Physics 41 Chapter 35 HW

Q: 1,6, 10, 12, 16, 19
P: 1, 3, 9, 10, 11, 19, 21, 26, 27, 32, 35, 36, 47

Q35.1 Light travels through a vacuum at a speed of 300 000 km per second. Thus, an image we see from a distant star or galaxy must have been generated some time ago. For example, the star Altair is 16 light-years away; if we look at an image of Altair today, we know only what was happening 16 years ago. This may not initially seem significant, but astronomers who look at other galaxies can gain an idea of what galaxies looked like when they were significantly younger. Thus, it actually makes sense to speak of “looking backward in time.”

Q35.6 The stealth fighter is designed so that adjacent panels are not joined at right angles, to prevent any retroreflection of radar signals. This means that radar signals directed at the fighter will not be channeled back toward the detector by reflection. Just as with sound, radar signals can be treated as *diverging* rays, so that any ray that is by chance reflected back to the detector will be too weak in intensity to distinguish from background noise. This author is still waiting for the automotive industry to utilize this technology.

Q35.10 If a laser beam enters a sugar solution with a concentration gradient (density and index of refraction increasing with depth) then the laser beam will be progressively bent downward (toward the normal) as it passes into regions of greater index of refraction.

Q35.12 Diamond has higher index of refraction than glass and consequently a smaller critical angle for total internal reflection. A brilliant-cut diamond is shaped to admit light from above, reflect it totally at the converging facets on the underside of the jewel, and let the light escape only at the top. Glass will have less light internally reflected.

Q35.16 At the altitude of the plane the surface of the Earth need not block off the lower half of the rainbow. Thus, the full circle can be seen. You can see such a rainbow by climbing on a stepladder above a garden sprinkler in the middle of a sunny day. Set the sprinkler for fine mist. Do not let the slippery children fall from the ladder.

Q35.19 A mirage occurs when light changes direction as it moves between batches of air having different indices of refraction because they have different densities at different temperatures. When the sun makes a blacktop road hot, an apparent wet spot is bright due to refraction of light from the bright sky. The light, originally headed a little below the horizontal, always bends up as it first enters and then leaves sequentially hotter, lower-density, lower-index layers of air closer to the road surface.

Problems

1. The *Apollo 11* astronauts set up a panel of efficient cornercube retroreflectors on the Moon’s surface. The speed of light can be found by measuring the time interval required for a laser beam to travel from Earth, reflect from the panel, and return to Earth. If this interval is measured to be 2.51 s, what is the measured speed of light? Take the center-tocenter distance from Earth to Moon to be 3.84×10^8 m, and do not ignore the sizes of the Earth and Moon.

P35.1 The Moon’s radius is 1.74×10^6 m and the Earth’s radius is 6.37×10^6 m. The total distance traveled by the light is:

$$d = 2\left(3.84 \times 10^8 \text{ m} - 1.74 \times 10^6 \text{ m} - 6.37 \times 10^6 \text{ m}\right) = 7.52 \times 10^8 \text{ m}.$$

This takes 2.51 s, so $v = \dfrac{7.52 \times 10^8 \text{ m}}{2.51 \text{ s}} = 2.995 \times 10^8 \text{ m/s} = \boxed{299.5 \text{ Mm/s}}$.

P35.3 The experiment is most convincing if the wheel turns fast enough to pass outgoing light through one notch and returning light through the next: $t = \dfrac{2l}{c}$

$$\theta = \omega t = \omega\left(\frac{2l}{c}\right) \text{ so } \qquad \omega = \frac{c\theta}{2l} = \frac{\left(2.998\times10^{8}\right)\left[2\pi/(720)\right]}{2\left(11.45\times10^{3}\right)} = \boxed{114 \text{ rad/s}}$$

The returning light would be blocked by a tooth at one-half the angular speed, giving another data point.

P35.9 Using Snell's law, $\sin\theta_2 = \dfrac{n_1}{n_2}\sin\theta_1$

$$\theta_2 = \boxed{25.5°}$$

$$\lambda_2 = \frac{\lambda_1}{n_1} = \boxed{442 \text{ nm}}$$

***P35.10** The law of refraction $n_1 \sin\theta_1 = n_2 \sin\theta_2$ can be put into the more general form

$$\frac{c}{v_1}\sin\theta_1 = \frac{c}{v_2}\sin\theta_2$$

$$\frac{\sin\theta_1}{v_1} = \frac{\sin\theta_2}{v_2}$$

In this form it applies to all kinds of waves that move through space.

$$\frac{\sin 3.5°}{343 \text{ m/s}} = \frac{\sin\theta_2}{1\,493 \text{ m/s}}$$

$$\sin\theta_2 = 0.266$$

$$\theta_2 = \boxed{15.4°}$$

The wave keeps constant frequency in

$$f = \frac{v_1}{\lambda_1} = \frac{v_2}{\lambda_2}$$

$$\lambda_2 = \frac{v_2\lambda_1}{v_1} = \frac{1\,493 \text{ m/s}(0.589 \text{ m})}{343 \text{ m/s}} = \boxed{2.56 \text{ m}}$$

The light wave slows down as it moves from air into water but the sound speeds up by a large factor. The light wave bends toward the normal and its wavelength shortens, but the sound wave bends away from the normal and its wavelength increases.

$\boxed{\textbf{11.}}$ An underwater scuba diver sees the Sun at an apparent angle of 45.0° above the horizon. What is the actual elevation angle of the Sun above the horizon?

P35.11 $n_1 \sin\theta_1 = n_2 \sin\theta_2$

$$\sin\theta_1 = 1.333 \sin 45°$$

$$\sin\theta_1 = (1.33)(0.707) = 0.943$$

$$\theta_1 = 70.5° \rightarrow \boxed{19.5° \text{ above the horizon}}$$

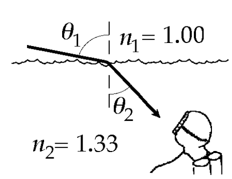
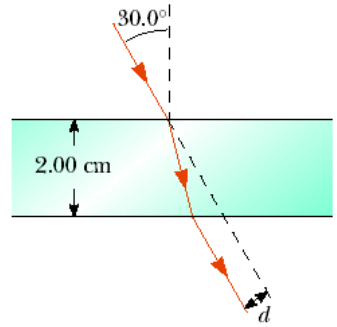


FIG. P35.13

19. When the light illustrated in Figure P35.19 passes through the glass block, it is shifted laterally by the distance d. Taking $n = 1.50$, find the value of d.



P35.21 At entry, $n_1 \sin\theta_1 = n_2 \sin\theta_2$

or $1.00 \sin 30.0° = 1.50 \sin\theta_2$

$\theta_2 = 19.5°$.

The distance h the light travels in the medium is given by

$$\cos\theta_2 = \frac{2.00 \text{ cm}}{h}$$

or $$h = \frac{2.00 \text{ cm}}{\cos 19.5°} = 2.12 \text{ cm}.$$

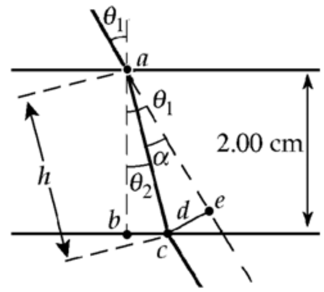


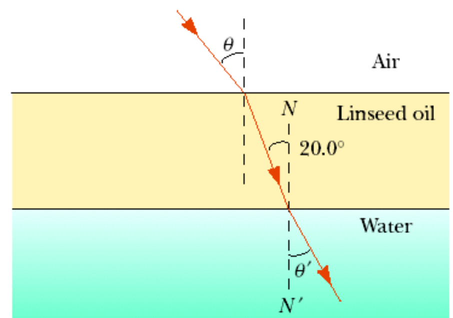
FIG. P35.21

The angle of deviation upon entry is $\alpha = \theta_1 - \theta_2 = 30.0° - 19.5° = 10.5°$.

The offset distance comes from $\sin\alpha = \frac{d}{h}$:

$d = (2.21 \text{ cm}) \sin 10.5° = \boxed{0.388 \text{ cm}}$.

21. The light beam shown in Figure P35.23 makes an angle of 20.0° with the normal line NN' in the linseed oil. Determine the angles θ and θ'. (The index of refraction of linseed oil is 1.48.)



P35.23 Applying Snell's law at the air-oil interface,

$$n_{\text{air}} \sin\theta = n_{\text{oil}} \sin 20.0°$$

yields $\boxed{\theta = 30.4°}$.

Applying Snell's law at the oil-water interface

$$n_w \sin\theta' = n_{\text{oil}} \sin 20.0°$$

yields $\boxed{\theta' = 22.3°}$.

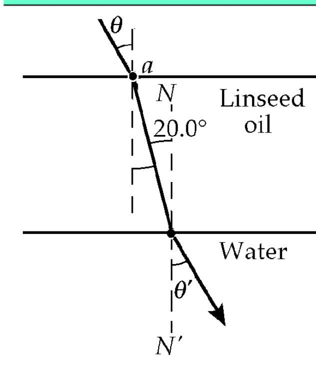


FIG. P35.23

26. Light of wavelength 700 nm is incident on the face of a fused quartz prism at an angle of 75.0° (with respect to the normal to the surface). The apex angle of the prism is 60.0°. Use the value of n from Figure 35.21 and calculate the angle (a) of refraction at this first surface, (b) of incidence at the second surface, (c) of refraction at the second surface, and (d) between the incident and emerging rays.

P35.26 From the figure on page 992: $n(700\text{ nm}) = 1.458$

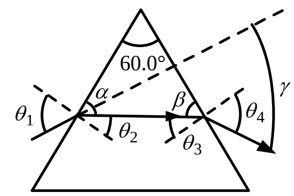


FIG. P35.30

(a) $(1.00)\sin 75.0° = 1.458\sin\theta_2$; $\theta_2 = \boxed{41.5°}$

(b) Let $\theta_3 + \beta = 90.0°$, $\theta_2 + \alpha = 90.0°$ then $\alpha + \beta + 60.0° = 180°$.

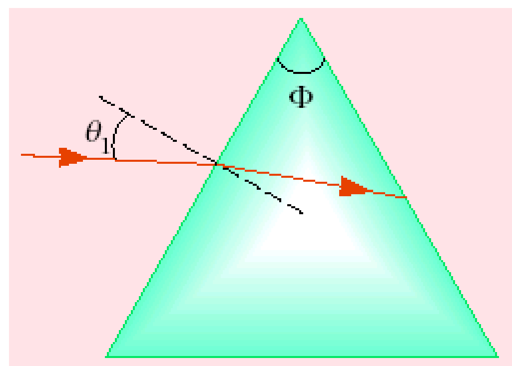
So $60.0° - \theta_2 - \theta_3 = 0 \Rightarrow 60.0° - 41.5° = \theta_3 = \boxed{18.5°}$.

(c) $1.458\sin 18.5° = 1.00\sin\theta_4 \qquad \theta_4 = \boxed{27.6°}$

(d) $\gamma = (\theta_1 - \theta_2) + [\beta - (90.0° - \theta_4)]$

$\gamma = 75.0° - 41.5° + (90.0° - 18.5°) - (90.0° - 27.6°) = \boxed{42.6°}$

27 A triangular glass prism with apex angle $\mathbf{\Phi}$ = 60.0° has an index of refraction n = 1.50 (Fig. P35.33). What is the smallest angle of incidence θ_1 for which a light ray can emerge from the other side?



P35.27

At the first refraction, $1.00\sin\theta_1 = n\sin\theta_2$.

The critical angle at the second surface is given by $n\sin\theta_3 = 1.00$:

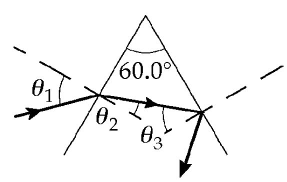


FIG. P35.33

or

$$\theta_3 = \sin^{-1}\left(\frac{1.00}{1.50}\right) = 41.8°.$$

But, $\theta_2 = 60.0° - \theta_3$.

Thus, to avoid total internal reflection at the second surface (i.e., have $\theta_3 < 41.8°$)

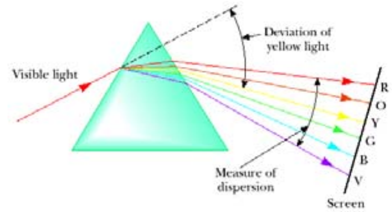
it is necessary that $\theta_2 > 18.2°$.

Since $\sin\theta_1 = n\sin\theta_2$, this becomes

$\sin\theta_1 > 1.50\sin 18.2° = 0.468$

or $\theta_1 > \boxed{27.9°}$.

31. The index of refraction for violet light in silica flint glass is 1.66, and that for red light is 1.62. What is the angular dispersion of visible light passing through a prism of apex angle 60.0° if the angle of incidence is 50.0°? (See Fig. P35.35.)



P35.31 For the incoming ray, $\sin\theta_2 = \dfrac{\sin\theta_1}{n}$.

Using the figure to the right,

$$(\theta_2)_{\text{violet}} = \sin^{-1}\left(\frac{\sin 50.0°}{1.66}\right) = 27.48°$$

$$(\theta_2)_{\text{red}} = \sin^{-1}\left(\frac{\sin 50.0°}{1.62}\right) = 28.22°.$$

For the outgoing ray, $\theta_3 = 60.0° - \theta_2$

and $\sin\theta_4 = n\sin\theta_3$: $(\theta_4)_{\text{violet}} = \sin^{-1}[1.66\sin 32.52°] = 63.17°$

$$(\theta_4)_{\text{red}} = \sin^{-1}[1.62\sin 31.78°] = 58.56°.$$

The angular dispersion is the difference $\Delta\theta_4 = (\theta_4)_{\text{violet}} - (\theta_4)_{\text{red}} = 63.17° - 58.56° = \boxed{4.61°}$.

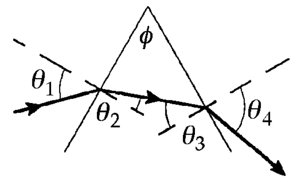


FIG. P35.35

35.32 From Fig 35.21 $n_v = 1.470$ at 400 nm and $n_r = 1.458$ at 700 nm

Then $1.00\sin\theta = 1.470\sin\theta_v$ and $1.00\sin\theta = 1.458\sin\theta_r$

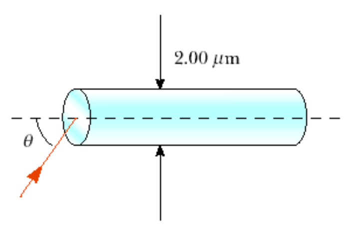
$$\delta_r - \delta_v = \theta_r - \theta_v = \sin^{-1}\left(\frac{\sin\theta}{1.458}\right) - \sin^{-1}\left(\frac{\sin\theta}{1.470}\right)$$

$$\Delta\delta = \sin^{-1}\left(\frac{\sin 30.0°}{1.458}\right) - \sin^{-1}\left(\frac{\sin 30.0°}{1.470}\right) = \boxed{0.171°}$$

P35.35 $\sin\theta_c = \dfrac{n_2}{n_1}$

$$n_2 = n_1\sin 88.8° = (1.000\,3)(0.999\,8) = \boxed{1.000\,08}$$

36. Determine the maximum angle θ for which the light rays incident on the end of the pipe in Figure P35.38 are subject to total internal reflection along the walls of the pipe. Assume that the pipe has an index of refraction of 1.36 and the outside medium is air.



P35.36 $\sin\theta_c = \dfrac{n_{\text{air}}}{n_{\text{pipe}}} = \dfrac{1.00}{1.36} = 0.735 \quad \theta_c = 47.3°$

Geometry shows that the angle of refraction at the end is

$$\phi = 90.0° - \theta_c = 90.0° - 47.3° = 42.7°.$$

Then, Snell's law at the end, $1.00\sin\theta = 1.36\sin 42.7°$

gives $\boxed{\theta = 67.2°}$.

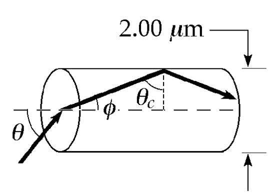
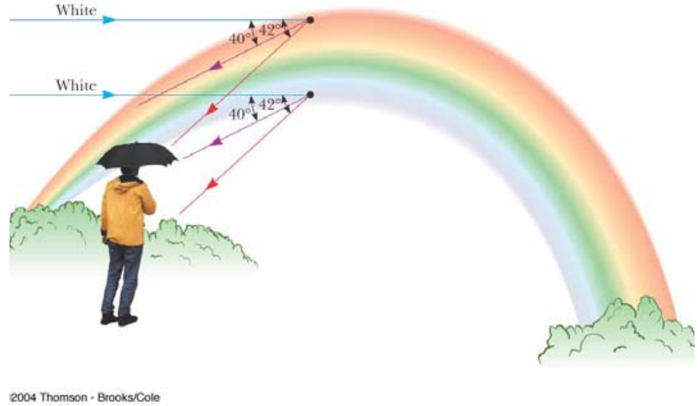


FIG. P35.38

The 2-μm diameter is unnecessary information.

47. A hiker stands on an isolated mountain peak near sunset and observes a rainbow caused by water droplets in the air 8.00 km away. The valley is 2.00 km below the mountain peak and entirely flat. What fraction of the complete circular arc of the rainbow is visible to the hiker? (See Fig. 35.24.)



P35.47 Horizontal light rays from the setting Sun pass above the hiker. The light rays are twice refracted and once reflected, as in Figure (b). The most intense light reaching the hiker, that which represents the visible rainbow, is located between angles of 40° and 42° from the hiker's shadow.

The hiker sees a greater percentage of the violet inner edge, so we consider the red outer edge. The radius R of the circle of droplets is

$$R = (8.00\text{ km})\sin 42.0° = 5.35\text{ km} .$$

Then the angle ϕ, between the vertical and the radius where the bow touches the ground, is given by

$$\cos\phi = \frac{2.00\text{ km}}{R} = \frac{2.00\text{ km}}{5.35\text{ km}} = 0.374$$

or $\phi = 68.1°$.

The angle filled by the visible bow is $360° - (2 \times 68.1°) = 224°$

so the visible bow is $\frac{224°}{360°} = \boxed{62.2\%\text{ of a circle}}$.

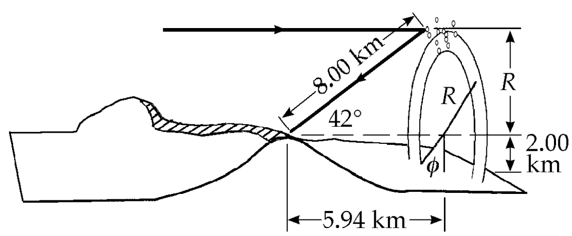


Figure (a)

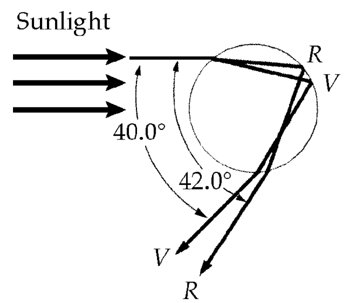


Figure (b)

FIG. P35.53