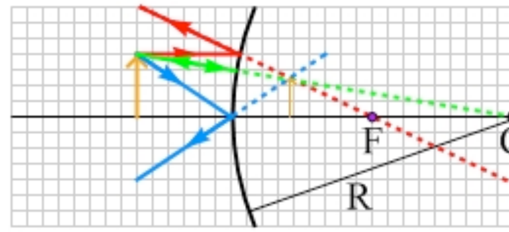

Figure 23.20: The new ray diagram shows that moving the object closer to the mirror results in the image increasing in size (but remaining smaller than the object) and moving closer to the surface of the mirror.

Answer to Essential Question 23.3: (a) The parallel ray is nice to work with, because its reflection does not change direction when the object is moved left or right. The ray that strikes the mirror at the principal axis, however, comes in at a larger angle of incidence, and thus reflects at a larger angle. As shown in Figure 23.20, when the object is closer to the mirror, the image increases in size and moves closer to the mirror.

(b) We have two ways of knowing how to draw the reflected rays properly. First, the law of reflection must be obeyed when the rays reflect from the mirror. Second, we know that when we extend the reflected rays back, they will pass through the tip of the image, which we located in Figure 23.20. Three additional rays are shown in Figure 23.21.

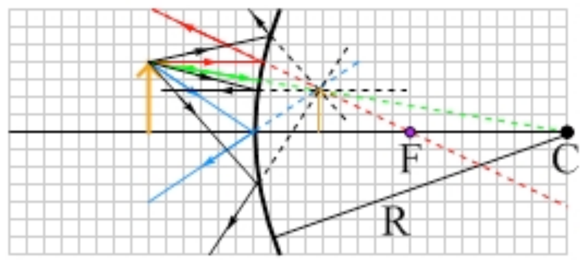

Figure 23.21: For all rays of light that leave the tip of the object and reflect from the mirror, the reflected rays can be extended back to pass through the tip of the image.

23-4 A Qualitative Approach: Image Characteristics

So far, we have looked at ray diagrams in two cases, the case of a plane mirror (section 23-2) and that of a convex mirror (section 23-3). In both cases, we had to extend the reflected rays back through the mirror to get the rays to intersect, giving us an image behind the mirror. We see this all the time with plane mirrors. If you stand 1.0 m in front of a plane mirror, you see an image of yourself 1.0 m behind the mirror. Is it always true that the image created by a mirror is located behind the mirror? We will first investigate the concave mirror, the last case we will deal with, and we will then summarize various image characteristics.

EXAMPLE 23.4 – A ray diagram for a concave mirror
An object, represented by an arrow, is located 15.0 cm in front of a concave mirror that has a focal length of +10.0 cm, as shown in Figure 23.22. Sketch a ray diagram to find the location of the tip of the image of the arrow, and sketch the image on the diagram.

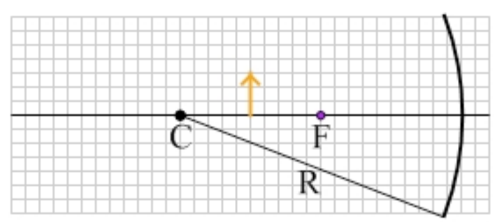

Figure 23.22: An object in front of a concave mirror. The squares in the grid measure 1.0 cm × 1.0 cm.

SOLUTION

Let's use the same procedure we have used previously, starting by drawing rays of light that leave the tip of the object. Again, one useful ray, shown in red, is the ray that travels parallel to the principal axis. The concave mirror reflects this ray so that it passes through the mirror's focal point. A second ray that we know how to draw is the one, in blue, that reflects from the mirror at the principal axis, reflecting at that point as if the mirror were a vertical plane mirror. Note that these two rays meet to the left of the mirror, giving us the location of the tip of the image. As usual, we draw the image of the arrow from that point to the principal axis, because the base of the object is also on the principal axis.

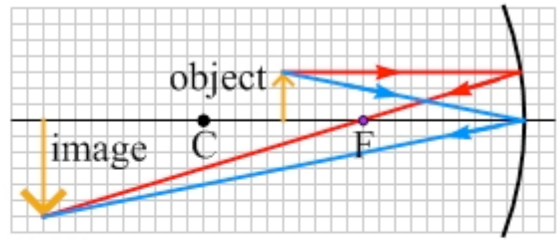

Figure 23.23: A ray diagram showing two of the several possible rays we can draw to locate the tip of the image.

Wave fronts

Figure 23.24 shows how the converging mirror affects the wave fronts (in purple). The light leaving the tip of the object, reflecting from the mirror, and arriving at the tip of the image, takes the same time no matter which path it takes.

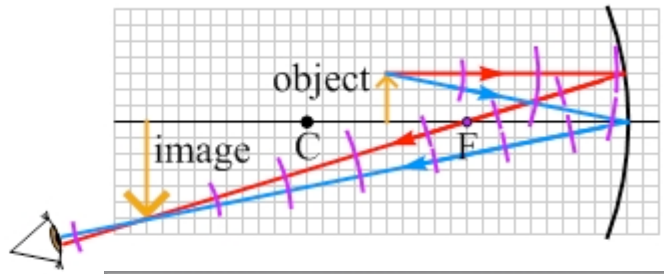

Figure 23.24: The wave fronts that leave the tip of the object converge on the tip of the image – the rays take the same time to reach the image. The wave fronts then diverge away from the image. To your brain, the image looks like an object.

Image characteristics

The image in Figure 23.23 is quite different from images we have seen earlier in the chapter. First, the image is inverted (upside down) compared to the object. Second, the image is larger than the object. Third, the image is formed from light rays that actually pass through the image. Note that concave mirrors do not always form images with these characteristics, as we will investigate in more detail in section 23-6. For now, however, let's discuss some general issues related to image characteristics.

Upright or inverted?

As we have seen, plane mirrors and convex mirrors produce an upright image. This is an image that is in the same orientation as the object. An inverted image, like that in Example 23.4, is one in which the image is upside down in relation to the object.

Real or virtual?

Most of the images we see on a daily basis in mirrors are virtual. A virtual image is one that the light does not actually pass through. Instead, our brains see an image there because, when we look in the mirror at the object, our brains are so used to light traveling in straight lines that we trace all the reflected rays back to their apparent source, the point behind the mirror where the light appears to come from. For a single mirror, when the image is virtual it is also upright.

In Example 23.4, we saw a situation in which the light rays passed through the mirror, creating a real image. Real images, from concave mirrors, have a three-dimensional quality that virtual images do not have, and it is worth going out of your way to see one. For a single mirror, when the image is real it is also inverted.

Larger or smaller?

A plane mirror, as we investigated earlier, produces an image that is always the same size as the object. Convex (diverging) mirrors, on the other hand, always produce an image that is smaller than the object. Concave (converging) mirrors, as we will investigate further in section 23-6, can produce an image that is larger, smaller, or the same size as the object. We will discuss these ideas in a more quantitative way when we define the magnification of a mirror, in section 23-5.

Related End-of-Chapter Exercises: 7, 11, 12.

Essential Question 23.4: Consider the ray diagram in Figure 23.23. If an object of the same size of the image was placed at the image's position, where would its image be located?