CHAPTER 33 HOMEWORK SOLUTIONS

33.3. IDENTIFY and SET UP: Use Eqs. (33.1) and (33.5) to calculate \( v \) and \( \lambda \).

EXECUTE: (a) \( n = \frac{c}{v} \) so \( v = \frac{c}{n} = \frac{2.998 \times 10^8 \text{ m/s}}{1.47} = 2.04 \times 10^8 \text{ m/s} \)

(b) \( \lambda = \frac{n \lambda}{n} = \frac{650 \text{ nm}}{1.47} = 442 \text{ nm} \)

EVALUATE: Light is slower in the liquid than in vacuum. By \( v = f \lambda \), when \( v \) is smaller, \( \lambda \) is smaller.

33.12. IDENTIFY: Apply Snell's law to the refraction at each interface.

SET UP: \( n_{air} = 1.00 \), \( n_{water} = 1.333 \).

EXECUTE: (a) \( \theta_{water} = \arcsin \left( \frac{n_{air} \sin \theta_{air}}{n_{water}} \right) = \arcsin \left( \frac{1.00 \sin 35.0^\circ}{1.333} \right) = 25.5^\circ. \)

EVALUATE: (b) This calculation has no dependence on the glass because we can omit that step in the chain: \( n_{air} \sin \theta_{air} = n_{glass} \sin \theta_{glass} = n_{water} \sin \theta_{water}. \)

33.19. IDENTIFY: Use the critical angle to find the index of refraction of the liquid.

SET UP: Total internal reflection requires that the light be incident on the material with the larger \( n \), in this case the liquid. Apply \( n_a \sin \theta_a = n_b \sin \theta_b \) with \( a \) = liquid and \( b \) = air, so \( n_a = n_{air} \) and \( n_b = 1.0. \)

EXECUTE: \( \theta_a = \theta_{crit} \) when \( \theta_b = 90^\circ \), so \( n_{air} \sin \theta_{crit} = (1.0) \sin 90^\circ \)

\( n_{air} = \frac{1}{\sin \theta_{crit}} = \frac{1}{\sin 42.5^\circ} = 1.48. \)

(a) \( n_a \sin \theta_a = n_b \sin \theta_b \) (\( a \) = liquid, \( b \) = air)
\( \sin \theta_b = \frac{n_a \sin \theta_a}{n_b} = \frac{(1.48) \sin 35.0^\circ}{1.0} = 0.8489 \) and \( \theta_b = 58.1^\circ \)

(b) Now \( n_b \sin \theta_b = n_a \sin \theta_a \) with \( a \) = air, \( b \) = liquid
\( \sin \theta_a = \frac{n_b \sin \theta_b}{n_a} = \frac{(1.0) \sin 35.0^\circ}{1.48} = 0.3876 \) and \( \theta_a = 22.8^\circ \)

EVALUATE: For light traveling liquid \( \rightarrow \) air the light is bent away from the normal. For light traveling air \( \rightarrow \) liquid the light is bent toward the normal.

33.22. IDENTIFY: If no light refracts out of the glass at the glass to air interface, then the incident angle at that interface is \( \theta_{crit}. \)

SET UP: The ray has an angle of incidence of \( 0^\circ \) at the first surface of the glass, so enters the glass without being bent, as shown in Figure 33.22. The figure shows that \( \alpha + \theta_{crit} = 90^\circ. \)

EXECUTE: (a) For the glass-air interface \( \theta_a = \theta_{crit}, \) \( n_a = 1.52, \) \( n_b = 1.00 \) and \( \theta_b = 90^\circ. \)
\( n_a \sin \theta_a = n_b \sin \theta_b \) gives \( \sin \theta_{crit} = \frac{(1.00) \sin 90^\circ}{1.52} \) and \( \theta_{crit} = 41.1^\circ. \) \( \alpha = 90^\circ - \theta_{crit} = 48.9^\circ. \)

(b) Now the second interface is glass \( \rightarrow \) water and \( n_b = 1.333, \) \( n_a \sin \theta_a = n_b \sin \theta_b \)
\( \sin \theta_{crit} = \frac{(1.333) \sin 90^\circ}{1.52} \) and \( \theta_{crit} = 61.3^\circ. \) \( \alpha = 90^\circ - \theta_{crit} = 28.7^\circ. \)

EVALUATE: The critical angle increases when the air is replaced by water and rays are bent as they refract out of the glass.
33.27. **IDENTIFY and SET UP:** Reflected beam completely linearly polarized implies that the angle of incidence equals the polarizing angle, so \( \theta_p = 54.5^\circ \). Use Eq.(33.8) to calculate the refractive index of the glass. Then use Snell’s law to calculate the angle of refraction.

**EXECUTE:**

(a) \( \tan \theta_p = \frac{n_a}{n_b} \) gives \( n_{\text{glass}} = n_{\text{air}} \tan \theta_p = (1.00) \tan 54.5^\circ = 1.40 \).

(b) \( n_\text{a} \sin \theta_\text{a} = n_\text{b} \sin \theta_\text{b} \)

\[
\sin \theta_b = \frac{n_\text{a} \sin \theta_\text{a}}{n_\text{b}} = \frac{(1.00) \sin 54.5^\circ}{1.40} = 0.5815 \text{ and } \theta_b = 35.5^\circ
\]

**EVALUATE:**

Note: \( \phi = 180.0^\circ - \theta_a - \theta_b \) and \( \theta_r = \theta_\text{a} \). Thus \( \phi = 180.0^\circ - 54.5^\circ - 35.5^\circ = 90.0^\circ \); the reflected ray and the refracted ray are perpendicular to each other. This agrees with Fig.33.28.

33.30. **IDENTIFY:** The reflected light is completely polarized when the angle of incidence equals the polarizing angle \( \theta_p \), where \( \tan \theta_p = \frac{n_b}{n_a} \).

**SET UP:** \( n_b = 1.66 \).

**EXECUTE:**

(a) \( n_a = 1.00 \). \( \tan \theta_p = \frac{1.66}{1.00} \) and \( \theta_p = 58.9^\circ \).

(b) \( n_a = 1.333 \). \( \tan \theta_p = \frac{1.66}{1.333} \) and \( \theta_p = 51.2^\circ \).

**EVALUATE:** The polarizing angle depends on the refractive indicies of both materials at the interface.

33.40. **IDENTIFY:** Use the change in transit time to find the speed \( v \) of light in the slab, and then apply \( n = \frac{c}{v} \) and \( \lambda = \frac{\lambda_0}{n} \).

**SET UP:** It takes the light an additional 4.2 ns to travel 0.840 m after the glass slab is inserted into the beam.
EXECUTE: \( \frac{0.840 \text{ m}}{c/n} - \frac{0.840 \text{ m}}{c} = (n-1)\frac{0.840 \text{ m}}{c} = 4.2 \text{ ns} \). We can now solve for the index of refraction: 
\[
n = \frac{(4.2 \times 10^{-9} \text{ s}) (3.00 \times 10^8 \text{ m/s})}{0.840 \text{ m}} + 1 = 2.50.
\]
The wavelength inside of the glass is 
\[
\lambda = \frac{490 \text{ nm}}{2.50} = 196 \text{ nm}.
\]
EVALUATE: Light travels slower in the slab than in air and the wavelength is shorter.

33.41. IDENTIFY: The angle of incidence at \( A \) is to be the critical angle. Apply Snell’s law at the air to glass refraction at the top of the block.

SET UP: The ray is sketched in Figure 33.41.

EXECUTE: For glass \( \rightarrow \) air at point \( A \), Snell's law gives \((1.38)\sin \theta_{\text{crit}} = (1.00)\sin 90^\circ \) and \( \theta_{\text{crit}} = 46.4^\circ \).

\[
\theta_b = 90^\circ - \theta_{\text{crit}} = 43.6^\circ.
\]
Snell's law applied to the refraction from air to glass at the top of the block gives \((1.00)\sin \theta_a = (1.38)\sin(43.6^\circ)\) and \( \theta_a = 72.1^\circ \).

EVALUATE: If \( \theta_a \) is larger than 72.1° then the angle of incidence at point \( A \) is less than the initial critical angle and total internal reflection doesn’t occur.

![Figure 33.41](image)

33.46. IDENTIFY: Apply Snell's law to the refraction of the light as it passes from water into air.

SET UP: \( \theta_a = \arctan \left( \frac{1.5 \text{ m}}{1.2 \text{ m}} \right) = 51^\circ \). \( n_a = 1.00 \). \( n_b = 1.333 \).

EXECUTE: \( \theta_b = \arcsin \left( \frac{n_a \sin \theta_a}{n_b} \right) = \arcsin \left( \frac{1.00}{1.333} \sin 51^\circ \right) = 36^\circ \). Therefore, the distance along the bottom of the pool from directly below where the light enters to where it hits the bottom is \( x = (4.0 \text{ m})\tan \theta_b = (4.0 \text{ m})\tan 36^\circ = 2.9 \text{ m} \). \( x_{\text{total}} = 1.5 \text{ m} + x = 1.5 \text{ m} + 2.9 \text{ m} = 4.4 \text{ m} \).

EVALUATE: The light ray from the flashlight is bent toward the normal when it refracts into the water.
33.52. **IDENTIFY:** The ray shown in the figure that accompanies the problem is to be incident at the critical angle.

**SET UP:** \( \theta_i = 90^\circ \). The incident angle for the ray in the figure is \( 60^\circ \).

**EXECUTE:** 

\[
n_a \sin \theta_a = n_b \sin \theta_b \quad \text{gives} \quad n_b = \left( \frac{n_a \sin \theta_a}{\sin \theta_b} \right) = \left( \frac{1.62 \sin 60^\circ}{\sin 90^\circ} \right) = 1.40.
\]

**EVALUATE:** Total internal reflection occurs only when the light is incident in the material of the greater refractive index.