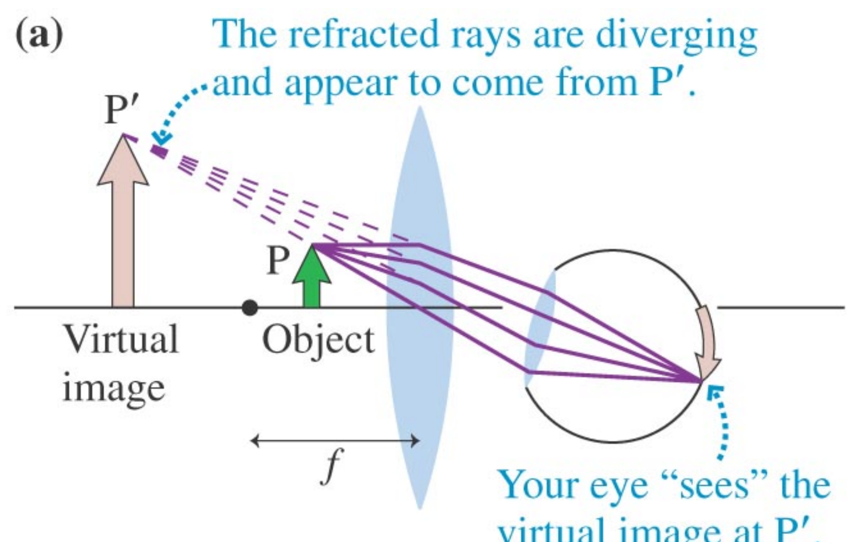


$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f} \qquad \text{(thin-lens equation)}$$

Magnifying Glass/Virtual Image



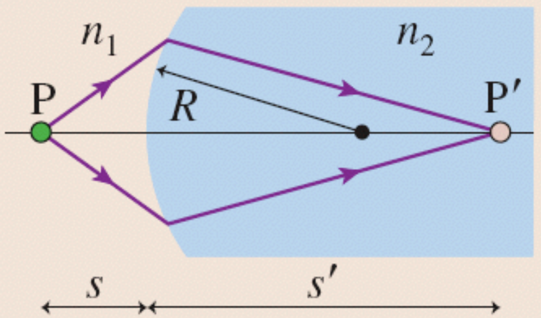




Important Concepts

Image formation

If rays diverge from P and interact with a lens or mirror so that the refracted/reflected rays *diverge* from P′ and appear to come from P′, then P′ is a virtual image of P.



If rays diverge from P and interact with a lens or mirror so that the refracted rays *converge* at P′, then P′ is a real image of P.

Spherical surface: Object and image distances are related by

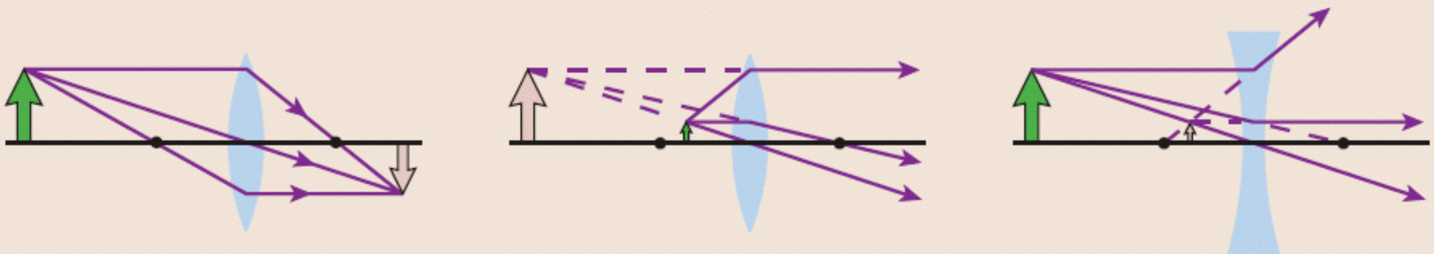
$$\frac{n_1}{s} + \frac{n_2}{s'} = \frac{n_2 - n_1}{R}$$

Plane surface: $R \to \infty$, so $|s'/s| = n_2/n_1$.

Applications

Ray tracing

3 special rays in 3 basic situations:



Converging lens
Real image

Converging lens
Virtual image

Diverging lens
Virtual image

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

m is $+$ for an upright image, $-$ for inverted.

The height ratio is $h'/h = |m|$.