

## Phys.12-Q3W2-Refraction-Qs.Bank

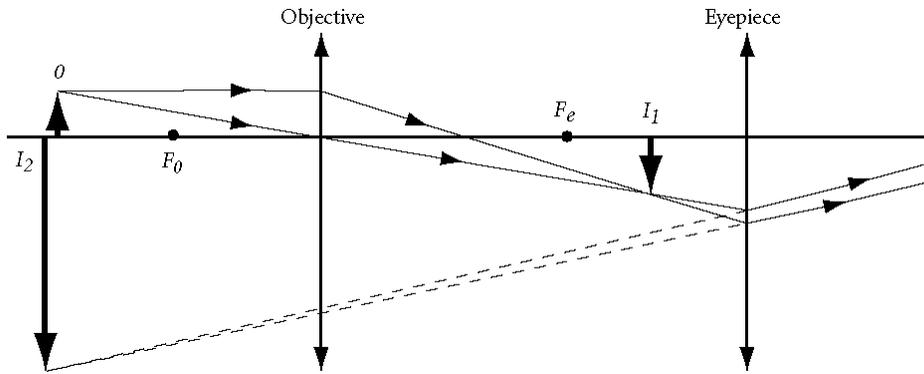
### Multiple Choice

Identify the choice that best completes the statement or answers the question.

- \_\_\_ 1. Part of a pencil that is placed in a glass of water appears bent in relation to the part of the pencil that extends out of the water. What is this phenomenon called?
- interference
  - refraction
  - diffraction
  - reflection
- \_\_\_ 2. Refraction is the bending of a wave disturbance as it passes at an angle from one \_\_\_ into another.
- glass
  - medium
  - area
  - boundary
- \_\_\_ 3. Which is an example of refraction?
- A parabolic mirror in a headlight focuses light into a beam.
  - A fish appears closer to the surface of the water than it really is when observed from a riverbank.
  - In a mirror, when you lift your right arm, the left arm of your image is raised.
  - Light is bent slightly around corners.
- \_\_\_ 4. The \_\_\_ of light can change when light is refracted because the medium changes.
- frequency
  - medium
  - wavelength
  - transparency
- \_\_\_ 5. The \_\_\_ of light can change when light is refracted because the velocity changes.
- frequency
  - medium
  - wavelength
  - transparency
- \_\_\_ 6. Light is *not* refracted when it is
- traveling from air into a glass of water at an angle of  $35^\circ$  to the normal.
  - traveling from water into air at an angle of  $35^\circ$  to the normal.
  - striking a wood surface at an angle of  $75^\circ$ .
  - traveling from air into a diamond at an angle of  $45^\circ$ .
- \_\_\_ 7. When light passes at an angle to the normal from one material into another material in which its speed is higher,
- it is bent toward the normal to the surface.
  - it always lies along the normal to the surface.
  - it is unaffected.
  - it is bent away from the normal to the surface.
- \_\_\_ 8. When light passes at an angle to the normal from one material into another material in which its speed is lower,
- it is bent toward the normal to the surface.
  - it always lies along the normal to the surface.
  - it is unaffected.
  - it is bent away from the normal to the surface.
- \_\_\_ 9. When a light ray moves from air into glass, which has a higher index of refraction, its path is
- bent toward the normal.
  - bent away from the normal.
  - parallel to the normal.
  - not bent.
- \_\_\_ 10. When a light ray passes from water ( $n = 1.333$ ) into diamond ( $n = 2.419$ ) at an angle of  $45^\circ$ , its path is
- bent toward the normal.
  - bent away from the normal.
  - parallel to the normal.
  - not bent.

- \_\_\_ 11. When a light ray passes from zircon ( $n = 1.923$ ) into fluorite ( $n = 1.434$ ) at an angle of  $60^\circ$ , its path is
- bent toward the normal.
  - bent away from the normal.
  - parallel to the normal.
  - not bent.
- \_\_\_ 12. A ray of light in air is incident on an air-to-glass boundary at an angle of exactly  $30.0^\circ$  with the normal. If the index of refraction of the glass is 1.65, what is the angle of the refracted ray within the glass with respect to the normal?
- $58.3^\circ$
  - $37.3^\circ$
  - $34.4^\circ$
  - $18.0^\circ$
- \_\_\_ 13. A beam of light in air is incident at an angle of  $35^\circ$  to the surface of a rectangular block of clear plastic ( $n = 1.49$ ). What is the angle of refraction?
- $12^\circ$
  - $23^\circ$
  - $42^\circ$
  - $57^\circ$
- \_\_\_ 14. Carbon tetrachloride ( $n = 1.46$ ) is poured into a container made of crown glass ( $n = 1.52$ ). If a light ray in the glass is incident on the glass-to-liquid boundary and makes an angle of  $30.0^\circ$  with the normal, what is the angle of the corresponding refracted ray with respect to the normal?
- $25.6^\circ$
  - $28.7^\circ$
  - $31.4^\circ$
  - $64.4^\circ$
- \_\_\_ 15. A lapidary cuts a diamond so that the light will refract at an angle of  $17.0^\circ$  to the normal. What is the index of refraction of the diamond when the angle of incidence is  $45.0^\circ$ ?
- 0.41
  - 0.74
  - 1.23
  - 2.42
- \_\_\_ 16. What type of image is formed when rays of light actually intersect?
- real
  - virtual
  - curved
  - projected
- \_\_\_ 17. What type of image does a converging lens produce?
- real
  - virtual
  - real or virtual
  - none of the above
- \_\_\_ 18. In what direction does a parallel ray from an object proceed after passing through a diverging lens?
- The ray passes through the center of curvature,  $C$ .
  - The ray continues parallel to the principal axis.
  - The ray passes through the center of the lens.
  - The ray is directed away from the focal point,  $F$ .
- \_\_\_ 19. In what direction does a focal ray from an object proceed after passing through a converging lens?
- The ray passes through the focal point,  $F$ .
  - The ray passes through the center of the lens.
  - The ray exits the lens parallel to the principal axis.
  - The ray intersects with the center of curvature,  $C$ .
- \_\_\_ 20. In what direction does a focal ray from an object proceed after passing through a diverging lens?
- The ray passes through the focal point,  $F$ .
  - The ray passes through the center of the lens.
  - The ray exits the lens parallel to the principal axis.
  - The ray intersects with the center of curvature,  $C$ .
- \_\_\_ 21. In what direction does a parallel ray from an object proceed after passing through a converging lens?
- The ray passes through the focal point,  $F$ .
  - The ray continues parallel to the principal axis.
  - The ray passes through the center of the lens.
  - The ray is directed away from the focal point,  $F$ .

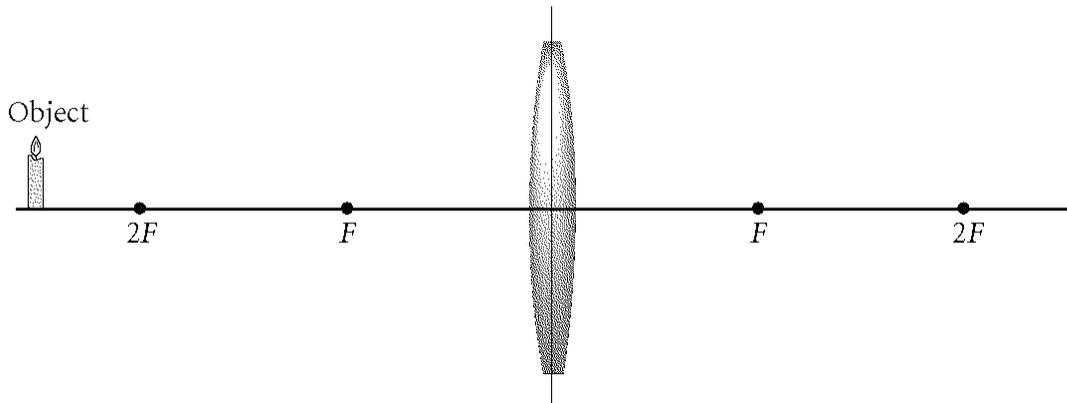




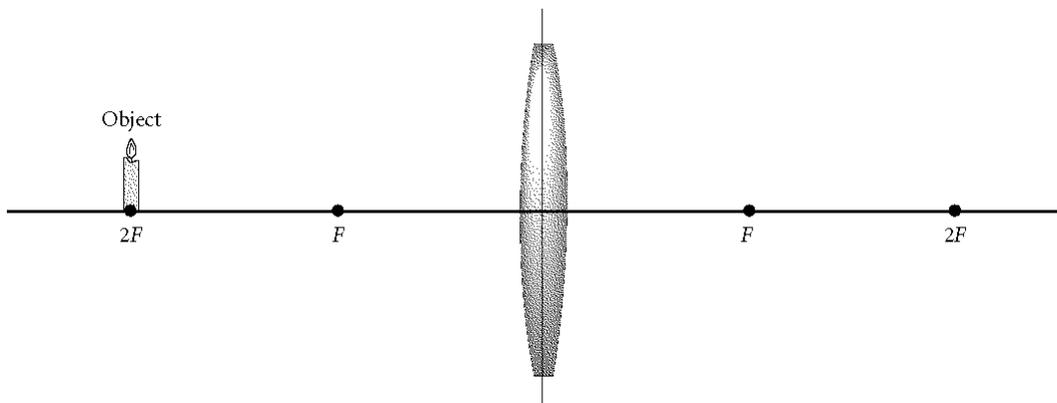
- \_\_\_ 32. In the diagram of a compound microscope shown above, where would you place the slide?
- at  $O$
  - at  $I_2$
  - at  $F_o$
  - at  $I_1$
- \_\_\_ 33. Which of the following describes what will happen to a light ray incident on a glass-to-air boundary at greater than the critical angle?
- total internal reflection
  - total external transmission
  - partial reflection, partial transmission
  - partial reflection, total transmission
- \_\_\_ 34. Atmospheric refraction of light rays is responsible for which of the following effects?
- spherical aberration
  - mirages
  - chromatic aberration
  - total internal reflection in a gemstone
- \_\_\_ 35. If atmospheric refraction did not occur, how would the apparent time of sunrise and sunset be changed?
- Both would be later.
  - Both would be earlier.
  - Sunrise would be later, and sunset would be earlier.
  - Sunrise would be earlier, and sunset would be later.
- \_\_\_ 36. Which is *not* correct when describing the formation of rainbows?
- A rainbow is really spherical in nature.
  - Sunlight is spread into a spectrum when it enters a spherical raindrop.
  - Sunlight is internally reflected on the back side of a raindrop.
  - All wavelengths refract at the same angle.

## Short Answer

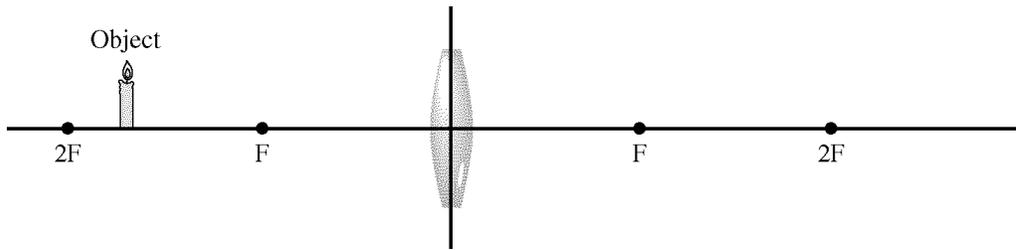
1. When does refraction occur?
2. What happens to the speed of light as it moves into a substance with a higher index of refraction?
3. What type of situation will produce the largest amount of bending when a light ray crosses the boundary between two transparent media?
4. No refraction occurs when a light ray that is parallel to the normal strikes a transparent medium. Use the wave model of light to explain why.
5. What are the two features of light that change when light moves from one transparent medium into another transparent medium?
6. If the angle of incidence is  $65.0^\circ$  and  $n_2 > n_1$ , does a light ray bend toward or away from the normal?
7. A light ray passes from benzene ( $n = 1.501$ ) into ice ( $n = 1.309$ ). Does the light ray bend toward or away from the normal?



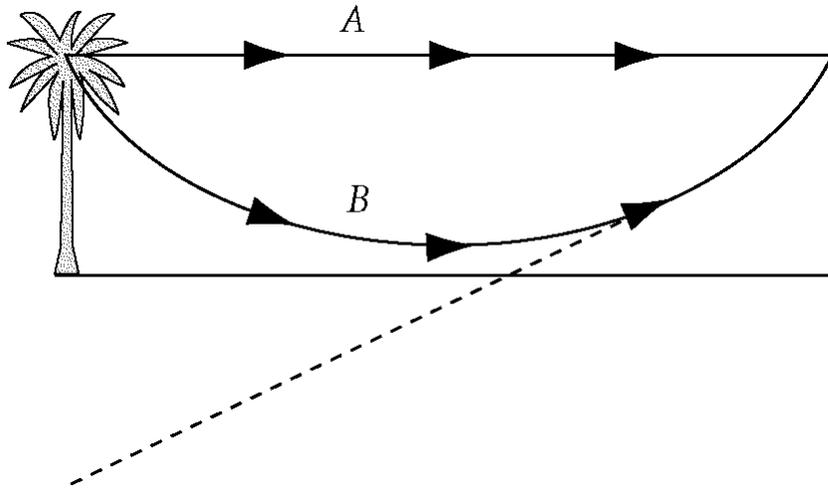
8. What is the position and kind of image produced by the lens shown above? Draw a ray diagram to support your answer.
9. A student burns a hole in a pencil with a magnifying lens. What is the position and kind of image produced by the lens? Draw a ray diagram to support your answer.



10. What is the position and kind of image produced by the lens shown above? Draw a ray diagram to support your answer.



11. What is the position and kind of image produced by the lens shown above? Draw a ray diagram to support your answer.
12. Under what conditions is the thin-lens equation applicable for determining object distance, image distance, and focal length?
13. A real image has a(n) \_\_\_\_\_ image distance ( $p$ ) and is located in \_\_\_\_\_ of the lens.
14. An object is placed 40.0 cm from a converging lens along the axis of the lens. If a virtual image forms at a distance of 50.0 cm from the lens on the same side as the object, what is the focal length of the lens?
15. What does a positive magnification signify?
16. How are two converging lenses used to view an object in a compound microscope?
17. Why is it impossible to see an atom with a compound microscope?
18. In a refracting telescope, why does the eyepiece act as a simple magnifier?
19. In a refracting telescope, is the image upright or inverted? Explain.
20. The critical angle for internal reflection inside a certain transparent material is found to be  $48^\circ$ . If entering light strikes the transparent material with an angle of incidence of  $52^\circ$ , predict how the light will be refracted.
21. What condition must be met before total internal refraction can occur?
22. Why are we able to see the sun in the morning before it actually rises above the horizon?
23. What atmospheric conditions produce a mirage?
24. Why do motorists sometimes see what appear to be wet spots on the road on a dry summer day?



25. Use the figure shown above to describe how a mirage is produced.
26. What is dispersion?
27. How does white light passing through a prism produce a visible spectrum?
28. What does the perceived color of each water droplet in a rainbow depend on?

## Problem

1. A ray of light passes from air into carbon disulfide ( $n = 1.63$ ) at an angle of  $44.1^\circ$  to the normal. What is the refracted angle?
2. A ray of light passes from air into cubic zirconia at an angle of  $46.9^\circ$  to the normal. The angle of refraction is  $19.4^\circ$ . What is the index of refraction of cubic zirconia?
3. A ray of light passes from air ( $n = 1.000$ ) into ice ( $n = 1.314$ ) at an angle of  $23.7^\circ$  to the normal. The refracted ray of light then passes from ice into glycerine ( $n = 1.477$ ). What is the angle of refraction of the ray of light in glycerine?
4. A ray of light passes from air into carbon disulfide ( $n = 1.628$ ) at an angle of  $55.6^\circ$  to the normal. The refracted ray of light then passes from carbon disulfide into water ( $n = 1.333$ ). What is the refracted angle in the water?
5. An object is placed along the principal axis of a thin converging lens that has a focal length of 14 cm. If the distance from the object to the lens is 21 cm, what is the distance from the image to the lens?
6. An object is placed along the principal axis of a thin converging lens that has a focal length of 34 cm. If the distance from the image in front of the lens is 59 cm, what is the distance from the object to the lens?
7. The objective lens of a compound microscope has a focal length of 1.08 cm. A specimen is 1.21 cm from the objective lens. The image formed by the objective lens is 0.154 cm inside the focal point of the eyepiece whose focal length is 1.57 cm. What is the distance from the eyepiece to the image formed by the eyepiece lens?
8. A telescope has an objective lens with a focal length of 49.40 cm. The image formed by the objective lens is 0.36 cm inside the focal point of the eyepiece. Where does the image of the eyepiece appear to be if the focal length of the eyepiece is 14.82 cm?
9. An inverted image 3.8 cm in height is formed in back of a lens. The object used to form the image is 0.54 cm in height. What is the magnification of the image? Is the image real or virtual?
10. A diverging lens has a focal length of 11.2 cm. An insect is placed 9.53 cm in front of the lens. What is the magnification of the image? Describe the image.
11. A converging lens has a focal length of 12.6 cm. If a virtual image of an object is formed 26.8 cm in front of the lens, what is the magnification of the image? Describe the image.
12. A candle that is 13.6 cm high is placed 39.3 cm in front of a diverging lens. The lens has a focal length of 26.1 cm. What is the height of the image?
13. A ray of light travels across a glass-to-liquid interface. The index of refraction is 1.62 for the glass and 1.32 for the liquid. If the light meets the interface at an angle of  $52.7^\circ$ , predict whether the light will refract or whether it will undergo total internal reflection.
14. A fiber-optic cable ( $n = 1.57$ ) is submerged in water ( $n = 1.33$ ). Predict whether light will be refracted or whether it will undergo total internal reflection if the angle of incidence is between  $65^\circ$  and  $70^\circ$ .
15. An optical fiber is made of a clear plastic ( $n = 1.35$ ). Light travels through the fiber at angles ranging from  $45^\circ$  to  $55^\circ$ . Predict whether the light will be refracted or whether it will undergo total internal reflection when the cable is in air.
16. The critical angle of refraction for a certain mineral is  $53.5^\circ$  when it forms a boundary with water ( $n = 1.333$ ). Use this information to determine the speed of light in the mineral.

**Phys.12-Q3W2-Refraction-Qs.Bank**  
**Answer Section**

**MULTIPLE CHOICE**

- |            |        |         |             |
|------------|--------|---------|-------------|
| 1. ANS: B  | PTS: 1 | DIF: I  | OBJ: 14-1.1 |
| 2. ANS: B  | PTS: 1 | DIF: I  | OBJ: 14-1.1 |
| 3. ANS: B  | PTS: 1 | DIF: II | OBJ: 14-1.1 |
| 4. ANS: C  | PTS: 1 | DIF: I  | OBJ: 14-1.1 |
| 5. ANS: C  | PTS: 1 | DIF: II | OBJ: 14-1.1 |
| 6. ANS: C  | PTS: 1 | DIF: I  | OBJ: 14-1.1 |
| 7. ANS: D  | PTS: 1 | DIF: I  | OBJ: 14-1.2 |
| 8. ANS: A  | PTS: 1 | DIF: I  | OBJ: 14-1.2 |
| 9. ANS: A  | PTS: 1 | DIF: II | OBJ: 14-1.2 |
| 10. ANS: A | PTS: 1 | DIF: II | OBJ: 14-1.2 |
| 11. ANS: B | PTS: 1 | DIF: II | OBJ: 14-1.2 |
| 12. ANS: D |        |         |             |

*Given*

$$\theta_i = 30.0^\circ$$

$$n_i = 1.00$$

$$n_r = 1.65$$

*Solution*

Rearrange Snell's law,  $n_i \sin \theta_i = n_r \sin \theta_r$ , and solve for  $\theta_r$ .

$$\theta_r = \sin^{-1} \left[ \frac{n_i}{n_r} (\sin \theta_i) \right] = \sin^{-1} \left[ \frac{1.00}{1.65} (\sin 3.0 \times 10^1) \right] = 18.0^\circ$$

PTS: 1                      DIF: IIIA                      OBJ: 14-1.3

13. ANS: B

*Given*

$$\theta_i = 35^\circ$$

$$n_i = 1.00$$

$$n_r = 1.49$$

*Solution*

Rearrange Snell's law,  $n_i \sin \theta_i = n_r \sin \theta_r$ , and solve for  $\theta_r$ .

$$\theta_r = \sin^{-1} \left[ \frac{n_i}{n_r} (\sin \theta_i) \right] = \sin^{-1} \left[ \frac{1.00}{1.49} (\sin 35^\circ) \right] = 23^\circ$$

PTS: 1                      DIF: IIIA                      OBJ: 14-1.3

14. ANS: C

*Given*

$$\theta_i = 30.0^\circ$$

$$n_i = 1.52$$

$$n_r = 1.46$$

*Solution*

Rearrange Snell's law,  $n_i \sin \theta_i = n_r \sin \theta_r$ , and solve for  $\theta_r$ .

$$\theta_r = \sin^{-1} \left[ \frac{n_i}{n_r} (\sin \theta_i) \right] = \sin^{-1} \left[ \frac{1.52}{1.46} (\sin 30.0^\circ) \right] = 31.4^\circ$$

PTS: 1                      DIF: IIIB                      OBJ: 14-1.3

15. ANS: D

*Given*

$$\theta_r = 17.0^\circ$$

$$\theta_i = 45.0^\circ$$

$$n_i = 1.00$$

*Solution*

Rearrange Snell's law,  $n_i \sin \theta_i = n_r \sin \theta_r$ , and solve for  $n_r$ .

$$n_r = n_i \left[ \frac{(\sin \theta_i)}{(\sin \theta_r)} \right] = (1.00) \left[ \frac{(\sin 45.0^\circ)}{(\sin 17.0^\circ)} \right] = 2.42$$

PTS: 1                      DIF: IIIB                      OBJ: 14-1.3

16. ANS: A                      PTS: 1                      DIF: I                      OBJ: 14-2.1

17. ANS: C                      PTS: 1                      DIF: I                      OBJ: 14-2.1

18. ANS: D                      PTS: 1                      DIF: I                      OBJ: 14-2.1

19. ANS: C                      PTS: 1                      DIF: I                      OBJ: 14-2.1

20. ANS: C                      PTS: 1                      DIF: I                      OBJ: 14-2.1

21. ANS: A                      PTS: 1                      DIF: I                      OBJ: 14-2.1

22. ANS: D                      PTS: 1                      DIF: II                      OBJ: 14-2.1

23. ANS: B                      PTS: 1                      DIF: II                      OBJ: 14-2.1

24. ANS: A                      PTS: 1                      DIF: I                      OBJ: 14-2.1

25. ANS: A                      PTS: 1                      DIF: I                      OBJ: 14-2.2

26. ANS: C                      PTS: 1                      DIF: I                      OBJ: 14-2.2

27. ANS: B                      PTS: 1                      DIF: I                      OBJ: 14-2.2

28. ANS: A

*Given*

$$p = 20.0 \text{ cm}$$

$$q = 8.00 \text{ cm } (q \text{ is positive, since the image is real and behind the lens})$$

*Solution*

Use the thin-lens equation to find  $f$ .

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q} = \frac{1}{20.0 \text{ cm}} + \frac{1}{8.00 \text{ cm}} = \frac{0.0500}{1 \text{ cm}} + \frac{0.125}{1 \text{ cm}} = \frac{0.175}{1 \text{ cm}}$$

$$f = 5.71 \text{ cm}$$

PTS: 1                      DIF: IIIA                      OBJ: 14-2.2

29. ANS: B

*Given*

$$p = 14.0 \text{ cm}$$

$$q = -10.0 \text{ cm} \text{ (} q \text{ is negative, since the image is virtual and in front of the lens)}$$

*Solution*

Use the thin-lens equation to find  $f$ .

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q} = \frac{1}{14.0 \text{ cm}} + \frac{1}{-10.0 \text{ cm}} = \frac{0.0714}{1 \text{ cm}} - \frac{0.100}{1 \text{ cm}} = -\frac{0.029}{1 \text{ cm}}$$

$$f = -34 \text{ cm}$$

PTS: 1                      DIF: IIIA                      OBJ: 14-2.2

30. ANS: A

*Given*

$$h' = 1.51 \text{ m} = 151 \text{ cm}$$

$$p = 4.00 \text{ m}$$

$$h = 1.07 \text{ cm}$$

*Solution*

Use the magnification of a lens equation,  $M = \frac{h'}{h}$ , to find  $M$ .

$$M = \frac{h'}{h} = \frac{(151 \text{ cm})}{(1.07 \text{ cm})} = 141$$

PTS: 1                      DIF: IIIA                      OBJ: 14-2.3

31. ANS: A

*Given*

$$p = 18.0 \text{ cm}$$

$$q = 22.5 \text{ cm} \text{ (} q \text{ is positive, since the image is real)}$$

*Solution*

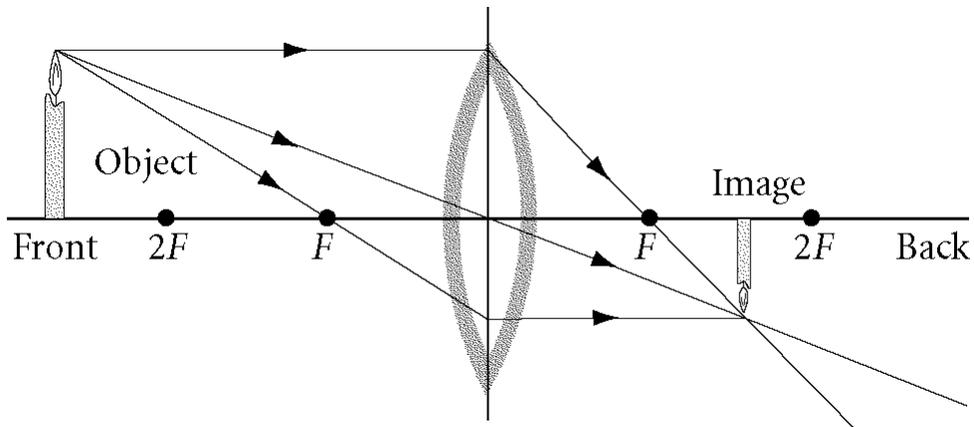
Use the magnification of a lens equation,  $M = -\frac{q}{p}$ , to find  $M$ .

$$M = -\frac{q}{p} = -\frac{(22.5 \text{ cm})}{(18.0 \text{ cm})} = -1.25 \text{ (since } M \text{ is negative, a real, inverted image is formed)}$$

	PTS: 1	DIF: IIIA	OBJ: 14-2.3	
32.	ANS: A	PTS: 1	DIF: I	OBJ: 14-2.4
33.	ANS: A	PTS: 1	DIF: I	OBJ: 14-3.1
34.	ANS: B	PTS: 1	DIF: I	OBJ: 14-3.2
35.	ANS: C	PTS: 1	DIF: II	OBJ: 14-3.2
36.	ANS: D	PTS: 1	DIF: I	OBJ: 14-3.3

## SHORT ANSWER

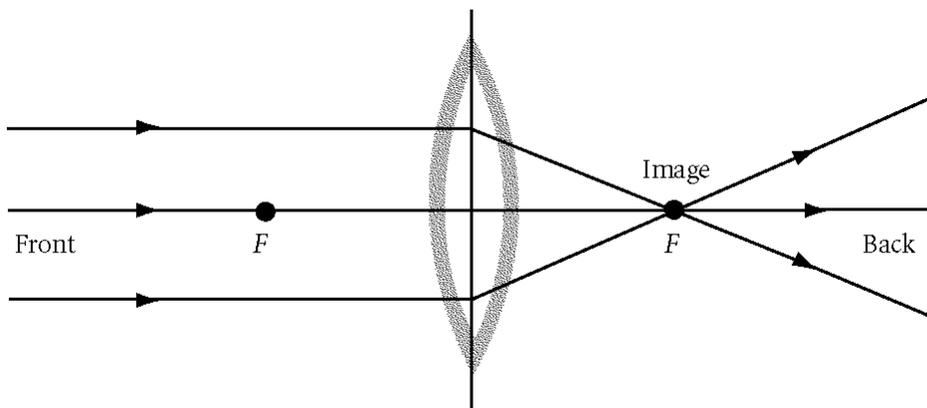
- ANS:  
Refraction occurs when light's velocity changes as it passes from one medium to another medium with a different index of refraction.  
  
PTS: 1                    DIF: I                    OBJ: 14-1.1
- ANS:  
The speed of light decreases.  
  
PTS: 1                    DIF: I                    OBJ: 14-1.1
- ANS:  
When the difference between the substances' indices of refraction is the greatest.  
  
PTS: 1                    DIF: II                    OBJ: 14-1.1
- ANS:  
A light ray represents the direction of propagation of a planar wave front, which is the superposition of all the spherical wave fronts. As these wave fronts enter a transparent medium, all of them strike the surface simultaneously and experience a similar change in velocity at the same instant. Although this results in a change in the overall wavelength of the spherical wave fronts, there is no change in the direction of the wave fronts relative to each other. Therefore, no refraction occurs.  
  
PTS: 1                    DIF: II                    OBJ: 14-1.2
- ANS:  
wavelength and velocity  
  
PTS: 1                    DIF: I                    OBJ: 14-1.2
- ANS:  
toward the normal  
  
PTS: 1                    DIF: I                    OBJ: 14-1.2
- ANS:  
away from the normal  
  
PTS: 1                    DIF: I                    OBJ: 14-1.2
- ANS:  
A real, inverted image that is smaller than the object will form between  $F$  and  $2F$ .



PTS: 1            DIF: II            OBJ: 14-2.1

9. ANS:

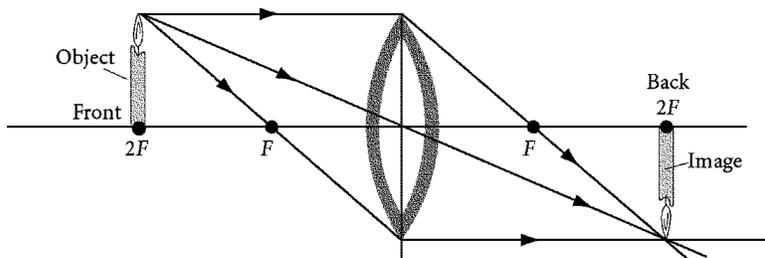
A real, point image will form at  $F$ .



PTS: 1            DIF: II            OBJ: 14-2.1

10. ANS:

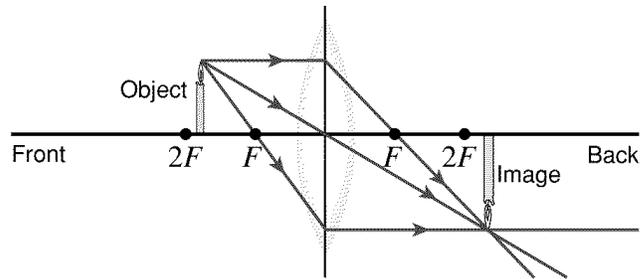
A real, inverted image that is the same size as the object will form at  $2F$ .



PTS: 1            DIF: II            OBJ: 14-2.1

11. ANS:

A real, inverted image that is larger than the object will form outside  $2F$ .



- PTS: 1                    DIF: II                    OBJ: 14-2.1  
 12. ANS:  
 when the lens thickness is much smaller than the focal length

- PTS: 1                    DIF: I                    OBJ: 14-2.2  
 13. ANS:  
 positive, back

- PTS: 1                    DIF: I                    OBJ: 14-2.2  
 14. ANS:  
*Given*  
 $p = 40.0 \text{ cm}$

$q = -50.0 \text{ cm}$  ( $q$  is negative, since the image is virtual and in front of the lens)

*Solution*

Use the thin-lens equation to find  $f$ .

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q} = \frac{1}{40.0 \text{ cm}} + \frac{1}{-50.0 \text{ cm}} = \frac{0.0250}{1 \text{ cm}} - \frac{0.0200}{1 \text{ cm}} = \frac{0.0050}{1 \text{ cm}}$$

$f = 2.0 \times 10^2 \text{ cm}$  (positive focal length is consistent with a converging lens)

- PTS: 1                    DIF: IIIA                    OBJ: 14-2.2  
 15. ANS:  
 The image is upright and virtual.

- PTS: 1                    DIF: I                    OBJ: 14-2.3  
 16. ANS:

An object placed just outside the focal length of the objective lens forms a real, inverted image just inside the focal point of the eyepiece. This eyepiece, the second lens, serves to magnify the image.

- PTS: 1                    DIF: II                    OBJ: 14-2.4  
 17. ANS:  
 In order to be seen, the object under a microscope must be at least as large as a wavelength of light. An atom is many times smaller than a wavelength of visible light.

- PTS: 1                    DIF: II                    OBJ: 14-2.4  
 18. ANS:  
 It acts as a simple magnifier because it is positioned so that its focal point lies very close to the focal point of the objective lens.

- PTS: 1                    DIF: I                    OBJ: 14-2.4  
19. ANS:  
It is inverted on the objective lens, and the eyepiece magnifies this inverted object, which lies just inside the focal point of the eyepiece.
- PTS: 1                    DIF: I                    OBJ: 14-2.4  
20. ANS:  
The light will undergo total internal reflection.
- PTS: 1                    DIF: II                    OBJ: 14-3.1  
21. ANS:  
The index of refraction of the first medium must be greater than the index of refraction of the second medium.
- PTS: 1                    DIF: I                    OBJ: 14-3.1  
22. ANS:  
Rays of light from the sun strike Earth's atmosphere and are bent because the atmosphere has an index of refraction greater than that of the near-vacuum of space.
- PTS: 1                    DIF: II                    OBJ: 14-3.2  
23. ANS:  
A mirage may be produced when the ground is so hot that the air above the ground is warmer than air at higher altitudes. The difference in temperature causes the air to have different indexes of refraction, so refraction occurs. This sends light from the sky upward into an observer's eyes.
- PTS: 1                    DIF: I                    OBJ: 14-3.2  
24. ANS:  
Light rays from the blue sky above are refracted by the warm air next to the dark, hot road and end up traveling upward into the motorists' eyes.
- PTS: 1                    DIF: II                    OBJ: 14-3.2  
25. ANS:  
In this situation, the observer sees the palm tree in two different ways. One group of light rays reaches the observer by the straight-line path *A*. In addition, a second group of rays travels along the curved path *B* because of refraction. Consequently, the observer also sees an inverted image of the palm tree.
- PTS: 1                    DIF: I                    OBJ: 14-3.2  
26. ANS:  
Dispersion is the process of separating polychromatic light into its component wavelengths because  $n$  is a function of wavelength for all material mediums. Snell's law states that the angles of refraction will be different for different wavelengths even if the angles of incidence are the same.
- PTS: 1                    DIF: I                    OBJ: 14-3.3  
27. ANS:  
Each colored component of the incoming ray is refracted depending on its wavelength. The rays fan out from the second face of the prism to produce a visible spectrum.
- PTS: 1                    DIF: I                    OBJ: 14-3.3  
28. ANS:  
The perceived color depends on the angle at which that drop is viewed.

PTS: 1

DIF: I

OBJ: 14-3.3

**PROBLEM**

1. ANS:  
25.3°

*Given*

$$\theta_i = 44.1^\circ$$

$$n_i = 1.00$$

$$n_r = 1.63$$

*Solution*

Rearrange Snell's law,  $n_i \sin \theta_i = n_r \sin \theta_r$ , and solve for  $\theta_r$ .

$$\theta_r = \sin^{-1} \left[ \frac{n_i}{n_r} (\sin \theta_i) \right] = \sin^{-1} \left[ \frac{1.00}{1.63} (\sin 44.1^\circ) \right]$$

$$\theta_r = \sin^{-1} \left[ \frac{1.00}{1.63} (0.696) \right]$$

$$\theta_r = \sin^{-1}(0.427)$$

$$\theta_r = 25.3^\circ$$

PTS: 1

DIF: IIIA

OBJ: 14-1.3

2. ANS:  
2.20

*Given*

$$\theta_i = 46.9^\circ$$

$$\theta_r = 19.4^\circ$$

$$n_i = 1.00$$

*Solution*

Rearrange Snell's law,  $n_i \sin \theta_i = n_r \sin \theta_r$ , and solve for  $n_r$ .

$$n_r = n_i \left[ \frac{(\sin \theta_i)}{(\sin \theta_r)} \right] = (1.00) \left[ \frac{(\sin 46.9^\circ)}{(\sin 19.4^\circ)} \right]$$

$$n_r = (1.00) \left[ \frac{(0.730)}{(0.332)} \right]$$

$$n_r = 2.20$$

PTS: 1                      DIF: IIB                      OBJ: 14-1.3

3. ANS:

15.8°

*Given*

$$\theta_i = 23.7^\circ$$

$$n_{air} = 1.000$$

$$n_{ice} = 1.314$$

$$n_{glycerine} = 1.477$$

*Solution*

First, determine the angle of refraction in ice.

Rearrange Snell's law,  $n_i \sin \theta_i = n_r \sin \theta_r$ , and solve for  $\theta_r$ .

$$\theta_{r(ice)} = \sin^{-1} \left[ \frac{n_i}{n_r} (\sin \theta_i) \right] = \sin^{-1} \left[ \frac{n_{air}}{n_{ice}} (\sin \theta_i) \right] = \sin^{-1} \left[ \frac{1.000}{1.314} (\sin 23.7^\circ) \right]$$

$$\theta_{r(ice)} = \sin^{-1} \left[ \frac{1.000}{1.314} (0.402) \right]$$

$$\theta_{r(ice)} = \sin^{-1} [0.306]$$

$$\theta_{r(ice)} = 17.8^\circ$$

Second, use  $\theta_{r(ice)}$  as the angle of incidence for the ice-glycerine boundary and solve for  $\theta_{r(glycerine)}$ .

$$\theta_{r(glycerine)} = \sin^{-1} \left[ \frac{n_i}{n_r} (\sin \theta_i) \right] = \sin^{-1} \left[ \frac{n_{ice}}{n_{glycerine}} (\sin \theta_{r(ice)}) \right] = \sin^{-1} \left[ \frac{1.314}{1.477} (\sin 17.8^\circ) \right]$$

$$\theta_{r(glycerine)} = \sin^{-1} \left[ \frac{1.314}{1.477} (0.306) \right]$$

$$\theta_{r(glycerine)} = \sin^{-1} [0.272]$$

$$\theta_{r(glycerine)} = 15.8^\circ$$

PTS: 1

DIF: IIC

OBJ: 14-1.3

4. ANS:

38.2°

*Given*

$$\theta_i = 55.6^\circ$$

$$n_{\text{air}} = 1.000$$

$$n_{\text{carbon disulfide}} = 1.628$$

$$n_{\text{water}} = 1.333$$

*Solution*

First, determine the angle of refraction in carbon disulfide.

Rearrange Snell's law,  $n_i \sin \theta_i = n_r \sin \theta_r$ , and solve for  $\theta_r$ .

$$\theta_{r(\text{carbon disulfide})} = \sin^{-1} \left[ \frac{n_i}{n_r} (\sin \theta_i) \right] = \sin^{-1} \left[ \frac{n_{\text{air}}}{n_{\text{carbon disulfide}}} (\sin \theta_i) \right]$$

$$\theta_{r(\text{carbon disulfide})} = \sin^{-1} \left[ \frac{1.000}{1.628} (\sin 55.6^\circ) \right] = \sin^{-1} \left[ \frac{1.000}{1.628} (0.825) \right]$$

$$\theta_{r(\text{carbon disulfide})} = \sin^{-1} [0.507]$$

$$\theta_{r(\text{carbon disulfide})} = 30.5^\circ$$

Second, use  $\theta_{r(\text{carbon disulfide})}$  as the angle of incidence for the carbon disulfide-water boundary and solve for

$\theta_{r(\text{water})}$ .

$$\theta_{r(\text{water})} = \sin^{-1} \left[ \frac{n_i}{n_r} (\sin \theta_i) \right] = \sin^{-1} \left[ \frac{n_{\text{carbon disulfide}}}{n_{\text{water}}} (\sin \theta_{r(\text{carbon disulfide})}) \right]$$

$$\theta_{r(\text{water})} = \sin^{-1} \left[ \frac{1.628}{1.333} (\sin 30.5^\circ) \right] = \sin^{-1} \left[ \frac{1.628}{1.333} (0.507) \right]$$

$$\theta_{r(\text{water})} = \sin^{-1} [0.619]$$

$$\theta_{r(\text{water})} = 38.2^\circ$$

PTS: 1

DIF: IIC

OBJ: 14-1.3

5. ANS:

42 cm

*Given*

$$p = 21 \text{ cm } (p > 0 \text{ for an object in front of the lens})$$

$$f = 14 \text{ cm } (f > 0 \text{ for a converging lens})$$

*Solution*

Rearrange the thin-lens equation,  $\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$ , and solve for  $q$ .

$$\frac{1}{q} = \frac{1}{f} - \frac{1}{p} = \frac{1}{14 \text{ cm}} - \frac{1}{21 \text{ cm}} = \frac{3}{42 \text{ cm}} - \frac{2}{42 \text{ cm}} = \frac{1}{42 \text{ cm}}$$

$q = 48 \text{ cm}$  ( $q > 0$ , so the image is real and in back of the lens)

PTS: 1                      DIF: IIB                      OBJ: 14-2.2

6. ANS:  
22 cm

*Given*

$q = -59 \text{ cm}$  ( $q < 0$  for an image in front of the lens)

$f = 34 \text{ cm}$  ( $f > 0$  for a converging lens)

*Solution*

Rearrange the thin-lens equation,  $\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$ , and solve for  $p$ .

$$\frac{1}{p} = \frac{1}{f} - \frac{1}{q} = \frac{1}{34 \text{ cm}} - \frac{1}{-59 \text{ cm}} = \frac{0.029}{1 \text{ cm}} + \frac{0.017}{1 \text{ cm}} = \frac{0.046}{1 \text{ cm}}$$

$p = 22 \text{ cm}$  ( $p > 0$ , so the object is in front of the lens)

PTS: 1                      DIF: IIB                      OBJ: 14-2.2

7. ANS:  
-15 cm

*Given*

$f_o = 1.08 \text{ cm}$  ( $f > 0$  for a converging lens)

$p_o = 1.21 \text{ cm}$  ( $p > 0$  for an object in front of the lens)

$f_e = 1.57 \text{ cm}$  ( $f > 0$  for a converging lens)

$p_e = 1.57 \text{ cm} - 0.154 \text{ cm} = 1.42 \text{ cm}$  ( $p > 0$  for an object in front of the lens)

*Solution*

The focal length and object distance of the objective lens do not enter into the calculation.

The image of the objective lens is the object of the eyepiece lens.

Rearrange the thin-lens equation,  $\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$ , and solve for  $q$ .

$$\frac{1}{q_e} = \frac{1}{f_e} - \frac{1}{p_e} = \frac{1}{1.57 \text{ cm}} - \frac{1}{1.42 \text{ cm}} = \frac{0.637}{1 \text{ cm}} - \frac{0.704}{1 \text{ cm}} = -\frac{0.067}{1 \text{ cm}}$$

$q_e = -15 \text{ cm}$  ( $q < 0$ , so the image is virtual and in front of the lens)

PTS: 1                    DIF: IIC                    OBJ: 14-2.2

8. ANS:  
-595 cm

*Given*

$$f_o = 49.40 \text{ cm } (f > 0 \text{ for a converging lens})$$

$$f_e = 14.82 \text{ cm } (f > 0 \text{ for a converging lens})$$

$$p_e = 14.82 \text{ cm} - 0.36 \text{ cm} = 14.46 \text{ cm } (p > 0 \text{ for an object in front of the lens})$$

*Solution*

The focal length of the objective lens does not enter into the calculation.

The image of the objective lens is the object of the eyepiece lens.

Rearrange the thin-lens equation,  $\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$ , and solve for  $q$ .

$$\frac{1}{q_e} = \frac{1}{f_e} - \frac{1}{p_e} = \frac{1}{14.82 \text{ cm}} - \frac{1}{14.46 \text{ cm}} = \frac{0.06748}{1 \text{ cm}} - \frac{0.06916}{1 \text{ cm}} = -\frac{0.00168}{1 \text{ cm}}$$

$$q_e = -595 \text{ cm } (q < 0, \text{ so the image is virtual and in front of the lens})$$

PTS: 1                    DIF: IIC                    OBJ: 14-2.2

9. ANS:  
-7.0;  $M < 0$ , so the image is real

*Given*

$$h' = -3.8 \text{ cm}$$

$$h = 0.54 \text{ cm}$$

*Solution*

Use the magnification of a lens equation,  $M = \frac{h'}{h}$ , to find  $M$ .

$$M = \frac{h'}{h} = \frac{(-3.8 \text{ cm})}{(0.54 \text{ cm})} = -7.0$$

$M < 0$ , so the image is real

PTS: 1                    DIF: IIIA                    OBJ: 14-2.3

10. ANS:  
0.540; The image is smaller than the object.  $M > 0$ , so the image is virtual and upright.

*Given*

$$p = 9.53 \text{ cm } (p > 0 \text{ for an object in front of the lens})$$

$$f = -11.2 \text{ cm } (f < 0 \text{ for a diverging lens})$$

*Solution*

First, rearrange the thin-lens equation,  $\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$ , to find  $q$ .

$$\frac{1}{q} = \frac{1}{f} - \frac{1}{p} = \frac{1}{-9.53 \text{ cm}} - \frac{1}{11.2 \text{ cm}} = -\frac{0.105}{1 \text{ cm}} - \frac{0.0893}{1 \text{ cm}} = -\frac{0.194}{1 \text{ cm}}$$

$q = -5.15 \text{ cm}$  (since  $q$  is negative, the image is virtual)

Use the magnification of a lens equation,  $M = -\frac{q}{p}$ , to find  $M$ .

$$M = -\frac{q}{p} = -\frac{(-5.15 \text{ cm})}{(9.53 \text{ cm})} = 0.540$$

The image is smaller than the object.  $M > 0$ , so the image is virtual and upright.

PTS: 1                    DIF: IIB                    OBJ: 14-2.3

11. ANS:

3.13; The image is three and a half times larger than the object.  $M > 0$ , so the image is virtual and upright.

*Given*

$f = 12.6 \text{ cm}$  ( $f > 0$  for a converging lens)

$q = -26.8 \text{ cm}$  ( $q < 0$  for an image in front of the lens)

*Solution*

First, rearrange the thin-lens equation,  $\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$ , to find  $p$ .

$$\frac{1}{p} = \frac{1}{f} - \frac{1}{q} = \frac{1}{12.6 \text{ cm}} - \frac{1}{-26.8 \text{ cm}} = \frac{0.0794}{1 \text{ cm}} + \frac{0.0373}{1 \text{ cm}} = \frac{0.1167}{1 \text{ cm}}$$

$p = 8.569 \text{ cm}$

Use the magnification of a lens equation,  $M = -\frac{q}{p}$ , to find  $M$ .

$$M = -\frac{q}{p} = -\frac{(-26.8 \text{ cm})}{(8.569 \text{ cm})} = 3.13$$

The image is three and a half times larger than the object.  $M > 0$ , so the image is virtual and upright.

PTS: 1                    DIF: IIC                    OBJ: 14-2.3

12. ANS:

5.43 cm

*Given*

$$h = 13.6 \text{ cm}$$

$$p = 39.3 \text{ cm } (p > 0 \text{ for an object in front of the lens})$$

$$f = -26.1 \text{ cm } (f < 0 \text{ for a diverging lens})$$

*Solution*

First, rearrange the thin-lens equation,  $\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$ , to find  $q$ .

$$\frac{1}{q} = \frac{1}{f} - \frac{1}{p} = \frac{1}{-26.1 \text{ cm}} - \frac{1}{39.3 \text{ cm}} = -\frac{0.0383}{1 \text{ cm}} - \frac{0.0254}{1 \text{ cm}} = -\frac{0.0637}{1 \text{ cm}}$$

$$q = -15.7 \text{ cm}$$

Rearrange the magnification of a lens equation,  $M = \frac{h'}{h} = -\frac{q}{p}$ , and solve for  $h'$ .

$$h' = -\frac{qh}{p} = -\frac{(-15.7 \text{ cm})(13.6 \text{ cm})}{(39.3 \text{ cm})} = 5.43 \text{ cm}$$

PTS: 1                    DIF: IIC                    OBJ: 14-2.3

13. ANS:

The angle of incidence,  $52.7^\circ$ , is less than the critical angle,  $54.6^\circ$ , so the light ray will refract.

*Given*

$$n_{\text{glass}} = 1.62$$

$$n_{\text{liquid}} = 1.32$$

$$\theta_i = 52.7^\circ$$

*Solution*

Rearrange the critical angle equation,  $\sin \theta_c = \frac{n_r}{n_i}$ , to find  $\theta_c$ .

$$\theta_c = \sin^{-1} \left( \frac{n_r}{n_i} \right) = \sin^{-1} \left( \frac{n_{\text{liquid}}}{n_{\text{glass}}} \right) = \sin^{-1} \left( \frac{1.32}{1.62} \right) = \sin^{-1}(0.815) = 54.6^\circ$$

The angle of incidence is less than the critical angle, so the light ray will refract.

PTS: 1                    DIF: IIIB                    OBJ: 14-3.1

14. ANS:

The angle of incidence is greater than the critical angle,  $57.9^\circ$ , so the light ray will undergo total internal reflection.

*Given*

$$n_{\text{optic cable}} = 1.57$$

$$n_{\text{water}} = 1.33$$

$$\theta_i = 65^\circ \text{ through } 70^\circ$$

*Solution*

Rearrange the critical angle equation,  $\sin \theta_c = \frac{n_r}{n_i}$ , to find  $\theta_c$ .

$$\theta_c = \sin^{-1}\left(\frac{n_r}{n_i}\right) = \sin^{-1}\left(\frac{n_{\text{water}}}{n_{\text{optic cable}}}\right) = \sin^{-1}\left(\frac{1.33}{1.57}\right) = \sin^{-1}(0.847) = 57.9^\circ$$

The angle of incidence is greater than the critical angle, so the light ray will undergo total internal reflection.

PTS: 1

DIF: IIB

OBJ: 14-3.1

15. ANS:

When the angle of incidence is greater than the critical angle, the light ray will undergo total internal reflection. Because the angle of incidence for the light rays ranges from  $45^\circ$  to  $55^\circ$ , some of the rays will undergo total internal reflection. Light rays whose angle of incidence is less than  $47.8^\circ$  will refract.

*Given*

$$n_{\text{optic cable}} = 1.35$$

$$n_{\text{air}} = 1.00$$

$$\theta_i = 45^\circ - 55^\circ$$

*Solution*

Rearrange the critical angle equation,  $\sin \theta_c = \frac{n_r}{n_i}$ , to find  $\theta_c$ .

$$\theta_c = \sin^{-1}\left(\frac{n_r}{n_i}\right) = \sin^{-1}\left(\frac{n_{\text{air}}}{n_{\text{optic cable}}}\right) = \sin^{-1}\left(\frac{1.00}{1.35}\right) = \sin^{-1}(0.741) = 47.8^\circ$$

When the angle of incidence is greater than the critical angle, the light ray will undergo total internal reflection. Because the angle of incidence for the light rays ranges from  $45^\circ$  to  $55^\circ$ , some of the rays will undergo total internal reflection. Light rays whose angle of incidence is less than  $47.8^\circ$  will refract.

PTS: 1

DIF: IIB

OBJ: 14-3.1

16. ANS:

$$1.81 \times 10^8 \text{ m/s}$$

*Given*

$$\theta_c = 53.5^\circ$$

$$n_{\text{water}} = 1.333$$

*Solution*

Rearrange the critical angle equation,  $\sin \theta_c = \frac{n_r}{n_i}$ , to find the index of refraction of the mineral.

$$n_{\text{mineral}} = \frac{n_{\text{water}}}{\sin \theta_c} = \frac{1.333}{\sin 53.5^\circ} = \frac{1.333}{0.804} = 1.66$$

Rearrange the index of refraction equation,  $n = \frac{c}{v}$ , to find velocity of light in the mineral.

$$v_{\text{light in mineral}} = \frac{c}{n_{\text{mineral}}} = \frac{(3.00 \times 10^8 \text{ m/s})}{(1.66)} = 1.81 \times 10^8 \text{ m/s}$$

PTS: 1

DIF: IIC

OBJ: 14-3.1