CHAPTER 34
GEOMETRIC OPTICS

Discussion Questions

Q34.1 Each section of a spherical mirror forms the entire image. The image formed by the bottom half of the mirror will be formed at the same location as the image formed by the mirror before it was cut in half. The only difference is that the image will be less intense (dimmer) because half as much light is reflected by half the mirror.

Q34.2 The image is on the side of the interface where the light comes from so the image is virtual and s' is negative.

Q34.3 The concave surface acts as a converging mirror for the waves and focuses the light to form the desired real image at the receiver. The image of the very distant object is at the focal point of the surface. The receiver should be a distance $f = R/2$ from the vertex of the surface.

Q34.4 $f = R/2$. For a flat surface $R \to \infty$ so $f \to \infty$. For a very distant object the image is very far from the mirror, corresponding to a focal point very far from the mirror. Rays incident parallel to the normal to the mirror are reflected parallel to the normal.

Q34.5 The focal length of the mirror follows from the curvature of the mirror and the laws of reflection. The law of reflection is independent of the wavelength of the light and the focal length doesn't change when the mirror is immersed in water.

Q34.6 $s' = sf/(s-f)$. For a real image $s' > 0$. For real objects, concave mirrors ($f > 0$) form real images when $s > f$. For real objects, convex mirrors ($f < 0$) never form real images.

Q34.7 Each image formed by one mirror serves as the object for the other mirror. At each reflection not all the light is reflected, so the more reflections to form an image the dimmer that image.

Q34.8 For $s = f$, a point object at the focal point of the mirror, the reflected rays are parallel to the mirror axis and no image is formed. The rays neither converge to a real image nor appear to diverge from a virtual image behind the mirror. For $s > f$, as s approaches f the real image becomes farther and farther from the mirror and becomes larger and larger. The image is large but it is also far away; its angular size is the same as the angular size relative to the mirror of the object. For $s < f$, as s approaches f the virtual image becomes farther and farther from the mirror and becomes larger and larger.

Q34.9 The mirror forms a virtual image that is smaller than the object. The purpose of the mirror is to allow you to see a wide area behind you, for safety. A concave mirror could also form a reduced image, for object distances greater than twice the focal of the mirror. But such images are real and therefore inverted, which is not desirable. The focal length is determined so that the desired viewing area has an image size that fits on the mirror surface.

Q34.10 Yes, a real image of the sun is formed at the focal point of the concave mirror. Rays are focused here and the image is bright. A convex mirror diverges the rays and doesn't focus them at a point; it doesn't work with a convex mirror.

Q34.11 If his face's distance s from the vertex of the surface is greater than $R/2$, where R is the radius of curvature of the spoon, the person sees a real, inverted image. For $s < R/2$ the image is upright. The convex side forms virtual, upright images no matter how far his face is from the spoon.

Q34.12 For s exactly equal to f the reflected rays are parallel to the axis and there is no image formed. For $s > f$, as s approaches f the real image gets larger and larger and farther and farther from the mirror. s' is positive and gets larger and larger as $s \to f$. For $s < f$, as s approaches f the virtual image gets larger and larger and farther and farther from the mirror. s' is negative and its magnitude gets larger and larger as $s \to f$.

Q34.13 $m = +1$ is a statement about the lateral magnification. $m = +1$ says that the object PQ has the same length as the image $P'Q'$, and this is what Fig.34.26 shows. The difference in length of the vertical arrow and its image refers to the longitudinal magnification. The longitudinal magnification for refraction at a plane refracting surface is not $m = +1$.

Q34.14 Yes. The mirror forms a reduced image so the car appears to be farther away than its actual distance.

Q34.15 Take a piece of paper and move the paper until the image of a distant object, such as the sun is focused on the paper. Then the distance between the lens and the paper is the focal length of the lens. The virtual image formed by a diverging lens cannot be focused onto a piece of paper, so this method cannot be used for a diverging lens.

Q34.16 The focal length of a thin lens is given by Eq.(34.19). The refractive index n of the lens material depends on the wavelength of the light and this causes f to depend on the wavelength. But the factor $n-1$ is always greater than zero so f has the same sign for all wavelengths.

Q34.17 When the lens is in water rather than in air the refractive indices of the lens and surrounding material are closer in value than when the lens is in air. Therefore, light is bent less when it enters and exits the lens and the focal length is greater when the lens is in water. (See Problem 34.92.)

Q34.18 A spherical drop of water acts as a converging lens and $|f|$ is proportional to the radius of curvature of the drop; a small radius gives a small focal length. For an air bubble the role of the two refractive indices, air and water, are reversed and the air bubble acts as a diverging lens. The magnitude of its focal length increases when its radius increases. A detailed analysis can be carried out by treating refraction as light enters and leaves the bubble. The bubble cannot be treated as a thin lens because the distance between the two surfaces where refraction occurs is not small compared to the radius of these surfaces.

Q34.19 Yes. This is discussed in the textbook at the end of Section 34.1 and this principle is used in Section 34.4 in the derivation of the lensmaker's equation. It doesn't matter if the first image is real or virtual. The concept of a first image is a convenient way to describe the direction the rays are traveling, either from or toward a real image or appearing to come from a virtual image, when they reach the second surface.

Q34.20 The rays of light do not converge at a virtual image but instead seem to come from a virtual image, so a virtual image cannot be projected onto film. But a virtual image can be photographed with a camera, just as an object or real image can be photographed by letting light from the object or image enter the camera lens. A simple example is a photograph of an image in a plane mirror.

Q34.21 All the formulas are the same if the image and object are interchanged. n_a and n_b must be interchanged and also y and y' in $m = y'/y$. Reversibility requires that the formulas be unchanged by the interchange of image and object.

Q34.22 A simple refracting telescope uses two converging lenses. The lens for the eyepiece should have a large focal length and the lens for the eyepiece needs to have a short focal length. Converging lenses will focus sunlight to a sharp point on the ground and a diverging lens won’t. The distance from the lens to the ground when the sunlight is sharply focused on the ground is the focal length of the lens.

Q34.23 Water on one side of the eye affects the refracting property of the eye. An image focused on the retina when air is on the outside of the eye is not focused when the air is replaced by water. Yes, you could wear eyeglasses that correct your underwater vision. The water has a refractive index closer to that of the eye so reduces the bending of the light as it enters the eye. To compensate for this you should use converging lenses in the eyeglasses.

Q34.24 Each section of a lens forms the entire image. The image formed by the bottom half of the lens will be identical in location, size and orientation to the image formed by the full lens. The only difference is that the image will be less intense (dimmer) because half as much light passes through the masked lens.