Answer to Essential Question 23.1: To explain the formation of your own shadow on a sunny day, we can treat the Sun as a point source located 150 million km away. On the other hand, the shadow that the Earth casts on the Moon during a lunar eclipse has a very dark region (the umbra) and a semi-dark region (the penumbra). This more complex shadow pattern can be partly explained by treating the Sun as a distributed source.

23-2 The Law of Reflection; Plane Mirrors

A ray of light that reflects from a surface obeys a very simple rule, known as the law of reflection. See, also, the illustrations in Figure 23.7.

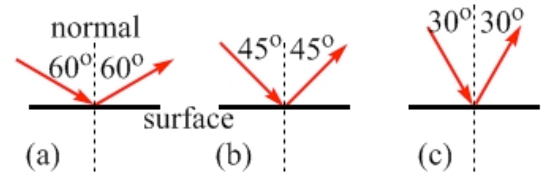

Figure 23.7: In each case, the ray obeys the Law of Reflection, in that the angle of incidence, measured from the normal, is equal to the angle of reflection. In the specific examples shown, both the incident ray and the reflected ray are at an angle, measured from the normal, of (a) 60°, (b) 45°, and (c) 30°.

The Law of Reflection: for a ray of light reflecting from a surface, the angle of incidence is equal to the angle of reflection. These angles are generally measured from the normal (perpendicular) to the surface.

A surface acts as a mirror when the law of reflection is followed on a large scale, as shown in Figure 23.8 (a). In that case, the whole beam of light, with many parallel rays, reflects as expected according to the law. This is known as **specular reflection**: mirror-like reflection that preserves the wave-front structure. In Figure 23.8 (b), however, the surface does not seem to obey the law of reflection. If we look at the magnified view, in (c), however, we see that the surface is irregular. The law of reflection is obeyed for each ray individually, but the irregularities in the surface cause the rays to move off in many different directions after being reflected. This is known as **diffuse reflection**: reflection in which the wave fronts are not preserved. Diffuse reflection explains why some surfaces that appear to be flat, such as a table or a road, do not act as mirrors. As far as light is concerned, these surfaces are far from flat.

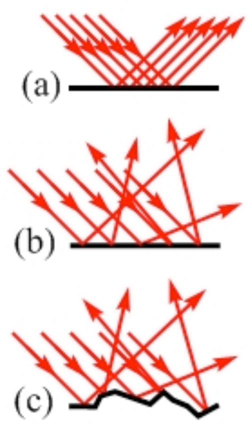

Figure 23.8: (a) Specular reflection from a flat mirror, in which all rays reflect at the same angle. (b) Many flat surfaces exhibit diffuse reflection, in which rays reflect at different angles. (c) A magnified view of the situation in (b). Even though the surface may appear flat to us, the surface is actually quite irregular as far as light is concerned.

The surface in Figure 23.8(a) is known as a plane mirror. Common examples are the mirrors in every bathroom. When we look at ourselves in such a mirror, where do we see our image? How large is the image? To answer such questions, we can use a ray diagram to determine where an image is formed and what its characteristics are.

EXPLORATION 23.2 – Using a ray diagram to find the location of an image

Step 1 – ***An arrow is placed in front of a vertical plane mirror, as shown in Figure 23.9. Sketch two rays of light, which travel in different directions, that leave the tip of the arrow and reflect off the mirror. Show the direction of these rays after they reflect from the mirror.***

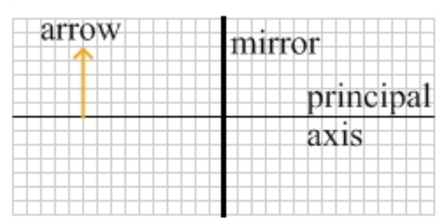

Figure 23.9: An arrow located some distance in front of a plane mirror.

Figure 23.10 shows a number of rays leaving the arrow and reflecting from the mirror, obeying the law of reflection. One of these, the horizontal ray, in red, that strikes the mirror at a 0° angle of incidence (measured from the normal to the mirror) is special, in that it reflects back along the path the ray came in on, and is thus easy to draw. However, you do not need to use this particular ray in the ray diagram – any two rays of light that reflect from the mirror can be used.

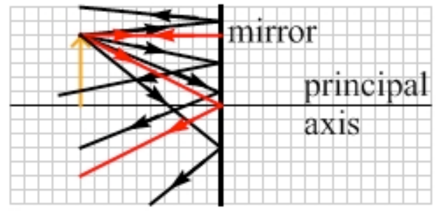

Figure 23.10: A selection of reflected rays. In each case, the reflected rays are drawn in the direction that is consistent with the law of reflection.

Step 2 – *The point where the reflected rays meet is where the tip of the image is located. Sketch the image of the arrow.* The reflected rays diverge as they travel away from the mirror to the left, but if we extend the reflected rays back through the mirror to the right, we find a point where they intersect. This is where the image of the tip of the arrow is located. Note that all the reflected rays, when they are extended back, pass through this point, which is why we can use any two reflected rays to create the ray diagram. Because the base of the arrow, which we call the object, is located on the principal axis (the horizontal line bisecting the mirror), we know that the base of the image will also be located there, so we draw an image of the arrow between the point where the image of the tip is and the principal axis.

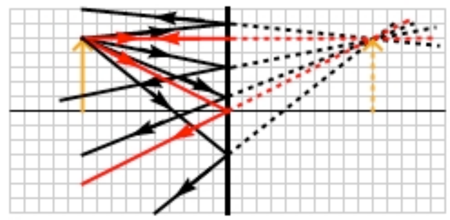

Figure 23.11: For a plane mirror, the reflected rays must be extended back through the mirror to find the location where they meet. Because the rays left the tip of the arrow, the point where the reflected rays meet is the location of the tip of the image of the arrow.

Step 3 – *Prove that the image is located as shown in Figure 23.11 by drawing two more ray diagrams, one showing the location of the image of the midpoint of the arrow, and one showing the location of the image of the base (bottom) of the arrow.* Figure 23.12 combines the ray diagram for the tip with those of the arrow's base and midpoint, showing that the image really is at the location shown in Figure 23.11.

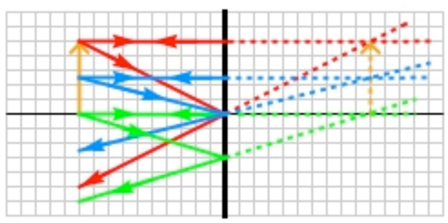

Figure 23.12: No matter which point on the object the rays start from, the reflected rays can be extended back to meet to the right of the mirror.

Step 4 – *Compare the reflected rays in Figure 23.12 to the rays in Figure 23.6.* Our brains cannot tell the difference between the two situations, which is why we see an image of the arrow formed at the location shown in Figure 23.13.

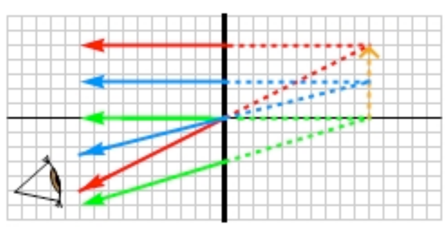

Figure 23.13: Our brains trace the reflected rays back along straight lines until they meet, and we see an image at that location.

Key idea for ray diagrams: The location of the image of any point on an object, when the image is created by a mirror, can be found by drawing rays of light that leave that point on the object and reflect from the mirror. The direction of the reflected rays must be consistent with the law of reflection. The point where the reflected rays meet is where the image of that point is.
Related End-of-Chapter Exercises: 1, 2, 5, 14.

Essential Question 23.2: First, make a prediction. When the arrow in Exploration 23.2 is moved closer to the mirror, will its image be larger, smaller, or the same size as the image we found in Step 2 above? Sketch a new ray diagram to check your prediction.