PHYS 111
1^{ST} semester 1439-1440

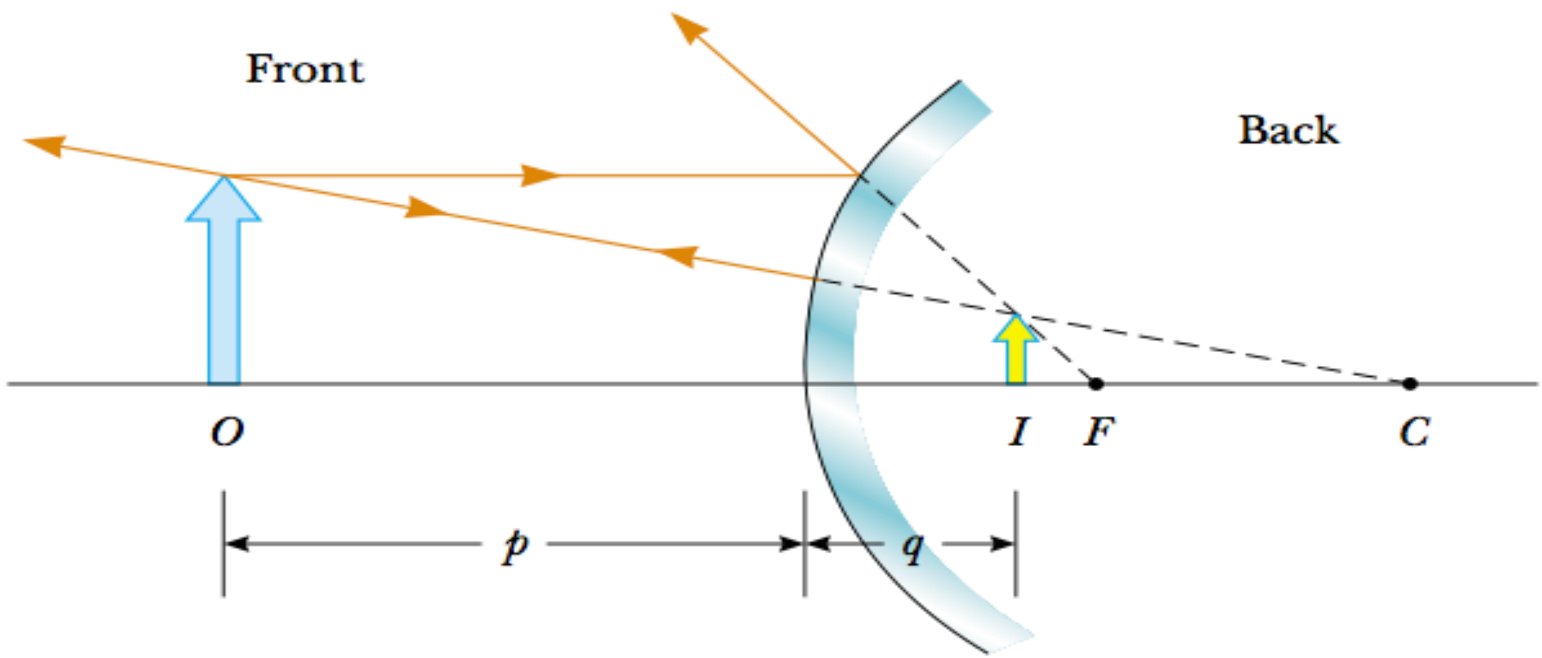
Dr. Nadyah Alanazi

Lecture 18

Chapter 36
Image Formation

36.2 Images Formed by Spherical Mirrors

- **Convex Mirrors**
- It is sometimes called a **diverging mirror** because the rays from any point on an object diverge after reflection.
- The image is **virtual**, **upright** and **smaller** than the object.



The equations for spherical mirrors

$$M = \frac{h'}{h} = -\frac{q}{p}$$

$$\frac{1}{p} + \frac{1}{q} = \frac{2}{R}$$

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

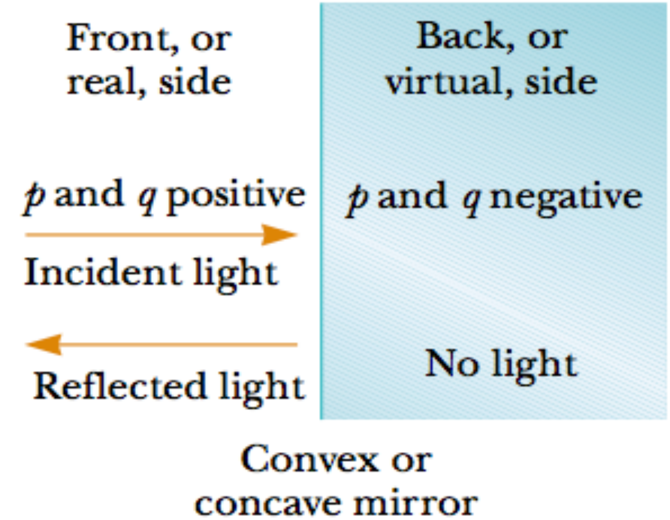


Figure 36.14 Signs of p and q for convex and concave mirrors.

Table 36.1

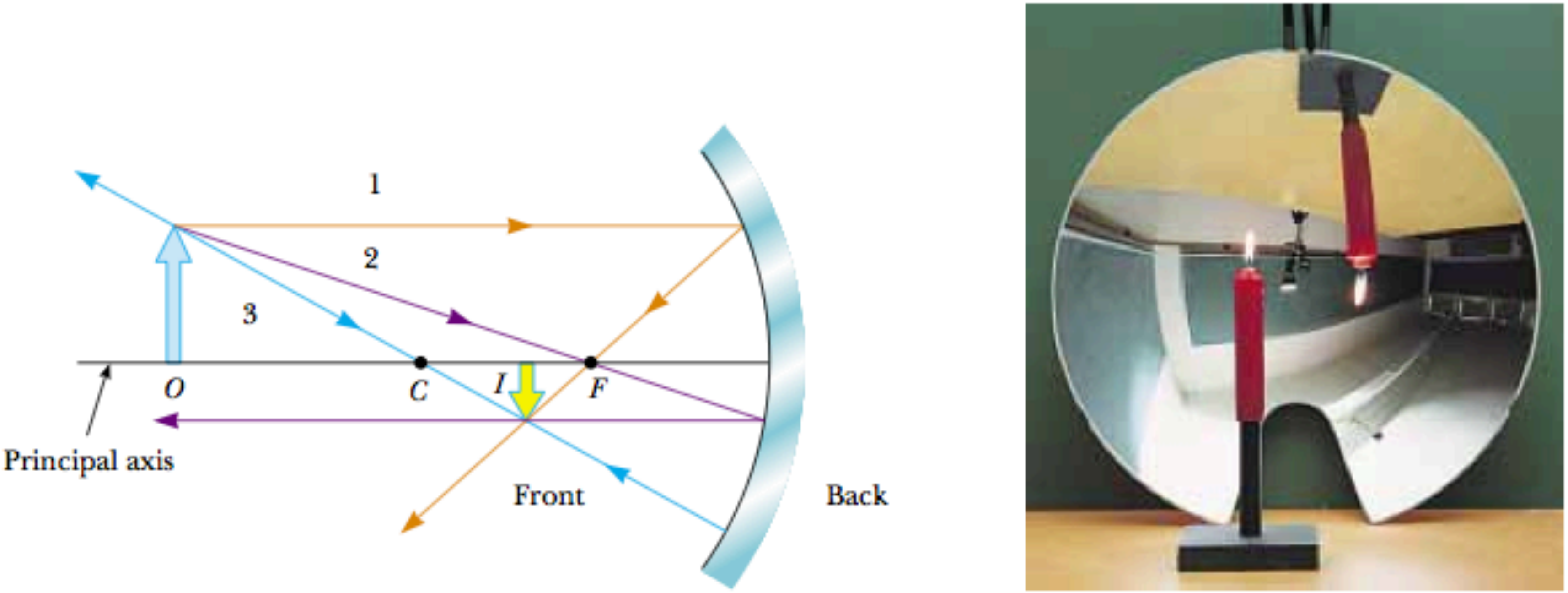
Sign Conventions for Mirrors		
Quantity	**Positive When**	**Negative When**
Object location (p)	Object is in front of mirror (real object)	Object is in back of mirror (virtual object)
Image location (q)	Image is in front of mirror (real image)	Image is in back of mirror (virtual image)
Image height (h')	Image is upright	Image is inverted
Focal length (f) and radius (R)	Mirror is concave	Mirror is convex
Magnification (M)	Image is upright	Image is inverted

Ray Diagrams for Mirrors

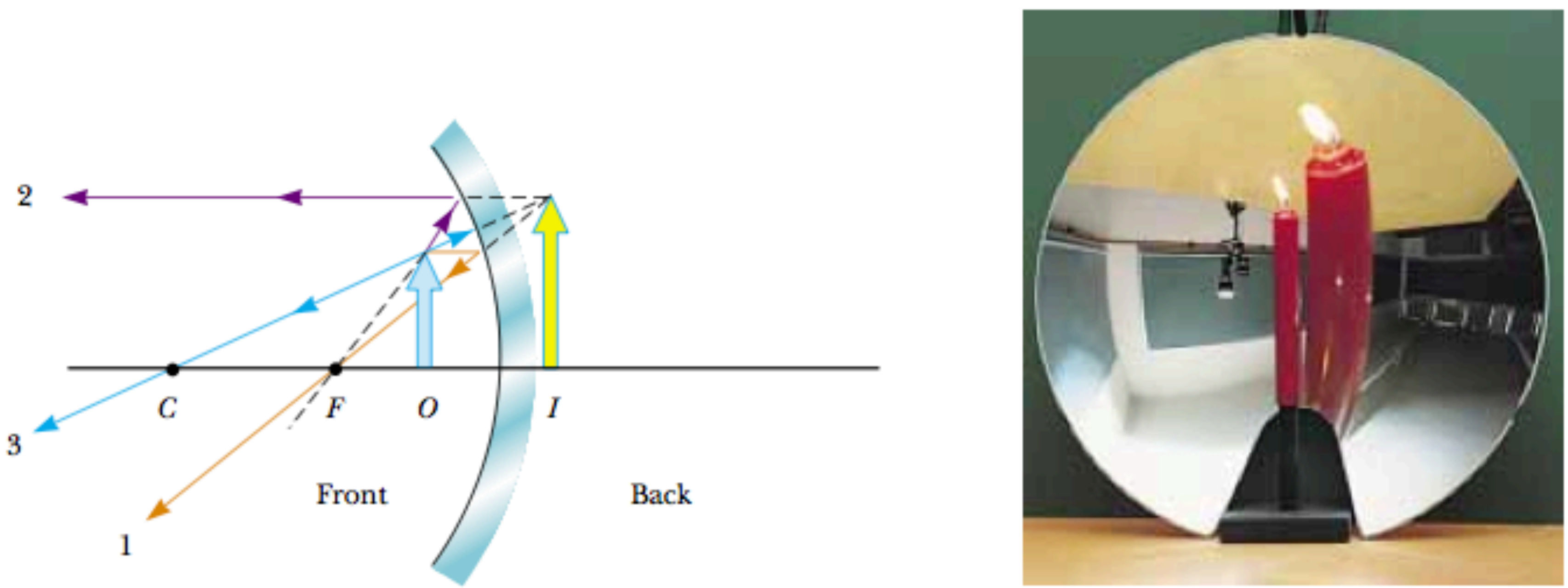
- The positions and sizes of images formed by mirrors can be conveniently determined with *ray diagrams.*
- We then draw three principal rays to locate the image,
- For **concave mirrors**, we draw the following three principal rays:

> - Ray 1 is drawn from the top of the object parallel to the principal axis and is reflected through the focal point *F*.
> - Ray 2 is drawn from the top of the object through the focal point and is reflected parallel to the principal axis.
> - Ray 3 is drawn from the top of the object through the center of curvature *C* and is reflected back on itself.

- The intersection of any two of these rays locates the image.



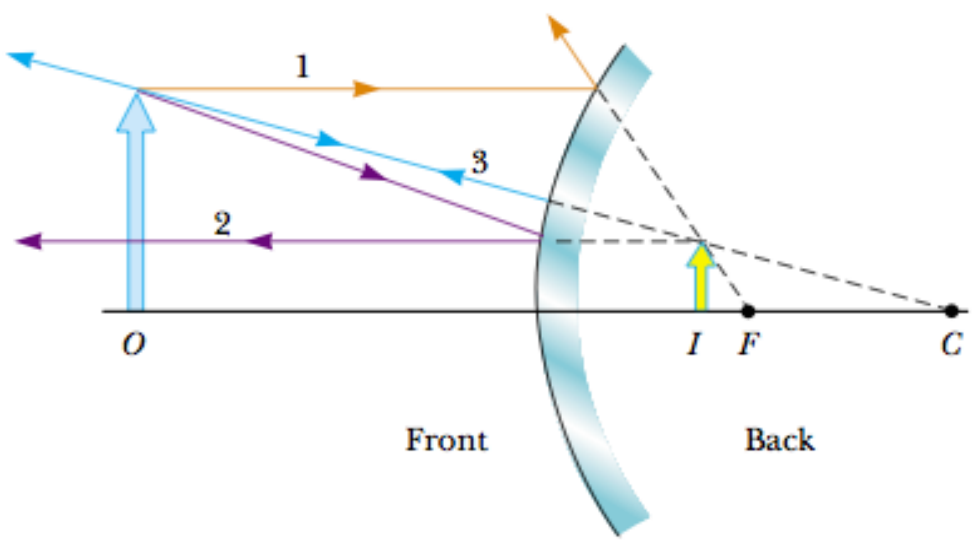
(a)



Ray Diagrams for Mirrors

- For **convex mirrors**, we draw the following three principal rays:

- Ray 1 is drawn from the top of the object parallel to the principal axis and is reflected *away from* the focal point *F*.
- Ray 2 is drawn from the top of the object toward the focal point on the back side of the mirror and is reflected parallel to the principal axis.
- Ray 3 is drawn from the top of the object toward the center of curvature *C* on the back side of the mirror and is reflected back on itself.



Photos courtesy David Rogers

Example 36.4 The Image formed by a Concave Mirror

Interactive

Assume that a certain spherical mirror has a focal length of +10.0 cm. Locate and describe the image for object distances of

(A) 25.0 cm,

(B) 10.0 cm, and

(C) 5.00 cm.

Solution Because the focal length is positive, we know that this is a concave mirror (see Table 36.1).

(A) This situation is analogous to that in Figure 36.15a; hence, we expect the image to be real. We find the image distance by using Equation 36.6:

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

$$\frac{1}{25.0\text{ cm}} + \frac{1}{q} = \frac{1}{10.0\text{ cm}}$$

$$q = 16.7\text{ cm}$$

The magnification of the image is given by Equation 36.2:

$$M = -\frac{q}{p} = -\frac{16.7\text{ cm}}{25.0\text{ cm}} = -0.668$$

The fact that the absolute value of M is less than unity tells us that the image is smaller than the object, and the negative sign for M tells us that the image is inverted. Because q is positive, the image is located on the front side of the mirror and is real.

(B) When the object distance is 10.0 cm, the object is located at the focal point. Now we find that

$$\frac{1}{10.0\text{ cm}} + \frac{1}{q} = \frac{1}{10.0\text{ cm}}$$

$$q = \infty$$

which means that rays originating from an object positioned at the focal point of a mirror are reflected so that the image is formed at an infinite distance from the mirror; that is, the rays travel parallel to one another after reflection. This is the situation in a flashlight, where the bulb filament is placed at the focal point of a reflector, producing a parallel beam of light.

(C) When the object is at $p = 5.00$ cm, it lies halfway between the focal point and the mirror surface, as shown in Figure 36.15b. Thus, we expect a magnified, virtual, upright image. In this case, the mirror equation gives

$$\frac{1}{5.00\text{ cm}} + \frac{1}{q} = \frac{1}{10.0\text{ cm}}$$

$$q = -10.0\text{ cm}$$

The image is virtual because it is located behind the mirror, as expected. The magnification of the image is

$$M = -\frac{q}{p} = -\left(\frac{-10.0\text{ cm}}{5.00\text{ cm}}\right) = +2.00$$

The image is twice as large as the object, and the positive sign for M indicates that the image is upright (see Fig. 36.15b).

Example 36.5 The Image from a Convex Mirror

Interactive

An anti-shoplifting mirror, as shown in Figure 36.17, shows an image of a woman who is located 3.0 m from the mirror. The focal length of the mirror is −0.25 m. Find

(A) the position of her image and

(B) the magnification of the image.

Solution (A) This situation is depicted in Figure 36.15c. We should expect to find an upright, reduced, virtual image. To find the image position, we use Equation 36.6:

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f} = \frac{1}{-0.25\text{ m}}$$

$$\frac{1}{q} = \frac{1}{-0.25\text{ m}} - \frac{1}{3.0\text{ m}}$$

$$q = \boxed{-0.23\text{ m}}$$

The negative value of q indicates that her image is virtual, or behind the mirror, as shown in Figure 36.15c.

(B) The magnification of the image is

$$M = -\frac{q}{p} = -\left(\frac{-0.23\text{ m}}{3.0\text{ m}}\right) = \boxed{+0.077}$$

The image is much smaller than the woman, and it is upright because M is positive.

Figure 36.17 (Example 36.5) Convex mirrors, often used for security in department stores, provide wide-angle viewing.

36.3 Images Formed by Refraction

- We describe how images are formed when light rays are refracted at the boundary between two transparent materials.
- Consider two transparent media having indices of refraction n_1 and n_2, where the boundary between the two media is a spherical surface of radius *R*.
- **Relation between object and image distance for a refracting surface**

$$\frac{n_1}{p} + \frac{n_2}{q} = \frac{n_2 - n_1}{R}$$

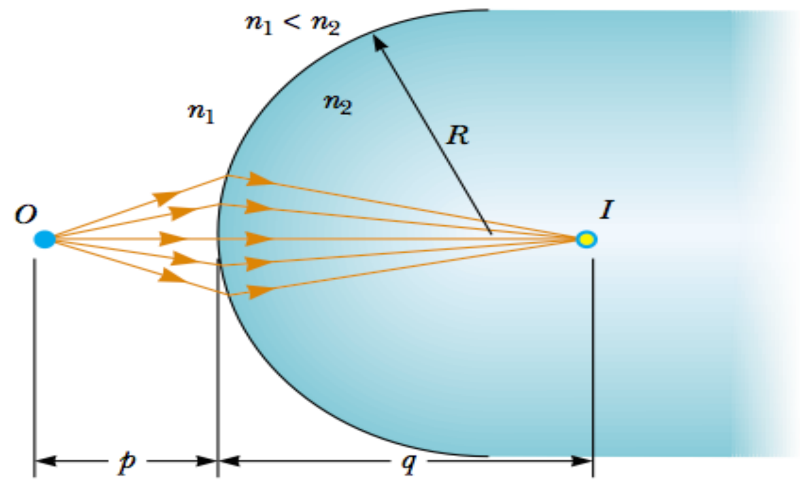


Table 36.2

Sign Conventions for Refracting Surfaces

Quantity	Positive When	Negative When
Object location (p)	Object is in front of surface (real object)	Object is in back of surface (virtual object)
Image location (q)	Image is in back of surface (real image)	Image is in front of surface (virtual image)
Image height (h')	Image is upright	Image is inverted
Radius (R)	Center of curvature is in back of surface	Center of curvature is in front of surface

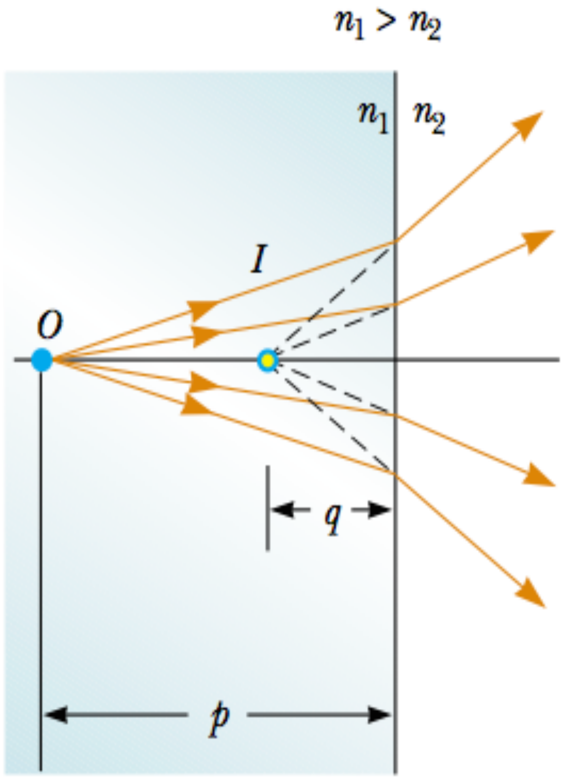
36.3 Images Formed by Refraction

- **Flat Refracting Surfaces**
  - If a refracting surface is flat, then *R* is infinite

$$\frac{n_1}{p} = -\frac{n_2}{q}$$

$$q = -\frac{n_2}{n_1}p$$

  - we see that the sign of *q* is opposite that of *p*. Thus, according to Table 36.2, **the image formed by a flat refracting surface is on the same side of the surface as the object.**
  - The object is in the medium of index n_1 and ($n_1 > n_2$). In this case, a virtual image is formed between the object and the surface.
  - If $n_1 < n_2$, the rays in the back side diverge from each other at lesser angles. As a result, the virtual image is formed to the left of the object.



Example 36.7 Gaze into the Crystal Ball

A set of coins is embedded in a spherical plastic paperweight having a radius of 3.0 cm. The index of refraction of the plastic is $n_1 = 1.50$. One coin is located 2.0 cm from the edge of the sphere (Fig. 36.21). Find the position of the image of the coin.

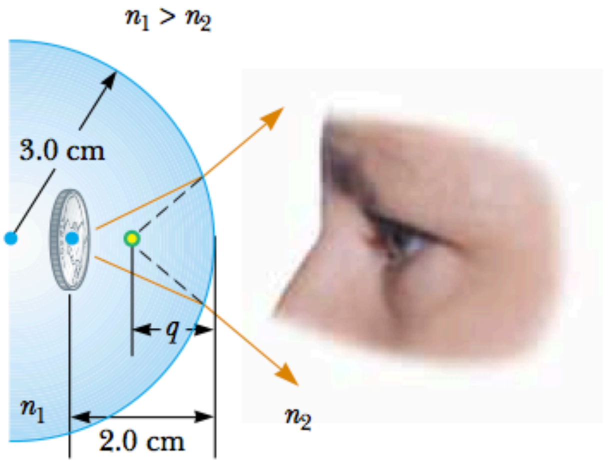


Figure 36.21 (Example 36.7) Light rays from a coin embedded in a plastic sphere form a virtual image between the surface of the object and the sphere surface. Because the object is inside the sphere, the front of the refracting surface is the *interior* of the sphere.

Solution Because $n_1 > n_2$, where $n_2 = 1.00$ is the index of refraction for air, the rays originating from the coin are refracted away from the normal at the surface and diverge outward. Hence, the image is formed inside the paperweight and is *virtual*. Applying Equation 36.8 and noting from Table 36.2 that R is negative, we obtain

$$\frac{n_1}{p} + \frac{n_2}{q} = \frac{n_2 - n_1}{R}$$

$$\frac{1.50}{2.0\text{ cm}} + \frac{1}{q} = \frac{1.00 - 1.50}{-3.0\text{ cm}}$$

$$q = \boxed{-1.7\text{ cm}}$$

The negative sign for q indicates that the image is in front of the surface—in other words, in the same medium as the object, as shown in Figure 36.21. Being in the same medium as the object, the image must be virtual. (See Table 36.2.) The coin appears to be closer to the paperweight surface than it actually is.

Example 36.8 The One That Got Away

A small fish is swimming at a depth d below the surface of a pond (Fig. 36.22). What is the apparent depth of the fish, as viewed from directly overhead?

Solution Because the refracting surface is flat, R is infinite. Hence, we can use Equation 36.9 to determine the location of the image with $p = d$. Using the indices of refraction given in Figure 36.22, we obtain

$$q = -\frac{n_2}{n_1} p = -\frac{1.00}{1.33} d = -0.752d$$

Because q is negative, the image is virtual, as indicated by the dashed lines in Figure 36.22. The apparent depth is approximately three-fourths the actual depth.

What If? **What if you look more carefully at the fish and measure its apparent *height*, from its upper fin to its lower fin? Is the apparent height h' of the fish different from the actual height h?**

Answer Because all points on the fish appear to be fractionally closer to the observer, we would predict that the height would be smaller. If we let the distance d in Figure 36.22 be measured to the top fin and the distance to the bottom fin be $d + h$, then the images of the top and bottom of the fish are located at

$$q_{\text{top}} = -0.752d$$
$$q_{\text{bottom}} = -0.752(d + h)$$

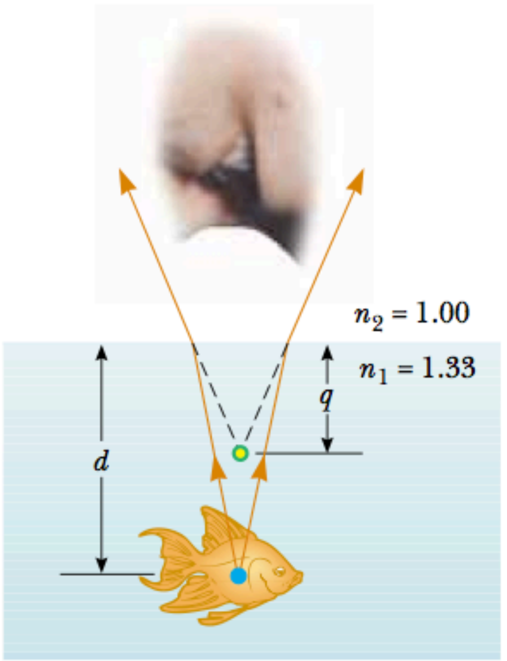


Figure 36.22 (Example 36.8) The apparent depth q of the fish is less than the true depth d. All rays are assumed to be paraxial.

The apparent height h' of the fish is

$$h' = q_{\text{top}} - q_{\text{bottom}} = -0.752d - [-0.752(d + h)]$$
$$= 0.752h$$

and the fish appears to be approximately three-fourths its actual height.