CONCEPTUAL QUESTIONS

1. **REASONING AND SOLUTION** A sign painted on a store window is reversed when viewed from inside the store. A person inside the store views the sign in a plane mirror. As discussed in the text, the image of an object formed in a plane mirror is upright, has the same size as the object, is located as far behind the mirror as the object is in front of it, and is reversed left to right. Therefore, since the image is reversed left to right, the image of the sign painted on the store window, when viewed in a plane mirror in the store, will appear as it does when viewed from outside the store.

2. **REASONING AND SOLUTION** As discussed in the text, the image of an object formed in a plane mirror is reversed left to right. If a clock is held in front of a mirror, its image is reversed left to right, but not up and down. In order to understand the appearance of the image of the second hand, as viewed by a person looking into the mirror, imagine replacing the second hand by a rotating vector that always points away from its rotation axis. At any instant, this vector can be resolved into horizontal and vertical components. Since the image is reversed left to right, the image of the horizontal component will be reversed in direction. In contrast, since the image is *not reversed* up and down, the image of the vertical component will point in the same direction as the object. Therefore, when the horizontal and vertical components of the image are combined, the resultant will rotate *counterclockwise*. Thus, from the point of view of a person looking into the mirror, the image of the second hand of the clock rotates in the counterclockwise direction.

3. **REASONING AND SOLUTION** When parallel rays of light strike a concave mirror, they are reflected; these reflected rays converge at the focal point of the mirror. When parallel rays of light strike a convex mirror, they are also reflected; these reflected rays diverge from the mirror’s surface and appear to originate from the focal point located behind the mirror.

   a. The earth-sun distance is very large; therefore, when rays of light from the sun reach the earth, they are essentially parallel. If it is desired to start a fire with sunlight, it is necessary to focus the parallel light rays from the sun on a very small area, preferably a point, on the piece of paper. Since a concave mirror reflects parallel rays so that they converge in front of the mirror, a concave mirror, rather than a convex mirror, should be used.

   b. For best results, the piece of paper should be placed at the focal point of the mirror since this is the location where the rays converge to a point and the heating would be greatest.

4. **REASONING AND SOLUTION** The photograph in the text shows an experimental device at Sandia National laboratories in New Mexico. The device is a mirror that focuses sunlight to heat sodium to a boil.
a. The earth-sun distance is very large; therefore, when rays of sunlight reach the earth, they are essentially parallel. A concave mirror reflects parallel rays of light so that the reflected rays converge at the focal point of the mirror. It is reasonable to conclude, therefore, that the mirror in the photograph is a concave mirror.

b. Since the rays of light converge at the focal point of the mirror, it is reasonable to conclude that the sodium unit is located at the mirror's focal point. Therefore, the distance between the mirror and the sodium unit is equal to the focal length of the mirror.

5. **REASONING AND SOLUTION** When parallel rays of light strike a concave mirror, they are reflected. For rays that lie close to the principal axis of the mirror, these rays will converge at a single point, namely the focal point of the mirror. Rays that are far from the principal axis do not converge to a single point after reflection. Each reflected ray obeys the law of reflection; namely, the angle of reflection, as measured with respect to the normal to the surface, is equal to the angle of incidence. Since the reflecting surface is spherical, the direction of the lines that are normal to the surface varies from point to point; however, they are directed radially with respect to the center of the "sphere." Rays that are farther from the principal axis have greater angles of incidence and greater angles of reflection. Therefore, when such rays reflect, they cross the principal axis to the right of the focal point $F$ in Figure 25.14. The top ray in this drawing could be directed through the focal point if the angle of reflection, and therefore, the angle of incidence were decreased. This can be accomplished by changing the shape of the mirror so that the line normal to the surface at the point of incidence is rotated upward as shown in the figure below.

![Spherical Concave mirror and Reshaped mirror](image)

Therefore, to bring the top ray closer to the focal point, the mirror must be "opened up" to produce a more gently curving surface.

6. **REASONING AND SOLUTION**
   a. For a real image, light rays actually pass through the points on the image. Such an image can be projected onto a screen directly. This can be accomplished by placing the screen at the location of the image. If the object is placed between the focal point and the center of curvature of a concave mirror, a real image is formed beyond the center of curvature. The real image is enlarged and inverted (see
Figure 25.19a). If the object is placed beyond the center of curvature, a real image is formed between the center of curvature and the focal point. This real image is reduced in size and inverted with respect to the object (see Figure 25.19b). In these cases, the image is real; therefore, it can be projected directly onto a screen (placed at the location of the image) without the help of other mirrors or lenses.

If, however, the object is placed between the focal point and the concave mirror, an enlarged, upright virtual image is produced (see Figure 25.20a). The image is behind the mirror and cannot be projected directly onto a screen without the help of other optical components.

b. A convex mirror always produces a virtual image that is behind the mirror; therefore the image cannot be projected directly onto a screen without the help of other optical components.

7. **REASONING AND SOLUTION**

a. The back side of a shiny teaspoon acts like a convex mirror. When an object is placed in front of a convex mirror, a virtual image is produced that is reduced in size and upright, as shown in Figure 25.22. Thus, when you look at the back side of a shiny teaspoon held at arms length, you will see yourself upright.

b. The concave side of a shiny teaspoon acts like a concave mirror. If the teaspoon is held at arm's length, then you (the object) are farther from the reflecting surface than the center of curvature of the surface. The situation is similar to that of an object located beyond the center of curvature of a concave mirror. A real image is formed that is reduced in size and inverted with respect to the object, as shown in Figure 25.19b. Therefore, when you look at the concave side of a shiny teaspoon, you will see yourself upside down.

8. **REASONING AND SOLUTION** If you stand between two parallel plane mirrors, you see an infinite number of images of yourself. This occurs because an image in one mirror is reflected in the other mirror to produce another image, which is then re-reflected, and so-forth. The multiple images are equally spaced.

The image produced by a convex mirror is reduced in size relative to the object. Like a plane mirror, the image is virtual and lies behind the mirror; however, the virtual image in a convex mirror is closer to the mirror than it would be if the mirror were planar. If you stand facing a convex mirror, with a plane mirror behind you, you will see an infinite number of images of yourself, as you do in the case of two parallel plane mirrors. The reason is that the first image in the convex mirror is reflected in the plane mirror, to produce an identical image behind it. The image behind the plane mirror is re-reflected in the convex mirror to produce another smaller image closer to the focal point of the convex mirror. This second image in the convex mirror is smaller than the first one, because the image behind the plane mirror is farther from the convex mirror than you are. Further reflections and re-reflections occur, leading to a series of images in the convex mirror that decrease in size as they occur closer and closer to the focal point. The images "pile up" so to speak, becoming closer and closer together as they approach the focal point. The size of the image becomes zero at the focal point. Thus, the series of images appears to vanish at the focal point of the convex mirror.
9. **REASONING AND SOLUTION**  The microphone arrangement shown in the figure is used to pick up weak sounds. It consists of a "hollowed-out" shell behind the mike. The shell acts like a mirror for sound waves. Therefore, when parallel rays of sound hit the inside surface of the shell, they will be reflected from it. Since the shell is concave, the reflected rays will converge at the focal point of the shell. Presumably, weak sounds will originate far from the microphone; therefore, when the they reach the microphone arrangement, these rays will be essentially parallel to the principal axis of the shell. Since the reflected rays will converge at the focal point, the microphone should be located at the focal point to detect them optimally.

10. **REASONING AND SOLUTION**  When you see the image of yourself formed by a mirror, it is because (1) light rays actually coming from a real image enter your eyes or (2) light rays appearing to come from a virtual image enter your eyes. If the light rays from the image do not enter your eyes, you do not see yourself.

   a. If you stand in front of a convex mirror on its principal axis, your virtual image is behind the mirror. The image will be reduced in size and upright regardless of your location. You will be able to see yourself at any location on the principal axis when you are in front of a convex mirror, because rays that appear to come from this image can enter your eyes.

   b. If you stand in front of a concave mirror on its principal axis, and you are beyond the center of curvature of the mirror, you will see a real image of yourself that is inverted and reduced in size relative to your size and orientation (Figure 25.19b). If you stand between the mirror and its focal point, you will see a virtual image of yourself that is upright and enlarged in size (Figure 25.20). In the former case, rays emanating from the real image can reach your eyes. In the latter case, rays that appear to emanate from the virtual image can reach your eyes.

   When you stand on the principal axis of a concave mirror so that you are between the center of curvature and the focal point of the mirror, the image is formed beyond the center of curvature (Figure 25.19a). You cannot see this image, because it is behind you.

11. **REASONING AND SOLUTION**  Plane mirrors and convex mirrors form virtual images. With a plane mirror, the image may be infinitely far behind the mirror, depending on where the object is located in front of the mirror.

   For an object in front of a single convex mirror, the greatest distance behind the mirror at which the image can be found is equal to the magnitude of the focal length of the mirror. This can be confirmed using the mirror equation (Equation 25.3): \[ \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \], where \( f \) is taken to be a negative number because the mirror is a convex mirror. The largest image distance occurs when the object is at infinity. Then \( \frac{1}{d_o} = \frac{1}{\infty} = 0 \), and the mirror equation gives \( d_i = f \). Since \( f \) is a negative number, \( d_i \) is a negative number, indicating that the image is behind the mirror. Therefore, the image will never be located beyond the focal point, behind the mirror.

12. **REASONING AND SOLUTION**  As shown in Figure 25.22, an object placed in front of a convex mirror produces a virtual image behind the mirror that is reduced in size and is upright in orientation for all object distances. Therefore, it is not possible to use a convex mirror to produce an image that is larger than the object.
13. **REASONING AND SOLUTION**  Suppose you stand in front of a spherical mirror (concave or convex). As shown in Figures 25.19 and 25.20, a concave mirror can form a real, inverted image (Figures 25.19a and 25.19b) or a virtual, upright image (Figure 25.20). As shown in Figure 25.22, a convex mirror can only form a virtual, upright image.

a. Therefore, it is not possible for your image to be real and upright.

b. Similarly, it is not possible for your image to be virtual and inverted.