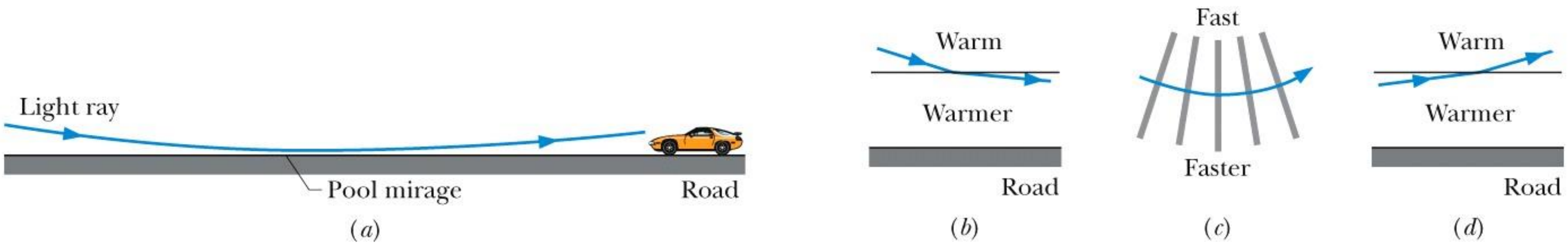
Chapter 34

Images

34-1 Images and Plane Mirrors

An image is a reproduction of an object via light. If the image can form on a surface, it is a real image and can exist even if no observer is present. If the image requires the visual system of an observer, it is a virtual image.

Here are some common examples of virtual image.



(a) A ray from a low section of the sky refracts through air that is heated by a road (without reaching the road). An observer who intercepts the light perceives it to be from a pool of water on the road. (b) Bending (exaggerated) of a light ray descending across an imaginary boundary from warm air to warmer air. (c) Shifting of wavefronts and associated bending of a ray, which occur because the lower ends of wavefronts move faster in warmer air. (d) Bending of a ray ascending across an imaginary boundary to warm air from warmer air.

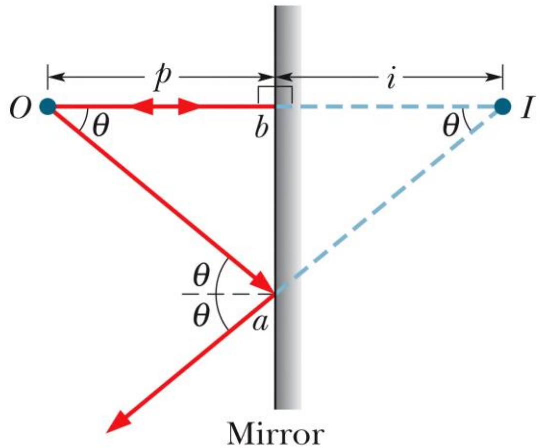
34-1 Images and Plane Mirrors

As shown in figure (a), a plane (flat) mirror can form a virtual image of a light source (said to be the object, O) by redirecting light rays emerging from the source. The image can be seen where backward extensions of reflected rays pass through one another. The object's distance *p* from the mirror is related to the (apparent) image distance *i* from the mirror by

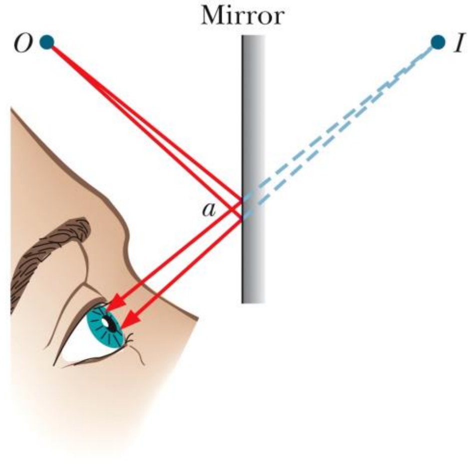
$$i = -p$$

Object distance *p* is a positive quantity. Image distance *i* for a virtual image is a negative quantity.

Only rays that are fairly close together can enter the eye after reflection at a mirror. For the eye position shown in Fig. (b), only a small portion of the mirror near point *a* (a portion smaller than the pupil of the eye) is useful in forming the image.



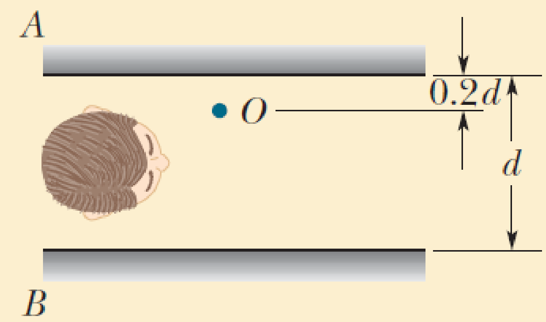
(a)



(b)

Checkpoint 1

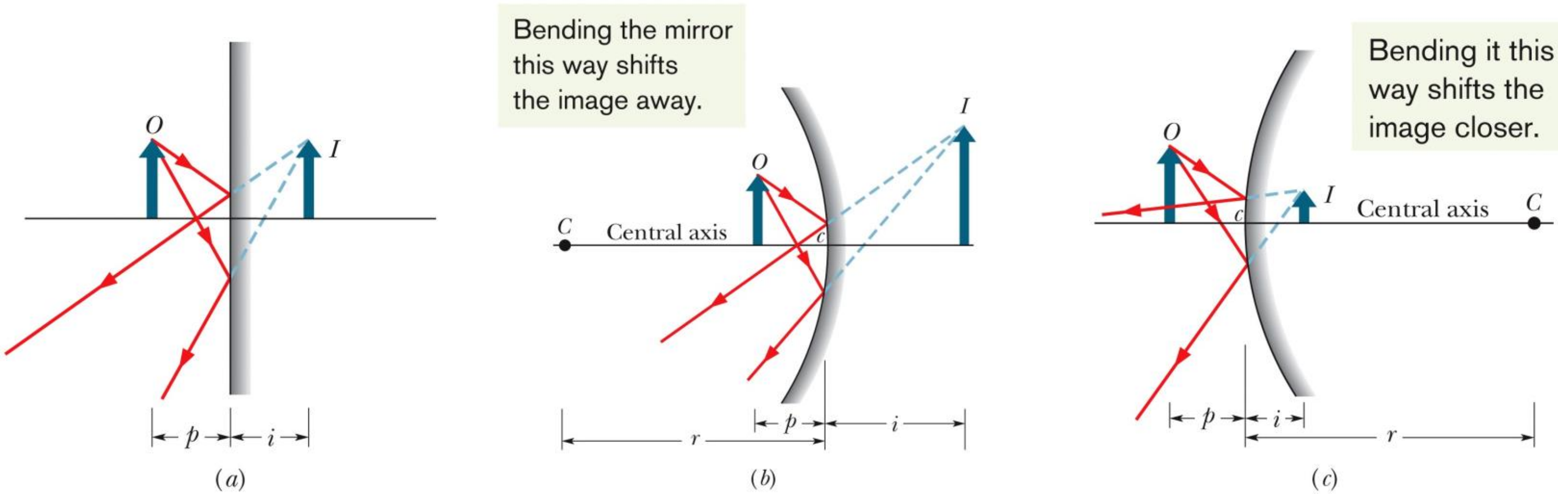
In the figure you are in a system of two vertical parallel mirrors A and B separated by distance d. A grinning gargoyle is perched at point O, a distance $0.2d$ from mirror A. Each mirror produces a *first* (least deep) image of the gargoyle. Then each mirror produces a *second* image with the object being the first image in the opposite mirror. Then each mirror produces a *third* image with the object being the second image in the opposite mirror, and so on—you might see hundreds of grinning gargoyle images. How deep behind mirror A are the first, second, and third images in mirror A?



$$0.2d, 1.8d, 2.2d$$

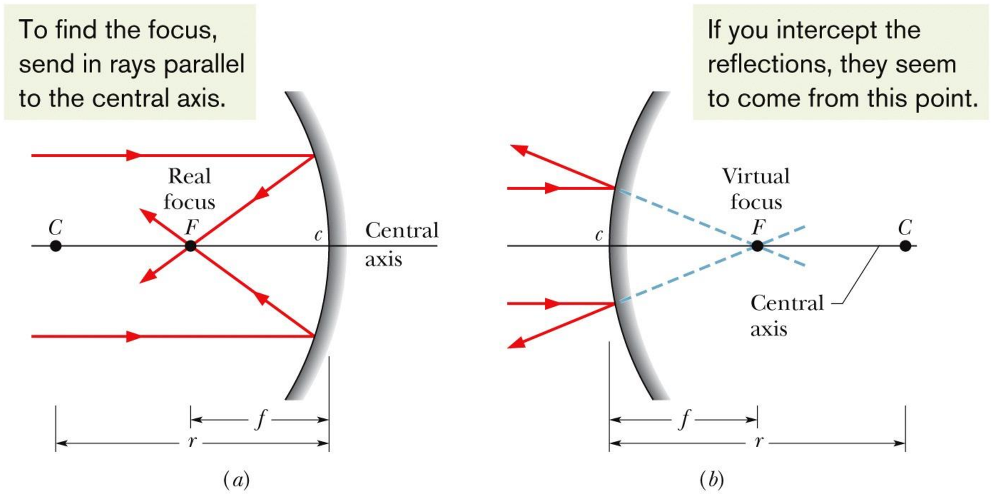
34-2 Spherical Mirrors

A spherical mirror is in the shape of a small section of a spherical surface and can be **concave** (the radius of curvature *r* is a positive quantity), **convex** (*r* is a negative quantity), or **plane** (flat, *r* is infinite).



We make a **concave mirror** by curving the mirror's surface so it is concave ("caved in" to the object) as in Fig. (b). We can make a **convex mirror** by curving a plane mirror so its surface is convex ("flexed out") as in Fig.(c). Curving the surface in this way (1) moves the *center of curvature C* to behind the mirror and (2) increases the field of view. It also (3) moves the image of the object closer to the mirror and (4) shrinks it. These iterated characteristics are the exact opposite for concave mirror.

34-2 Spherical Mirrors



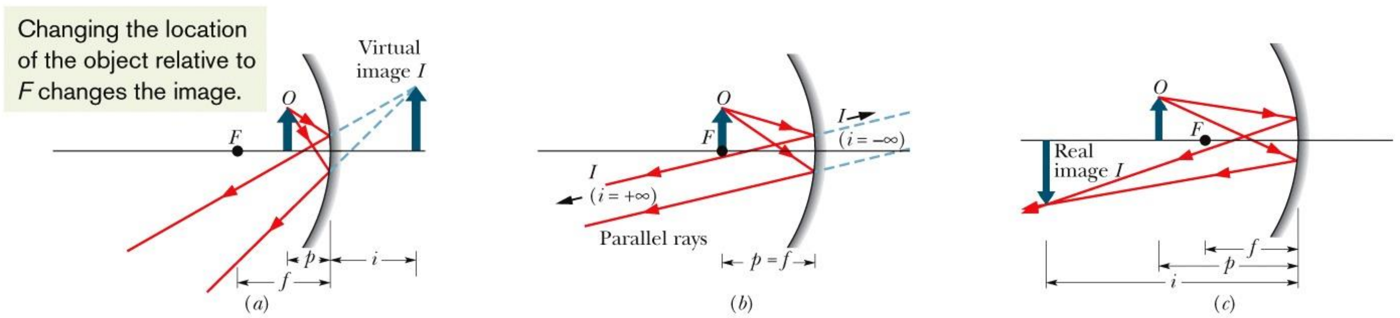
If parallel rays are sent into a (spherical) concave mirror parallel to the central axis, the reflected rays pass through a common point (a real focus *F*) at a distance *f* (a positive quantity) from the mirror (figure a). If they are sent toward a (spherical) convex mirror, backward extensions of the reflected rays pass through a common point (a virtual focus *F*) at a distance f (a negative quantity) from the mirror (figure b).

For mirrors of both types, the focal length *f* is related to the radius of curvature *r* of the mirror by

$$f = \frac{1}{2}r$$

where *r* (and *f*) is positive for a concave mirror and negative for a convex mirror.

34-2 Spherical Mirrors



(a) An object O inside the focal point of a concave mirror, and its virtual image I. (b) The object at the focal point F. (c) The object outside the focal point, and its real image I.

- A concave mirror can form a real image (if the object is outside the focal point) or a virtual image (if the object is inside the focal point).
- A convex mirror can form only a virtual image.
- The mirror equation relates an object distance *p*, the mirror's focal length *f* and radius of curvature *r*, and the image distance *i*:

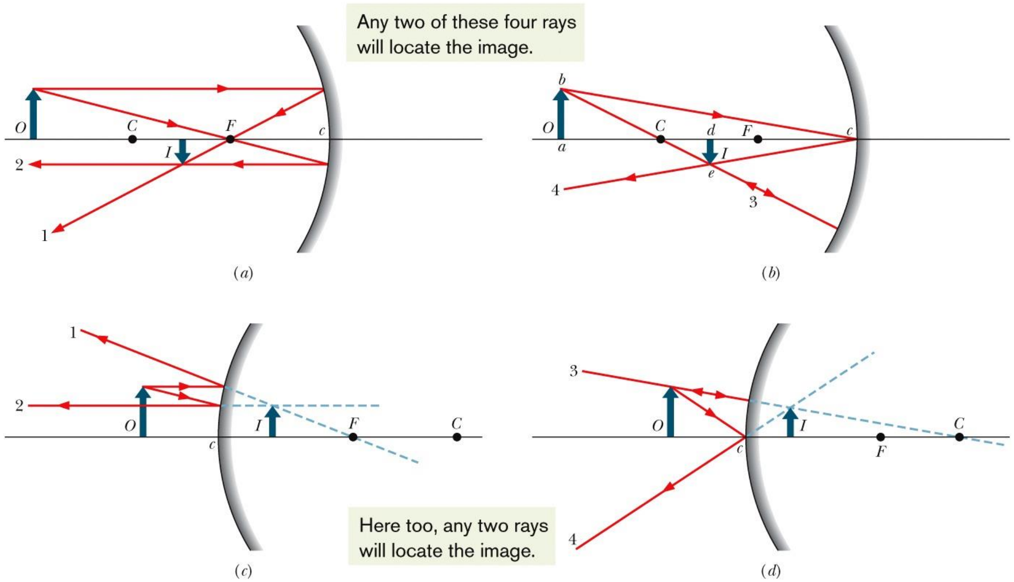
$$\frac{1}{p} + \frac{1}{i} = \frac{1}{f}$$

- The magnitude of the lateral magnification m of an object is the ratio of the image height h' to object height h,

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

$$m = -\frac{i}{p}$$

34-2 Spherical Mirrors



Locating Images by Drawing Rays

1. A ray that is initially parallel to the central axis reflects through the focal point *F* (ray 1 in Fig. a).
2. A ray that reflects from the mirror after passing through the focal point emerges parallel to the central axis (Fig. a).
3. A ray that reflects from the mirror after passing through the center of curvature *C* returns along itself (ray 3 in Fig. b).
4. A ray that reflects from the mirror at point *c* is reflected symmetrically about that axis (ray 4 in Fig. b).

The image of the point is at the intersection of the two special rays you choose. The image of the object can then be found by locating the images of two or more of its off-axis points (say, the point most off axis) and then sketching in the rest of the image. You need to modify the descriptions of the rays slightly to apply them to convex mirrors, as in Figs. c and d.

Checkpoint 2

A Central American vampire bat, dozing on the central axis of a spherical mirror, is magnified by $m = -4$. Is its image (a) real or virtual, (b) inverted or of the same orientation as the bat, and (c) on the same side of the mirror as the bat or on the opposite side?

(a) real; (b) inverted; (c) same

Sample Problem 34.01 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?

Reasoning: Because the image has the same orientation as the tarantula (the object), it must be virtual and on the opposite side of the mirror. (You can easily see this result if you have filled out Table 34-1.)

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

KEY IDEA

We *cannot* tell the type of mirror from the type of image because both types of mirror can produce virtual images. Similarly, we cannot tell the type of mirror from the sign of the focal length f, as obtained from Eq. 34-3 or Eq. 34-4, because we lack enough information to use either equation. However, we can make use of the magnification information.

Calculations: From the given information, we know that the ratio of image height h' to object height h is 0.20. Thus, from Eq. 34-5 we have

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

Because the object and image have the same orientation, we know that m must be positive: $m = +0.20$. Substituting this into Eq. 34-6 and solving for, say, i gives us

$$i = -0.20p,$$

which does not appear to be of help in finding f. However, it is helpful if we substitute it into Eq. 34-4. That equation gives us

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

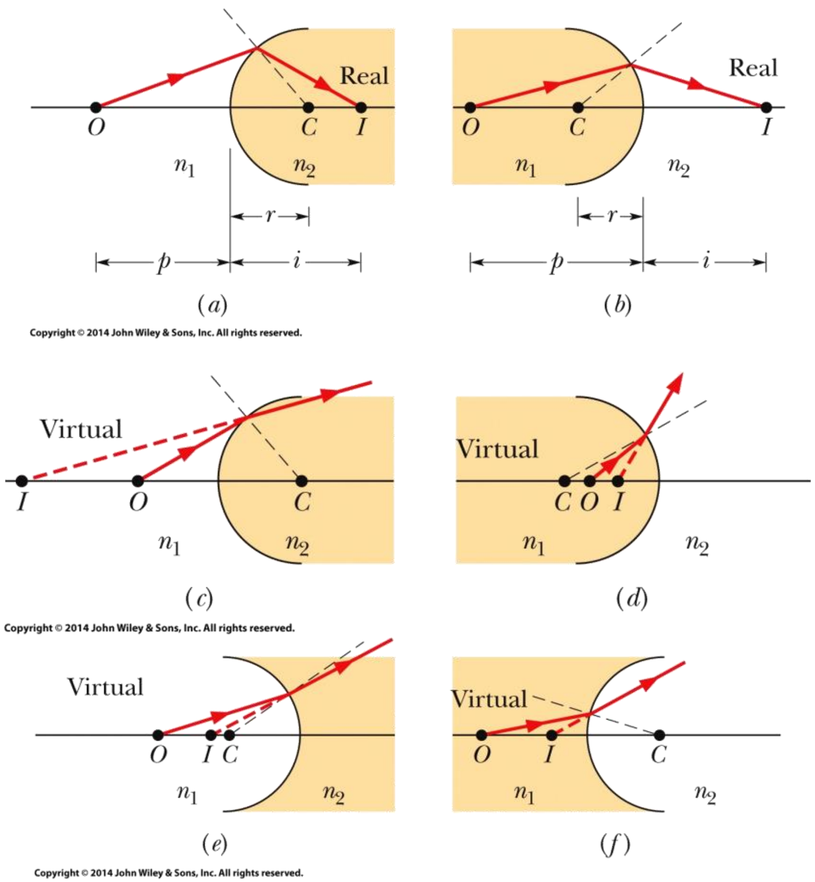
from which we find

$$f = -p/4.$$

Now we have it: Because p is positive, f must be negative, which means that the mirror is convex with

$$f = -40 \text{ cm}. \qquad \text{(Answer)}$$

34-3 Spherical Refracting Surface



Real images are formed in (a) and (b); virtual images are formed in the other four situations.

- A single spherical surface that refracts light can form an image.
- The object distance p, the image distance i, and the radius of curvature r of the surface are related by

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

where n_1 is the index of refraction of the material where the object is located and n_2 is the index of refraction on the other side of the surface.

- If the surface faced by the object is convex, r is positive, and if it is concave, r is negative.

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.