Name: Key

Practice - 25.3-25.4 Refraction and Total Internal Reflection

1. What is the speed of light in water?

$$v_w = \frac{c}{n_w} = \frac{3.00\times10^8 \frac{m}{s}}{1.333} = \boxed{2.25\times10^8 \frac{m}{s}}$$

2. What is the speed of light in air?

$$v_A = \frac{c}{n_A} = \frac{3.00\times10^8 \frac{m}{s}}{1.000293} = \boxed{3.00\times10^8 \frac{m}{s}}$$

$2.9964\times10^8 \frac{m}{s}$

3. What is the speed of light in crown glass?

$$v_{CG} = \frac{c}{n_{CG}} = \frac{3.00\times10^8 \frac{m}{s}}{1.52} = \boxed{1.97\times10^8 \frac{m}{s}}$$

4. Calculate the index of refraction for a medium in which the speed of light is 2.012×108 m/s , and identify the most likely substance based on Table 25.1.

$$n = \frac{c}{v} = \frac{3.00\times10^8 \frac{m}{s}}{2.012\times10^8 \frac{m}{s}} = \boxed{1.49}\ \boxed{\text{polystyrene}}$$

Table 25.1 Index of Refraction in Various Media

Medium	n
Gases at 0°C , 1 atm	
Air	1.000293
Carbon dioxide	1.00045
Hydrogen	1.000139
Oxygen	1.000271
Liquids at 20°C	
Benzene	1.501
Carbon disulfide	1.628
Carbon tetrachloride	1.461
Ethanol	1.361
Glycerine	1.473
Water, fresh	1.333
Solids at 20°C	
Diamond	2.419
Fluorite	1.434
Glass, crown	1.52
Glass, flint	1.66
Ice at 20°C	1.309
Polystyrene	1.49
Plexiglas	1.51
Quartz, crystalline	1.544
Quartz, fused	1.458
Sodium chloride	1.544
Zircon	1.923

5. In what substance in Table 25.1 is the speed of light 2.290 x 10^8 m/s?

$$n = \frac{3.00\times10^8 \frac{m}{s}}{2.29\times10^8 \frac{m}{s}} = \boxed{1.31}\ \boxed{\text{Ice}}$$

6. There was a major collision of an asteroid with the Moon in medieval times. It was described by monks at Canterbury Cathedral in England as a red glow on and around the Moon. How long after the asteroid hit the Moon, which is 3.84 x 10^5 km away, would the light first arrive on Earth?

$$x = vt \Rightarrow t = \frac{x}{c} = \frac{3.84\times10^5 km}{3.00\times10^5 \frac{km}{s}} = \boxed{1.28 s}$$

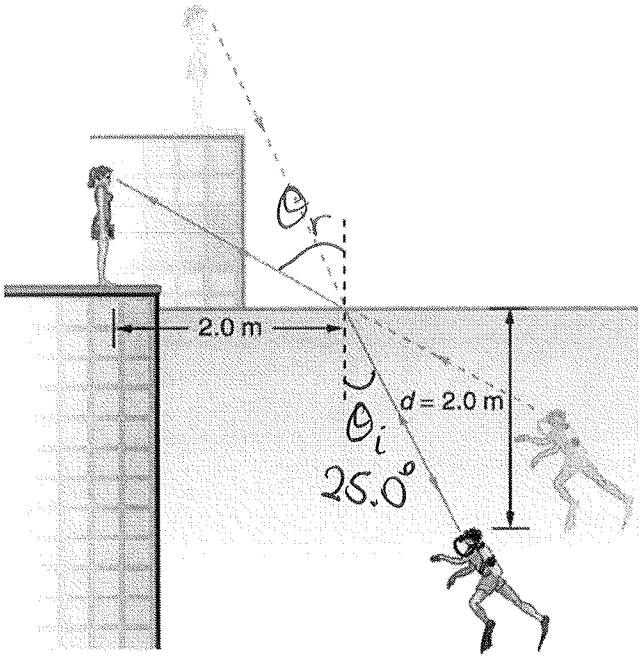
7. A scuba diver training in a pool looks at his instructor. What angle does the ray from the instructor's face make with the perpendicular to the water at the point where the ray enters? The angle between the ray in the water and the perpendicular to the water is 25.0°.

$$n_r \sin\theta_r = n_i \sin\theta_i$$

$$\theta_r = \sin^{-1}\left(\frac{n_i}{n_r}\sin\theta_i\right)$$

$$= \sin^{-1}\left(\frac{1.333}{1.00}\sin 25.0^\circ\right)$$

$$= \boxed{34.3^\circ}$$

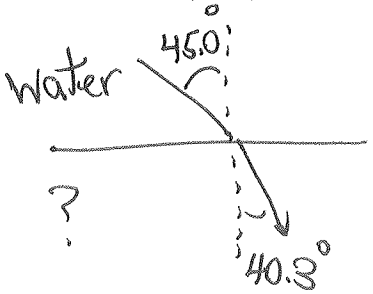


8. Components of some computers communicate with each other through optical fibers having an index of refraction n = 1.55. What time in nanoseconds is required for a signal to travel 0.200 m through such a fiber?

$$t = \frac{x}{v} = \frac{x}{\frac{c}{n}} = \frac{nx}{c} = \frac{(1.55)(0.200\text{m})}{3.00\times10^8 \frac{\text{m}}{\text{s}}} = 1.03\times10^{-9}\,\text{s}$$

$$= \boxed{1.03\,\text{ns}}$$

9. Suppose you have an unknown clear substance immersed in water, and you wish to identify it by finding its index of refraction. You arrange to have a beam of light enter it at an angle of 45.0°, and you observe the angle of refraction to be 40.3°. What is the index of refraction of the substance and its likely identity?



$$n_i \sin\theta_i = n_r \sin\theta_r$$

$$n_r = n_i \frac{\sin\theta_i}{\sin\theta_r} = 1.333\,\frac{\sin 45.0^\circ}{\sin 40.3^\circ}$$

$$= \boxed{1.46} \quad \boxed{\text{fused quartz}}$$

10. On the Moon's surface, lunar astronauts placed a corner reflector, off which a laser beam is periodically reflected. The distance to the Moon is calculated from the round-trip time. What percent correction is needed to account for the delay in time due to the slowing of light in Earth's atmosphere? Assume the distance to the Moon is precisely 3.84×10^8 m, and Earth's atmosphere (which varies in density with altitude) is equivalent to a layer 30.0 km thick with a constant index of refraction n = 1.000293.

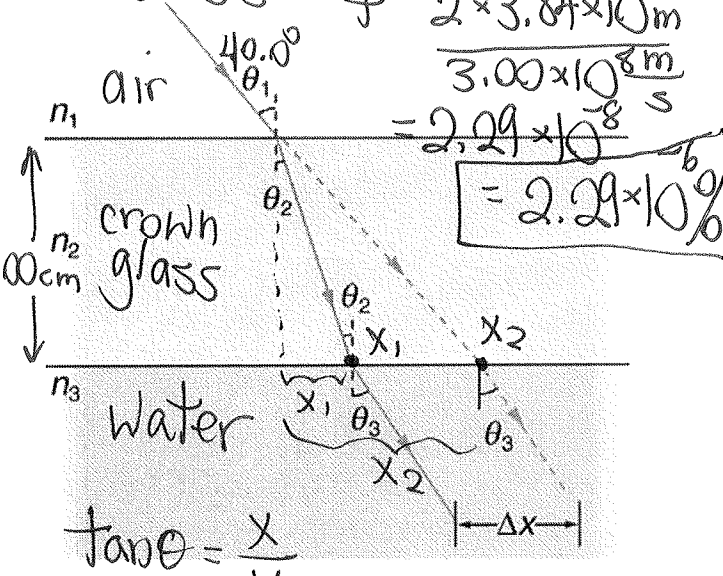
$$t = \frac{x}{v} = \frac{x}{\frac{c}{n}} = \frac{nx}{c} \qquad \Delta t = \frac{nx}{c} - \frac{x}{c} = \frac{x}{c}(n-1)$$

$$\Delta t = \frac{2 \times 30.0 \times 10^3 \text{ m}}{3.00 \times 10^8 \text{ m/s}}(1.000293 - 1) = 5.86 \times 10^{-8} \text{ s}$$

$$\frac{\Delta t}{t} = \frac{5.86 \times 10^{-8} \text{ s}}{\frac{2 \times 3.84 \times 10^8 \text{ m}}{3.00 \times 10^8 \text{ m/s}}} = 2.29 \times 10^{-8}$$

$$= 2.29 \times 10^{-6}\%$$

11. Suppose a ray of light going from air through crown glass into water, such as going into a fish tank. Calculate the amount the ray is displaced by the glass (Δx), given that the incident angle is 40.0° and the glass is 1.00 cm thick.



$$\theta_r = \sin^{-1}\left(\frac{n_i}{n_r}\sin\theta_i\right)$$

$$= \sin^{-1}\left(\frac{1.00}{1.52}\sin 40.0°\right) = 25.02°$$

$$\Delta x = x_2 - x_1 = y(\tan\theta_{x_2} - \tan\theta_{x_1})$$

$$= (1.00 \times 10^{-2} \text{ m})(\tan 40.0° - \tan 25.02°) = \boxed{3.72 \times 10^{-3} \text{ m}}$$

12. What is the critical angle for light going from water to air?

$$n_i \sin\theta_i = n_r \sin\theta_r$$

$$n_i \sin\theta_c = n_r \sin 90°$$

$$\Rightarrow \theta_c = \sin^{-1}\left(\frac{n_r}{n_i}\right) = \sin^{-1}\left(\frac{1.00}{1.333}\right) = \boxed{48.6°}$$

13. What is the critical angle for light going from diamond to air?

$$\theta_c = \sin^{-1}\left(\frac{n_r}{n_i}\right) = \sin^{-1}\left(\frac{1.00}{2.419}\right) = \boxed{24.4°}$$

14. An optical fiber uses flint glass clad with crown glass. What is the critical angle?

$$\theta_c = \sin^{-1}\left(\frac{n_r}{n_i}\right) = \sin^{-1}\left(\frac{1.52}{1.66}\right) = \boxed{66.3°}$$

(1.66 ↖ n_i, 1.52 ↖ n_r)

15. Suppose you are using total internal reflection to make an efficient corner reflector. If there is air outside and the incident angle is 45.0°, what must be the minimum index of refraction of the material from which the reflector is made?

$n_i \sin\theta_i = n_r \sin\theta_r$

$n_i \sin\theta_c = n_r \Rightarrow n_i = \frac{n_r}{\sin\theta_c} = \frac{1.000293}{\sin 45.0°} = \boxed{1.41}$

16. A. What is the index of refraction of a substance that has a critical angle of 68.4° when submerged in water? What is the substance, based on Table 25.1?

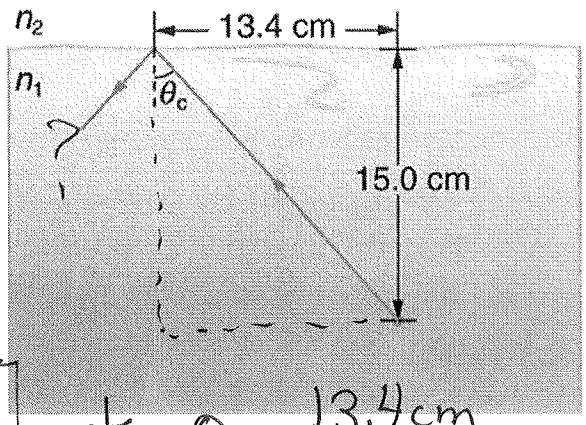
$n_i = \frac{n_r}{\sin\theta_c} = \frac{1.333}{\sin 68.4°} = \boxed{1.43}$ $\boxed{\text{Fluorite}}$

B. What would the critical angle be for this substance in air?

$\theta_c = \sin^{-1}\left(\frac{n_r}{n_i}\right) = \sin^{-1}\left(\frac{1.00}{1.43}\right) = \boxed{44.2°}$

17. A ray of light, emitted beneath the surface of an unknown liquid with air above it, undergoes total internal reflection. What is the index of refraction for the liquid and its likely identification?

air



$n_i \sin\theta_i = n_r \sin\theta_r$

$n_i \sin\theta_c = n_r$

$n_i = \frac{n_r}{\sin\theta_c} = \frac{1.00}{\sin 41.8°} = \boxed{1.50}$

$\boxed{\text{Benzene}}$

$\tan\theta_c = \frac{13.4\text{ cm}}{15.0\text{ cm}}$

$= 41.8°$