University of Mosul

College of Science

Department of Physics

Third Stage

Lecture 5

Geometric Optics

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Lecture 5: Mirrors and Lenses

Preparation

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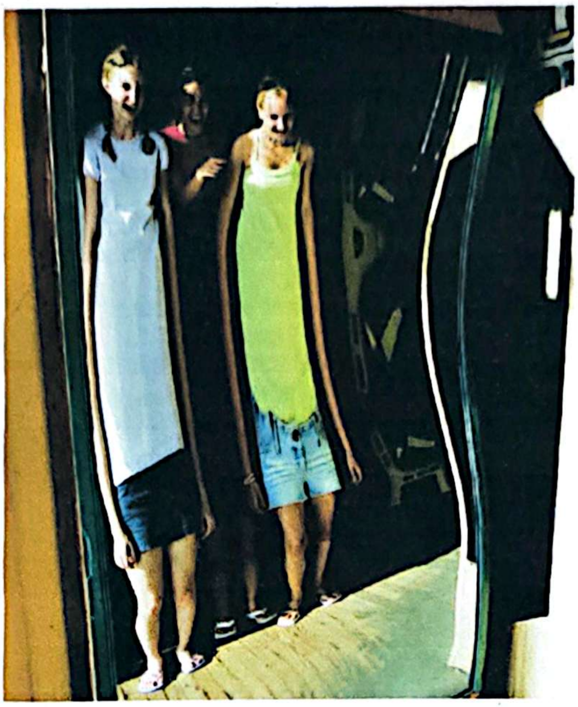
Funhouse mirrors distort images because the curved surfaces essentially change the angle of incidence of incoming rays, change that differs depending on the mirror's shape in a given location. In every case, however, the angle of reflection equals the angle of incidence.



Gail Mooney/Masterfile Corporation

23 Mirrors and Lenses

The development of the technology of mirrors and lenses led to a revolution in the progress of science. These devices, relatively simple to construct from cheap materials, led to microscopes and telescopes, extending human sight and opening up new pathways to knowledge, from microbes to distant planets.

This chapter covers the formation of images when plane and spherical light waves fall on plane and spherical surfaces. Images can be formed by reflection from mirrors or by refraction through lenses. In our study of mirrors and lenses, we continue to assume light travels in straight lines (the ray approximation), ignoring diffraction.

23.1 Flat Mirrors

We begin by examining the flat mirror. Consider a point source of light placed at O in Figure 23.1, a distance p in front of a flat mirror. The distance p is called **the object distance.** Light rays leave the source and are reflected from the mirror. After reflection, the rays diverge (spread apart), but they appear to the viewer to come from a point I behind the mirror. Point I is called the **image** of the object at O. Regardless of the system under study, **images are formed at the point where rays of light actually intersect or where they appear to originate.** Because the rays in the figure appear to originate at I, which is a distance q behind the mirror, that is the location of the image. The distance q is called the **image distance.**

Images are classified as real or virtual. In the formation of a ***real image,*** light actually passes through the image point. For a ***virtual image,*** light doesn't pass through the image point, but appears to come (diverge) from there. The image formed by the flat mirror in Figure 23.1 is a virtual image. In fact, the images seen in flat mirrors are always virtual (for real objects). Real images can be displayed on a screen (as at a movie), but virtual images cannot.

We examine some of the properties of the images formed by flat mirrors by using the simple geometric techniques. To find out where an image is formed, it's necessary to follow at least two rays of light as they reflect from the mirror as in Active Figure 23.2. One of those rays starts at P, follows the horizontal path PQ to the mirror, and reflects back on itself. The second ray follows the oblique path PR and reflects as shown. An observer to the left of the mirror would trace the two reflected rays back to the point from which they appear to have originated: point P'. A continuation of this process for points other than P on the object would result in a virtual image (drawn as a yellow arrow) to the right of the mirror. Because triangles PQR and $P'QR$ are identical, $PQ = P'Q$. Hence, we conclude that **the image formed by an object placed in front of a flat mirror is as far behind the mirror as the object is in front of the mirror.** Geometry also shows that the object height h equals the image height h'. The **lateral magnification** M is defined as

$$M = \frac{\text{image height}}{\text{object height}} = \frac{h'}{h} \qquad [23.1]$$

Equation 23.1 is a general definition of the lateral magnification of any type of mirror. For a flat mirror, $M = 1$ because $h' = h$.

In summary, the image formed by a flat mirror has the following properties:

1. The image is as far behind the mirror as the object is in front.
2. The image is unmagnified, virtual, and upright. (By *upright*, we mean that if the object arrow points upward, as in Active Figure 23.2, so does the image arrow. The opposite of an upright image is an inverted image.)

Finally, note that a flat mirror produces an image having an *apparent* left–right reversal. You can see this reversal standing in front of a mirror and raising your right hand. Your image in the mirror raises the left hand. Likewise, your hair appears to be parted on the opposite side, and a mole on your right cheek appears to be on your image's left cheek.

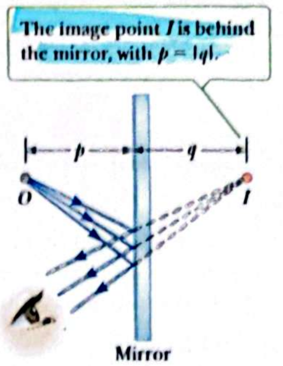
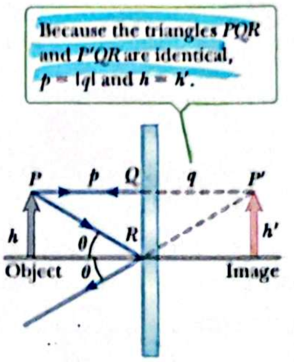


Figure 23.1 An image formed by reflection from a flat mirror. The image at point I is virtual. In Section 23.3, it will be shown that q must be taken as negative for virtual images: the object distance p, therefore, equals the absolute value of the image distance q.



Active Figure 23.2 A geometric construction to locate the image of an object placed in front of a flat mirror.

Quick Quiz

23.1 In the overhead view of Figure 23.3, the image of the stone seen by observer 1 is at C. Where does observer 2 see the image: at A, at B, at C, at D, at E, or not at all?

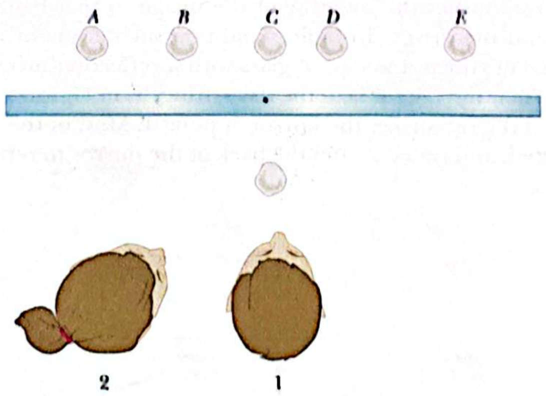


Figure 23.3 (Quick Quiz 23.1)

Tip 23.1 Magnification ≠ Enlargement

Note that the word *magnification*, as used in optics, doesn't always mean *enlargement* because the image could be smaller than the object.

EXAMPLE 23.1 "Mirror, Mirror, on the Wall"

GOAL Apply the properties of a flat mirror.

PROBLEM A man 1.80 m tall stands in front of a mirror and sees his full height, no more and no less. If his eyes are 0.14 m from the top of his head, what is the minimum height of the mirror?

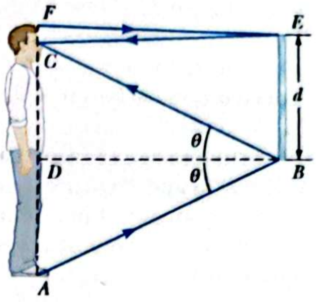


Figure 23.4 (Example 23.1)

STRATEGY Figure 23.4 shows two rays of light, one from the man's feet and the other from the top of his head, reflecting off the mirror and entering his eye. The ray from his feet just strikes the bottom of the mirror, so if the mirror were longer, it would be too long, and if shorter, the ray would not be reflected. The angle of incidence and the angle of reflection are equal, labeled θ. This means the two triangles, *ABD* and *DBC*, are identical because they are right triangles with a common side (*DB*) and two identical angles θ. Use this key fact and the small isosceles triangle *FEC* to solve the problem.

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SOLUTION

We need to find *BE*, which equals *d*. Relate this length to lengths on the man's body:

(1) $BE = DC + \frac{1}{2}CF$

We need the lengths *DC* and *CF*. Set the sum of sides opposite the identical angles θ equal to *AC*:

AF CF

(2) $AD + DC = AC = (1.80 - 0.14) = 1.66\text{ m}$

$AD = DC$, so substitute into Equation (2) and solve for DC:

$AD + DC = 2DC = 1.66\text{ m} \rightarrow DC = 0.83\text{ m}$

CF is given as 0.14 m. Substitute this value and *DC* into Equation (1):

$BE = d = DC + \frac{1}{2}CF = 0.83\text{ m} + \frac{1}{2}(0.14\text{ m}) = 0.90\text{ m}$

REMARKS The mirror must be exactly equal to half the height of the man for him to see only his full height and nothing more or less. Notice that the answer doesn't depend on his distance from the mirror.

QUESTION 23.1 Would a taller man be able to see his full height in the same mirror?

EXERCISE 23.1 How large should the mirror be if he wants to see only the upper third of his body?

ANSWER 0.30 m

AF = 1.8 ÷ 3 = 0.60 ⟹ AC = 0.60 − 0.14 = 0.46 m ∴ DC = 0.23
∴ BE = 0.23 + ½(0.14) = 0.30 m

APPLICATION
Day and Night Settings for Rearview Mirrors

Most rearview mirrors in cars have a day setting and a night setting. The night setting greatly diminishes the intensity of the image so that lights from trailing cars will not blind the driver. To understand how such a mirror works, consider Figure 23.5. The mirror is a wedge of glass with a reflecting metallic coating on the back side. When the mirror is in the day setting, as in Figure 23.5a, light from an object behind the car strikes the mirror at point 1. Most of the light enters the wedge, is refracted, and reflects from the back of the mirror to return to the front

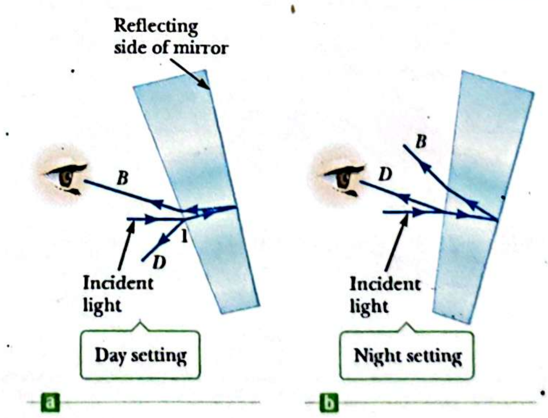


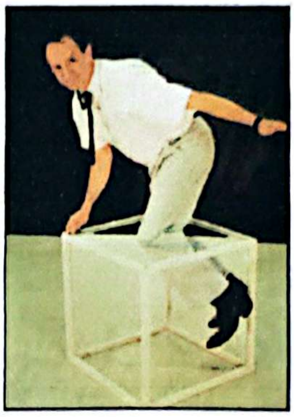
Figure 23.5 Cross-sectional views of a rearview mirror. (a) With the day setting, the silvered back surface of the mirror reflects a bright ray *B* into the driver's eyes. (b) With the night setting, the glass of the unsilvered front surface of the mirror reflects a dim ray *D* into the driver's eyes.

surface, where it is refracted again as it reenters the air as ray *B* (for *bright*). In addition, a small portion of the light is reflected at the front surface, as indicated by ray *D* (for *dim*). This dim reflected light is responsible for the image observed when the mirror is in the night setting, as in Figure 23.5b. Now the wedge is rotated so that the path followed by the bright light (ray *B*) doesn't lead to the eye. Instead, the dim light reflected from the front surface travels to the eye, and the brightness of trailing headlights doesn't become a hazard.

APPLYING PHYSICS 23.1 Illusionist's Trick

The professor in the box shown in Figure 23.6 appears to be balancing himself on a few fingers with both of his feet elevated from the floor. He can maintain this position for a long time, and appears to defy gravity. How do you suppose this illusion was created?

EXPLANATION This trick is an example of an optical illusion, used by magicians, that makes use of a mirror. The box the professor is standing in is a cubical open frame that contains a flat, vertical mirror through a diagonal plane. The professor straddles the mirror so that one leg is in front of the mirror and the other leg is behind it, out of view. When he raises his front leg, that leg's reflection rises also, making it appear both his feet are off the ground, creating the illusion that he's floating in the air. In fact, he supports himself with the leg behind the mirror, which remains in contact with the ground. ■



Courtesy of Henry Leap and Jim Lehman

Figure 23.6 (Applying Physics 23.1)

23.2 Images Formed by Concave Mirrors

A **spherical mirror**, as its name implies, has the shape of a segment of a sphere. Figure 23.7 shows a spherical mirror with a silvered inner, concave surface; this type of mirror is called a **concave mirror**. The mirror has radius of curvature *R*, and its center of curvature is at point *C*. Point *V* is the center of the spherical segment, and a line drawn from *C* to *V* is called the **principal axis** of the mirror.

Now consider a point source of light placed at point *O* in Figure 23.7b, on the principal axis and outside point *C*. Several diverging rays originating at *O* are shown. After reflecting from the mirror, these rays converge to meet at *I*, called the **image point**. The rays then continue and diverge from *I* as if there were an object there. As a result, a real image is formed. **Whenever reflected light actually passes through a point, the image formed there is real.**

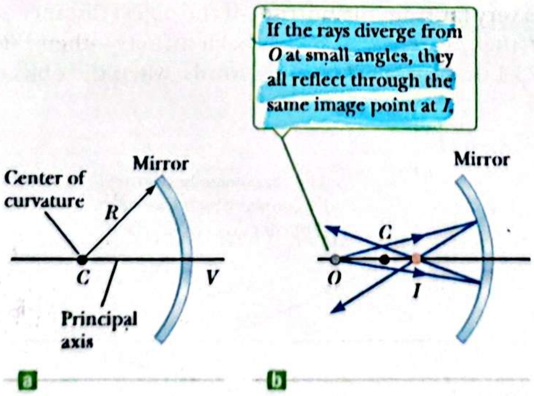


Figure 23.7 (a) A concave mirror of radius *R*. The center of curvature, *C*, is located on the principal axis. (b) A point object placed at *O* in front of a concave spherical mirror of radius *R*, where *O* is any point on the principal axis farther than *R* from the surface of the mirror, forms a real image at *I*.