Q25.6 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.

Q25.7 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.

Q25.8 The index of refraction of diamond varies with the frequency of the light. Different color-components of the white light are refracted off in different directions by the jewel. The diamond disperses light to form a spectrum, as any prism does.

Q25.9 A faceted diamond or a stone of cubic zirconia sparkles because the light entering the stone from above is totally internally reflected and the stone is cut so the light can only escape back out the top. If the diamond or the cubic zirconia is immersed in a high index of refraction liquid, then the total internal reflection is thwarted and the diamond loses its "sparkle". For an exact match of index of refraction between cubic zirconia and corn syrup, the cubic zirconia stone would be invisible.

Q25.10 Take a half-circular disk of plastic. Center it on a piece of polar-coordinate paper on a horizontal corkboard. Slowly move a pin around the curved side while you look for it, gazing at the center of the flat wall. When you can barely see the pin as your line of sight grazes the flat side of the block, the light from the pin is reaching the origin at the critical angle θ_c. You can conclude that the index of refraction of the plastic is $\dfrac{1}{\sin\theta_c}$.

Q25.11 The light with the greater change in speed will have the larger deviation. If the glass has a higher index than the surrounding medium, X travels slower in the glass.

Q25.12 Total internal reflection occurs only when light moving originally in a medium of high index of refraction falls on an interface with a medium of lower index of refraction. Thus, light moving from air ($n=1$) to water ($n=1.33$) cannot undergo total internal reflection.

Q25.13 Highly silvered mirrors reflect about 98% of the incident light. With a 2-mirror periscope, that results in approximately a 4% decrease in intensity of light as the light passes through the periscope. This may not seem like much, but in low-light conditions, that lost light may mean the difference between being able to distinguish an enemy armada or an iceberg from the sky beyond. Using prisms results in total internal reflection, meaning that 100% of the incident light is reflected by each prism. That is the "total" in total internal reflection. At the surfaces of entry into and exit from the prisms, antireflective coatings can minimize light loss.

Q25.14 Light from the lamps along the edges of the sheet enters the plastic. Then it is totally internally reflected by the front and back faces of the plastic, wherever the plastic has an interface with air. If the refractive index of the grease is intermediate between 1.55 and 1.00, some of this light can leave the plastic into the grease and leave the grease into the air. The surface of the grease is rough, so the grease can send out light in all directions. The customer sees the grease shining against a black background. The spotlight method of producing the same effect is much less efficient. With it, much of the light from the spotlight is absorbed by the blackboard. The refractive index of the grease must be less than 1.55. Perhaps the best choice would be $\sqrt{1.55\times 1.00}=1.24$.

Q25.15 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.

Q25.16 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.

SOLUTIONS TO PROBLEMS

Section 25.1 The Nature of Light

No problems in this section

Section 25.2 The Ray Model in Geometric Optics

Section 25.3 The Wave Under Reflection

Section 25.4 The Wave Under Refraction

P25.1 (a) From geometry, $1.25\text{ m}=d\sin 40.0°$

so $d=\boxed{1.94\text{ m}}$.

(b) $\boxed{50.0°\text{ above the horizontal}}$

or parallel to the incident ray.

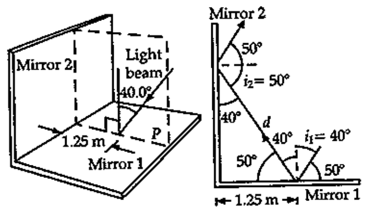


FIG. P25.1

P25.2 (a) **Method One:**

The incident ray makes angle $\alpha=90°-\theta_1$

with the first mirror. In the picture, the law of reflection implies that

$$\theta_1=\theta_1'.$$

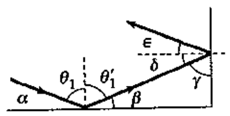


FIG. P25.2

Then $$\beta=90°-\theta_1'=90-\theta_1=\alpha.$$

In the triangle made by the mirrors and the ray passing between them,

$$\beta+90°+\gamma=180°$$
$$\gamma=90°-\beta.$$

continued on next page

Further, $\delta = 90° - \gamma = \beta = \alpha$

and $\epsilon = \delta = \alpha$.

Thus the final ray makes the same angle with the first mirror as did the incident ray. Its direction is opposite to the incident ray.

Method Two:

The vector velocity of the incident light has a component v_y perpendicular to the first mirror and a component v_x perpendicular to the second. The v_y component is reversed upon the first reflection, which leaves v_x unchanged. The second reflection reverses v_x and leaves v_y unchanged. The doubly reflected ray then has velocity opposite to the incident ray.

(b) The incident ray has velocity $v_x\hat{i} + v_y\hat{j} + v_z\hat{k}$. Each reflection reverses one component and leaves the other two unchanged. After all the reflections, the light has velocity $-v_x\hat{i} - v_y\hat{j} - v_z\hat{k}$, opposite to the incident ray.

P25.3 The incident light reaches the left-hand mirror at distance

$(1.00 \text{ m})\tan 5.00° = 0.087\,5 \text{ m}$

above its bottom edge. The reflected light first reaches the right-hand mirror at height

$2(0.087\,5 \text{ m}) = 0.175 \text{ m}$.

It bounces between the mirrors with this distance between points of contact with either.

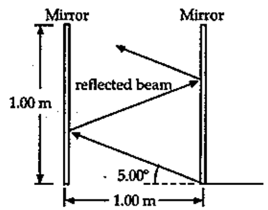


FIG. P25.3

Since $\dfrac{1.00 \text{ m}}{0.175 \text{ m}} = 5.72$

the light reflects $\boxed{\text{five times from the right-hand mirror and six times from the left}}$.

P25.4 Using Snell's law, $\sin\theta_2 = \dfrac{n_1}{n_2}\sin\theta_1$

$\theta_2 = \boxed{25.5°}$

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

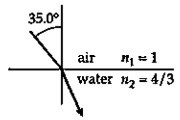


FIG. P25.4

*P25.5 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

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

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

P25.6 (a) $f = \dfrac{c}{\lambda} = \dfrac{3.00\times10^8 \text{ m/s}}{6.328\times10^{-7} \text{ m}} = \boxed{4.74\times10^{14} \text{ Hz}}$

(b) $\lambda_{glass} = \dfrac{\lambda_{air}}{n} = \dfrac{632.8 \text{ nm}}{1.50} = \boxed{422 \text{ nm}}$

(c) $v_{glass} = \dfrac{c_{air}}{n} = \dfrac{3.00\times10^8 \text{ m/s}}{1.50} = 2.00\times10^8 \text{ m/s} = \boxed{200 \text{ Mm/s}}$

P25.7 $n_1\sin\theta_1 = n_2\sin\theta_2$

$\sin\theta_1 = 1.333\sin 45°$

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

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

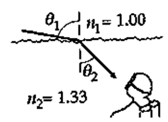


FIG. P25.7

*P25.8 We find the angle of incidence:

$n_1\sin\theta_1 = n_2\sin\theta_2$

$1.333\sin\theta_1 = 1.52\sin 19.6°$

$\theta_1 = 22.5°$

The angle of reflection of the beam in water is then also $\boxed{22.5°}$.

***P25.9** (a) As measured from the diagram, the incidence angle is 60°, and the refraction angle is 35°. From Snell's law, $\frac{\sin\theta_2}{\sin\theta_1}=\frac{v_2}{v_1}$, then $\frac{\sin 35°}{\sin 60°}=\frac{v_2}{c}$ and the speed of light in the block is

$\boxed{2.0\times10^8\text{ m/s}}$

(b) The frequency of the light does not change upon refraction. Knowing the wavelength in a vacuum, we can use the speed of light in a vacuum to determine the frequency: $c=f\lambda$, thus $3.00\times10^8=f\left(632.8\times10^{-9}\right)$, so the frequency is $\boxed{474.1\text{ THz}}$.

(c) To find the wavelength of light in the block, we use the same wave speed relation, $v=f\lambda$, so $2.0\times10^8=\left(4.741\times10^{14}\right)\lambda$, so $\lambda_{glass}=\boxed{420\text{ nm}}$.

P25.10 (a) $n_1\sin\theta_1=n_2\sin\theta_2$

$1.00\sin 30.0°=n\sin 19.24°$

$n=\boxed{1.52}$

(c) $f=\frac{c}{\lambda}=\frac{3.00\times10^8\text{ m/s}}{6.328\times10^{-7}\text{ m}}=\boxed{4.74\times10^{14}\text{ Hz}}$ in air and in syrup.

(d) $v=\frac{c}{n}=\frac{3.00\times10^8\text{ m/s}}{1.52}=1.98\times10^8\text{ m/s}=\boxed{198\text{ Mm/s}}$

(b) $\lambda=\frac{v}{f}=\frac{1.98\times10^8\text{ m/s}}{4.74\times10^{14}/\text{s}}=\boxed{417\text{ nm}}$

P25.11 (a) Flint Glass: $v=\frac{c}{n}=\frac{3.00\times10^8\text{ m/s}}{1.66}=1.81\times10^8\text{ m/s}=\boxed{181\text{ Mm/s}}$

(b) Water: $v=\frac{c}{n}=\frac{3.00\times10^8\text{ m/s}}{1.333}=2.25\times10^8\text{ m/s}=\boxed{225\text{ Mm/s}}$

(c) Cubic Zirconia: $v=\frac{c}{n}=\frac{3.00\times10^8\text{ m/s}}{2.20}=1.36\times10^8\text{ m/s}=\boxed{136\text{ Mm/s}}$

P25.12 $n_1\sin\theta_1=n_2\sin\theta_2$: $1.333\sin 37.0°=n_2\sin 25.0°$

$n_2=1.90=\frac{c}{v}$: $v=\frac{c}{1.90}=1.58\times10^8\text{ m/s}=\boxed{158\text{ Mm/s}}$

P25.13 $n_1\sin\theta_1=n_2\sin\theta_2$: $\theta_2=\sin^{-1}\left(\frac{n_1\sin\theta_1}{n_2}\right)$

$\theta_2=\sin^{-1}\left\{\frac{1.00\sin 30°}{1.50}\right\}=\boxed{19.5°}$

θ_2 and θ_3 are alternate interior angles formed by the ray cutting parallel normals.

So, $\theta_3=\theta_2=\boxed{19.5°}$

$1.50\sin\theta_3=1.00\sin\theta_4$

$\theta_4=\boxed{30.0°}$

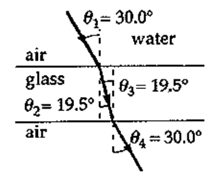


FIG. P25.13

P25.14 $\sin\theta_1=n_w\sin\theta_2$

$\sin\theta_2=\frac{1}{1.333}\sin\theta_1=\frac{1}{1.333}\sin(90.0°-28.0°)=0.662$

$\theta_2=\sin^{-1}(0.662)=41.5°$

$h=\frac{d}{\tan\theta_2}=\frac{3.00\text{ m}}{\tan 41.5°}=\boxed{3.39\text{ m}}$

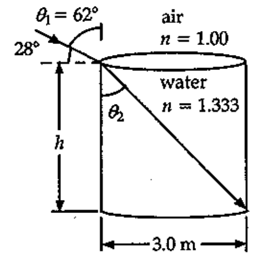


FIG. P25.14

P25.15 For $\alpha+\beta=90°$

with $\theta_1'+\alpha+\beta+\theta_2=180°$

we have $\theta_1'+\theta_2=90°$.

Also, $\theta_1'=\theta_1$

and $1\sin\theta_1=n\sin\theta_2$.

Then, $\sin\theta_1=n\sin(90-\theta_1)=n\cos\theta_1$

$\frac{\sin\theta_1}{\cos\theta_1}=n=\tan\theta_1$ $\boxed{\theta_1=\tan^{-1}n}$.

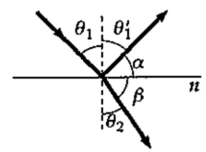


FIG. P25.15

***P25.16** From Snell's law, $\sin\theta = \left(\frac{n_{medium}}{n_{liver}}\right)\sin 50.0°$

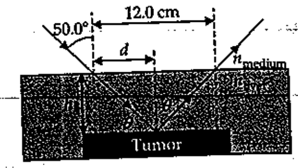


FIG. P25.16

But, $\frac{n_{medium}}{n_{liver}} = \frac{c/v_{medium}}{c/v_{liver}} = \frac{v_{liver}}{v_{medium}} = 0.900$,

so, $\theta = \sin^{-1}[(0.900)\sin 50.0°] = 43.6°$.

From the law of reflection,

$d = \frac{12.0 \text{ cm}}{2} = 6.00 \text{ cm}$, and $h = \frac{d}{\tan\theta} = \frac{6.00 \text{ cm}}{\tan(43.6°)} = \boxed{6.30 \text{ cm}}$

P25.17 At entry, $n_1 \sin\theta_1 = n_2 \sin\theta_2$

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

$\theta_2 = 19.5°$.

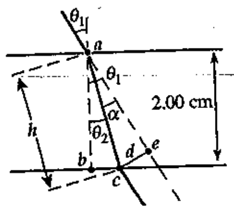


FIG. P25.17

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

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

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

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

The offset distance comes from $\sin\alpha = \frac{d}{h}$: $d = (2.21 \text{ cm})\sin 10.5° = \boxed{0.388 \text{ cm}}$.

P25.18 The distance, h, traveled by the light is $h = \frac{2.00 \text{ cm}}{\cos 19.5°} = 2.12 \text{ cm}$.

The speed of light in the material is $v = \frac{c}{n} = \frac{3.00 \times 10^8 \text{ m/s}}{1.50} = 2.00 \times 10^8 \text{ m/s}$.

Therefore, $t = \frac{h}{v} = \frac{2.12 \times 10^{-2} \text{ m}}{2.00 \times 10^8 \text{ m/s}} = 1.06 \times 10^{-10} \text{ s} = \boxed{106 \text{ ps}}$.

P25.19 Applying Snell's law at the air-oil interface,

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

yields $\boxed{\theta = 30.4°}$.

Applying Snell's law at the oil-water interface

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

yields $\boxed{\theta' = 22.3°}$.

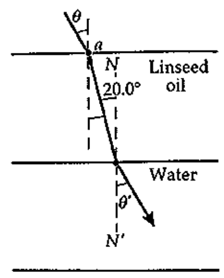


FIG. P25.19

P25.20 From the figure we have $w = 2b + a$

$b = \frac{w - a}{2} = \frac{700\ \mu\text{m} - 1\ \mu\text{m}}{2} = 349.5\ \mu\text{m}$

$\tan\theta_2 = \frac{b}{t} = \frac{349.5\ \mu\text{m}}{1\,200\ \mu\text{m}} = 0.291 \quad \theta_2 = 16.2°$

For refraction at entry,

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

$\theta_1 = \sin^{-1}\frac{n_2 \sin\theta_2}{n_1} = \sin^{-1}\frac{1.55 \sin 16.2°}{1.00} = \sin^{-1} 0.433 = \boxed{25.7°}$

P25.21 Consider glass with an index of refraction of 1.5, which is 3 mm thick. The speed of light in the glass is

$$\frac{3 \times 10^8 \text{ m/s}}{1.5} = 2 \times 10^8 \text{ m/s}.$$

The extra travel time is $\frac{3 \times 10^{-3} \text{ m}}{2 \times 10^8 \text{ m/s}} - \frac{3 \times 10^{-3} \text{ m}}{3 \times 10^8 \text{ m/s}} \boxed{\sim 10^{-11} \text{ s}}$.

For light of wavelength 600 nm in vacuum and wavelength $\frac{600 \text{ nm}}{1.5} = 400 \text{ nm}$ in glass,

the extra optical path, in wavelengths, is $\frac{3 \times 10^{-3} \text{ m}}{4 \times 10^{-7} \text{ m}} - \frac{3 \times 10^{-3} \text{ m}}{6 \times 10^{-7} \text{ m}} \boxed{\sim 10^3 \text{ wavelengths}}$.

P25.22 See the sketch showing the path of the light ray. α and γ are angles of incidence at mirrors 1 and 2.

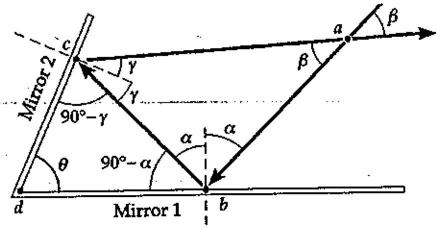


FIG. P25.22

For triangle *abca*,

$$2\alpha+2\gamma+\beta=180°$$

or $\beta=180°-2(\alpha+\gamma)$. (1)

Now for triangle *bcdb*,

$$(90.0°-\alpha)+(90.0°-\gamma)+\theta=180°$$

or $\theta=\alpha+\gamma$. (2)

Substituting Equation (2) into Equation (1) gives $\boxed{\beta=180°-2\theta}$.

Note: From Equation (2), $\gamma=\theta-\alpha$. Thus, the ray will follow a path like that shown only if $\alpha<\theta$. For $\alpha>\theta$, γ is negative and multiple reflections from each mirror will occur before the incident and reflected rays intersect.

Section 25.5 Dispersion and Prisms

P25.23 From the dispersion curve for fused quartz in the chapter (that is, the graph of its refractive index versus wavelength) we have

$$n_v=1.470 \text{ at } 400 \text{ nm} \quad \text{and} \quad n_r=1.458 \text{ at } 700 \text{ nm}.$$

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

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

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

P25.24 $n_1\sin\theta_1=n_2\sin\theta_2$: $\quad \theta_2=\sin^{-1}\left(\frac{n_1\sin\theta_1}{n_2}\right)$

$$\theta_2=\sin^{-1}\left(\frac{1.00\sin 30.0°}{1.50}\right)=\boxed{19.5°}$$

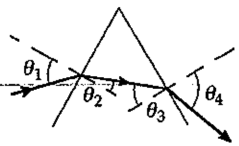


FIG. P25.24

The surface of entry, the surface of exit, and the ray within the prism form a triangle. Inside the triangle the angles must add up according to

$$90.0°-\theta_2+60.0°+90.0°-\theta_3=180°$$

$$\theta_3=([(90.0°-19.5°)+60.0°]-180°)+90.0°=\boxed{40.5°}$$

$n_3\sin\theta_3=n_4\sin\theta_4$: $\quad \theta_4=\sin^{-1}\left(\frac{n_3\sin\theta_3}{n_4}\right)=\sin^{-1}\left(\frac{1.50\sin 40.5°}{1.00}\right)=\boxed{77.1°}$

P25.25 At the first refraction, $\quad 1.00\sin\theta_1=n\sin\theta_2$.

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

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

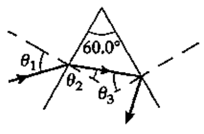


FIG. P25.25

But, $\quad \theta_2=60.0°-\theta_3$.

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

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

Since $\sin\theta_1=n\sin\theta_2$, this becomes $\quad \sin\theta_1>1.50\sin 18.2°=0.468$

or $\quad \theta_1>\boxed{27.9°}$.

P25.26 At the first refraction, $\quad 1.00\sin\theta_1=n\sin\theta_2$.

The critical angle at the second surface is given by

$n\sin\theta_3=1.00$, or $\quad \theta_3=\sin^{-1}\left(\frac{1.00}{n}\right)$.

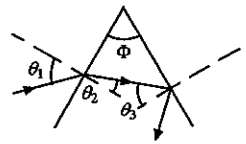


FIG. P25.26

But $\quad (90.0°-\theta_2)+(90.0°-\theta_3)+\Phi=180°$

which gives $\quad \theta_2=\Phi-\theta_3$.

Thus, to have $\theta_3<\sin^{-1}\left(\frac{1.00}{n}\right)$ and avoid total internal reflection at the second surface,

it is necessary that $\quad \theta_2>\Phi-\sin^{-1}\left(\frac{1.00}{n}\right)$.

Since $\sin\theta_1=n\sin\theta_2$, this requirement becomes $\quad \sin\theta_1>n\sin\left[\Phi-\sin^{-1}\left(\frac{1.00}{n}\right)\right]$

or $\quad \theta_1>\boxed{\sin^{-1}\left(n\sin\left[\Phi-\sin^{-1}\left(\frac{1.00}{n}\right)\right]\right)}$.

Through the application of trigonometric identities, $\quad \theta_1>\boxed{\sin^{-1}\left(\sqrt{n^2-1}\sin\Phi-\cos\Phi\right)}$.

As n increases, θ_1 increases. As Φ increases, both of the terms inside the parentheses increase, so θ_1 increases. It becomes easier to produce total internal reflection. If Φ decreases below $\tan^{-1}\left(\left(n^2-1\right)^{-1/2}\right)$ it becomes necessary for θ_1 to be negative for total internal reflection to occur. That is, the incident ray must be on the other side of the normal to the first surface, but the equation is still true. If the quantity $\sqrt{n^2-1}\sin\Phi-\cos\Phi$ is greater than 1, total internal reflection happens for all values of θ_1. However, if this quantity is greater than n, the ray internal to the prism never reaches the second surface.

P25.27 For the incoming ray, $\sin\theta_2 = \frac{\sin\theta_1}{n}$.

Using the figure to the right, $(\theta_2)_{violet} = \sin^{-1}\left(\frac{\sin 50.0°}{1.66}\right) = 27.48°$

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

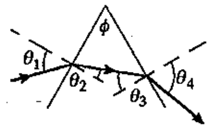


FIG. P25.27

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

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

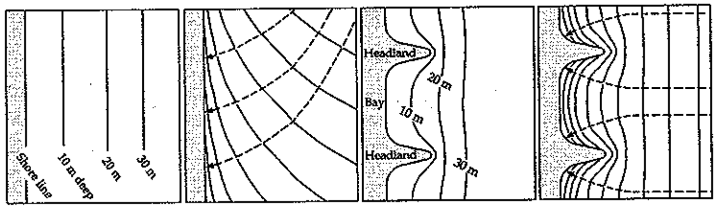
$(\theta_4)_{red} = \sin^{-1}[1.62\sin 31.78°] = 58.56°$.

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

Section 25.6 Huygens's Principle

P25.28 (a) For the diagrams of contour lines and wave fronts and rays, see Figures (a) and (b) below. As the waves move to shallower water, the wave fronts bend to become more nearly parallel to the contour lines.

(b) For the diagrams of contour lines and wave fronts and rays, see Figures (c) and (d) below. We suppose that the headlands are steep underwater, as they are above water. The rays are everywhere perpendicular to the wave fronts of the incoming refracting waves. As shown, the rays bend toward the headlands and deliver more energy per length at the headlands.



(a) Contour lines (b) Wave fronts and rays (c) Contour lines (d) Wave fronts and rays

FIG. P25.28

Section 25.7 Total Internal Reflection

P25.29 $n\sin\theta = 1$. From the table of refractive indices

(a) $\theta = \sin^{-1}\left(\frac{1}{2.419}\right) = \boxed{24.4°}$

(b) $\theta = \sin^{-1}\left(\frac{1}{1.66}\right) = \boxed{37.0°}$

(c) $\theta = \sin^{-1}\left(\frac{1}{1.309}\right) = \boxed{49.8°}$

P25.30 (a) $\frac{\sin\theta_2}{\sin\theta_1} = \frac{v_2}{v_1}$

and $\theta_2 = 90.0°$ at the critical angle

$$\frac{\sin 90.0°}{\sin\theta_c} = \frac{1\,850\text{ m/s}}{343\text{ m/s}}$$

so $\theta_c = \sin^{-1}(0.185) = \boxed{10.7°}$.

(b) Sound can be totally reflected if it is traveling in the medium where it travels slower: $\boxed{\text{air}}$.

(c) $\boxed{\text{Sound in air falling on the wall from most directions is 100\% reflected}}$, so the wall is a good mirror.

P25.31 $\sin\theta_c = \frac{n_2}{n_1}$

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

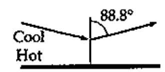


FIG. P25.31

P25.32 For plastic with index of refraction $\boxed{n \geq 1.42}$ surrounded by air, the critical angle for total internal reflection is given by

$$\theta_c = \sin^{-1}\left(\frac{1}{n}\right) \leq \sin^{-1}\left(\frac{1}{1.42}\right) = 44.8°.$$

In the gasoline gauge, skylight from above travels down the plastic. The rays close to the vertical are totally reflected from the sides of the slab and from both facets at the lower end of the plastic, where it is not immersed in gasoline. This light returns up inside the plastic and makes it look bright. Where the plastic is immersed in gasoline, with index of refraction about 1.50, total internal reflection should not happen. The light passes out of the lower end of the plastic with little reflected, making this part of the gauge look dark. To frustrate total internal reflection in the gasoline, the index of refraction of the plastic should be $\boxed{n < 2.12}$

since $\theta_c = \sin^{-1}\left(\frac{1.50}{2.12}\right) = 45.0°.$

Section 25.8 Context Connection—Optical Fibers

P25.33 $\sin\theta_c = \frac{n_{air}}{n_{pipe}} = \frac{1.00}{1.36} = 0.735 \qquad \theta_c = 47.3°$

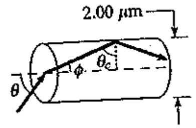


FIG. P25.33

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 $\boxed{\theta = 67.2°}$.

The 2-μm diameter is unnecessary information.

P25.34 For total internal reflection, $n_1 \sin\theta_1 = n_2 \sin 90.0°$

$1.50 \sin\theta_1 = 1.33(1.00)$ or $\theta_1 = \boxed{62.4°}$

P25.35 As the beam enters the slab,

$$1.00 \sin 50.0° = 1.48 \sin\theta_2$$

giving $\theta_2 = 31.2°$.

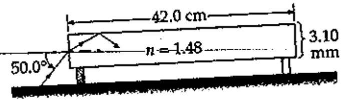


FIG. P25.35

The beam then strikes the top of the slab at $x_1 = \frac{1.55 \text{ mm}}{\tan 31.2°}$ from the left end. Thereafter, the beam strikes a face each time it has traveled a distance of $2x_1$ along the length of the slab. Since the slab is 420 mm long, the beam has an additional $420 \text{ mm} - x_1$ to travel after the first reflection. The number of additional reflections is

continued on next page

$$\frac{420 \text{ mm} - x_1}{2x_1} = \frac{420 \text{ mm} - 1.55 \text{ mm}/\tan 31.2°}{3.10 \text{ mm}/\tan 31.2°} = 81.5 \qquad \text{or 81 reflections}$$

since the answer must be an integer. The total number of reflections made in the slab is then $\boxed{82}$.

P25.36 (a) A ray along the inner edge will escape if any ray escapes. Its angle of incidence is described by $\sin\theta = \frac{R-d}{R}$ and by $n \sin\theta > 1 \sin 90°$. Then

$\frac{n(R-d)}{R} > 1 \qquad nR - nd > R \qquad nR - R > nd \qquad R > \boxed{\frac{nd}{n-1}}$.

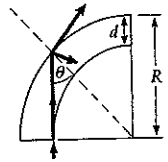


FIG. P25.36

(b) As $d \to 0$, $R_{min} \to 0$. This is reasonable.

As n increases, R_{min} decreases. This is reasonable.

As n decreases toward 1, R_{min} increases. This is reasonable.

(c) $R_{min} = \frac{1.40(100 \times 10^{-6} \text{ m})}{0.40} = \boxed{350 \times 10^{-6} \text{ m}}$

Additional Problems

*P25.37 For sheets 1 and 2 as described,

$n_1 \sin 26.5° = n_2 \sin 31.7°$

$0.849 n_1 = n_2$

For the trial with sheets 3 and 2,

$n_3 \sin 26.5° = n_2 \sin 36.7°$

$0.747 n_3 = n_2$

Now

$0.747 n_3 = 0.849 n_1$

$n_3 = 1.14 n_1$

For the third trial,

$n_1 \sin 26.5° = n_3 \sin\theta_3 = 1.14 n_1 \sin\theta_3$

$\theta_3 = \boxed{23.1°}$

*P25.38 Scattered light leaves the center of the photograph (a) in all horizontal directions between $\theta_1 = 0°$ and $90°$ from the normal. When it immediately enters the water (b), it is gathered into a fan between $0°$ and $\theta_{2\,max}$ given by

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$
$$1.00 \sin 90 = 1.333 \sin\theta_{2\,max}$$
$$\theta_{2\,max} = 48.6°$$

The light leaves the cylinder without deviation, so the viewer only receives light from the center of the photograph when he has turned by an angle less than 48.6°. When the paperweight is turned farther, light at the back surface undergoes total internal reflection (c). The viewer sees things outside the globe on the far side.

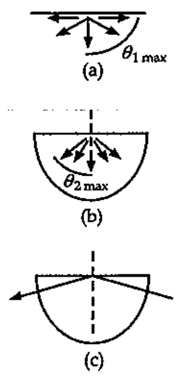


FIG. P25.38

P25.39 Let $n(x)$ be the index of refraction at distance x below the top of the atmosphere and $n(x=h)=n$ be its value at the planet surface.

Then,
$$n(x) = 1.000 + \left(\frac{n-1.000}{h}\right)x.$$

(a) The total time interval required to traverse the atmosphere is

$$\Delta t = \int_0^h \frac{dx}{v} = \int_0^h \frac{n(x)}{c}dx: \qquad \Delta t = \frac{1}{c}\int_0^h \left[1.000 + \left(\frac{n-1.000}{h}\right)x\right]dx$$

$$\Delta t = \frac{h}{c} + \frac{(n-1.000)}{ch}\left(\frac{h^2}{2}\right) = \boxed{\frac{h}{c}\left(\frac{n+1.000}{2}\right)}.$$

(b) The travel time in the absence of an atmosphere would be $\frac{h}{c}$.

Thus, the time in the presence of an atmosphere is $\boxed{\left(\frac{n+1.000}{2}\right) \text{ times larger}}$.

P25.40 (a) $\theta_1' = \theta_1 = \boxed{30.0°}$ $\quad n_1 \sin\theta_1 = n_2 \sin\theta_2$

$$1.00 \sin 30.0° = 1.55 \sin\theta_2$$
$$\theta_2 = \boxed{18.8°}$$

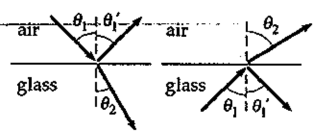


FIG. P25.40

(b) $\theta_1' = \theta_1 = \boxed{30.0°}$ $\quad \theta_2 = \sin^{-1}\left(\frac{n_1 \sin\theta_1}{n_2}\right)$

$$= \sin^{-1}\left(\frac{1.55 \sin 30.0°}{1}\right) = \boxed{50.8°}$$

continued on next page

(c), (d) The other entries are computed similarly, and are shown in the table below.

(c) air into glass, angles in degrees			(d) glass into air, angles in degrees		
incidence	reflection	refraction	incidence	reflection	refraction
0	0	0	0	0	0
10.0	10.0	6.43	10.0	10.0	15.6
20.0	20.0	12.7	20.0	20.0	32.0
30.0	30.0	18.8	30.0	30.0	50.8
40.0	40.0	24.5	40.0	40.0	85.1
50.0	50.0	29.6	50.0	50.0	none*
60.0	60.0	34.0	60.0	60.0	none*
70.0	70.0	37.3	70.0	70.0	none*
80.0	80.0	39.4	80.0	80.0	none*
90.0	90.0	40.2	90.0	90.0	none*

*total internal reflection

P25.41 For water, $\sin\theta_c = \frac{1}{4/3} = \frac{3}{4}$.

Thus $\theta_c = \sin^{-1}(0.750) = 48.6°$

and $d = 2[(1.00 \text{ m})\tan\theta_c]$

$$d = (2.00 \text{ m})\tan 48.6° = \boxed{2.27 \text{ m}}.$$

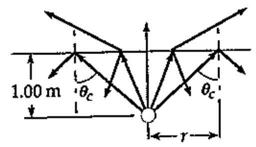


FIG. P25.41

P25.42 Call θ_1 the angle of incidence and of reflection on the left face and θ_2 those angles on the right face. Let α represent the complement of θ_1 and β be the complement of θ_2. Now $\alpha = \gamma$ and $\beta = \delta$ because they are pairs of alternate interior angles. We have

$$A = \gamma + \delta = \alpha + \beta$$

and $B = \alpha + A + \beta = \alpha + \beta + A = \boxed{2A}$.

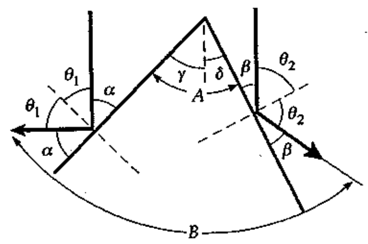


FIG. P25.42

P25.43 (a) We see the Sun moving from east to west across the sky. Its angular speed is

$$\omega = \frac{\Delta\theta}{\Delta t} = \frac{2\pi \text{ rad}}{86\,400 \text{ s}} = 7.27 \times 10^{-5} \text{ rad/s}.$$

The direction of sunlight crossing the cell from the window changes at this rate, moving on the opposite wall at speed

$$v = r\omega = (2.37 \text{ m})(7.27 \times 10^{-5} \text{ rad/s}) = 1.72 \times 10^{-4} \text{ m/s} = \boxed{0.172 \text{ mm/s}}.$$

continued on next page

(b) The mirror folds into the cell the motion that would occur in a room twice as wide:

$$v = r\omega = 2(0.174\ \text{mm/s}) = \boxed{0.345\ \text{mm/s}}.$$

(c), (d) As the Sun moves southward and upward at 50.0°, we may regard the corner of the window as fixed, and both patches of light move $\boxed{\text{northward and downward at } 50.0°}$.

P25.44 (a) $\boxed{45.0°}$ as shown in the first figure to the right.

(b) $\boxed{\text{Yes}}$

If grazing angle is halved, the number of reflections from the side faces is doubled.

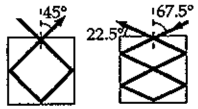


FIG. P25.44

P25.45 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, (the light that 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 $\frac{224°}{360°} = \boxed{62.2\% \text{ of a circle}}$.

This striking view motivated Charles Wilson's 1906 invention of the cloud chamber, a standard tool of nuclear physics. The effect is mentioned in the Bible Ezekiel 1:29.

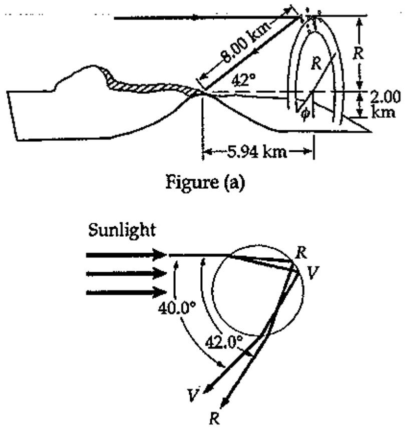


FIG. P25.45

P25.46 Light passing the top of the pole makes an angle of incidence $\phi_1 = 90.0° - \theta$. It falls on the water surface at distance from the pole

$$s_1 = \frac{L-d}{\tan\theta}$$

and has an angle of refraction ϕ_2 from $1.00\sin\phi_1 = n\sin\phi_2$.

Then $s_2 = d\tan\phi_2$

and the whole shadow length is

$$s_1 + s_2 = \frac{L-d}{\tan\theta} + d\tan\left(\sin^{-1}\left(\frac{\sin\phi_1}{n}\right)\right)$$

$$s_1 + s_2 = \frac{L-d}{\tan\theta} + d\tan\left(\sin^{-1}\left(\frac{\cos\theta}{n}\right)\right)$$

$$= \frac{2.00\ \text{m}}{\tan 40.0°} + (2.00\ \text{m})\tan\left(\sin^{-1}\left(\frac{\cos 40.0°}{1.33}\right)\right) = \boxed{3.79\ \text{m}}$$

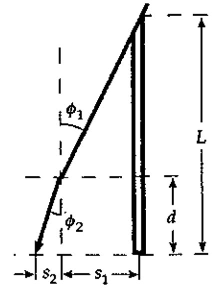


FIG. P25.46

P25.47 (a) $\frac{S_1'}{S_1} = \left[\frac{n_2 - n_1}{n_2 + n_1}\right]^2 = \left[\frac{1.52 - 1.00}{1.52 + 1.00}\right]^2 = \boxed{0.042\,6}$

(b) If medium 1 is glass and medium 2 is air, $\frac{S_1'}{S_1} = \left[\frac{n_2 - n_1}{n_2 + n_1}\right]^2 = \left[\frac{1.00 - 1.52}{1.00 + 1.52}\right]^2 = 0.042\,6$.

There is $\boxed{\text{no difference}}$.

P25.48 (a) With $n_1 = 1$

and $n_2 = n$

the reflected fractional intensity is $\frac{S_1'}{S_1} = \left(\frac{n-1}{n+1}\right)^2$.

The remaining intensity must be transmitted:

$$\frac{S_2}{S_1} = 1 - \left(\frac{n-1}{n+1}\right)^2 = \frac{(n+1)^2 - (n-1)^2}{(n+1)^2} = \frac{n^2 + 2n + 1 - n^2 + 2n - 1}{(n+1)^2} = \boxed{\frac{4n}{(n+1)^2}}.$$

(b) At entry, $\frac{S_2}{S_1} = 1 - \left(\frac{n-1}{n+1}\right)^2 = \frac{4(2.419)}{(2.419+1)^2} = 0.828$.

At exit, $\frac{S_3}{S_2} = 0.828$.

Overall, $\frac{S_3}{S_1} = \left(\frac{S_3}{S_2}\right)\left(\frac{S_2}{S_1}\right) = (0.828)^2 = 0.685$

or $\boxed{68.5\%}$.

P25.49 Define $T = \frac{4n}{(n+1)^2}$ as the transmission coefficient for one encounter with an interface. For diamond and air, it is 0.828, as in Problem P25.48.

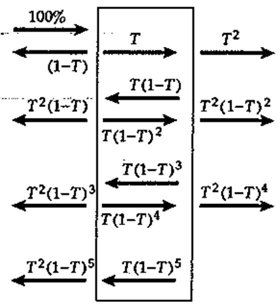


FIG. P25.49

As shown in the figure, the total amount transmitted is

$T^2+T^2(1-T)^2+T^2(1-T)^4+T^2(1-T)^6$
$+\ldots+T^2(1-T)^{2n}+\ldots$

We have $1-T=1-0.828=0.172$ so the total transmission is

$(0.828)^2\left[1+(0.172)^2+(0.172)^4+(0.172)^6+\ldots\right]$.

To sum this series, define $F=1+(0.172)^2+(0.172)^4+(0.172)^6+\ldots$.

Note that $(0.172)^2F=(0.172)^2+(0.172)^4+(0.172)^6+\ldots$, and
$1+(0.172)^2F=1+(0.172)^2+(0.172)^4+(0.172)^6+\ldots=F$.

Then, $1=F-(0.172)^2F$ or $F=\frac{1}{1-(0.172)^2}$.

The overall transmission is then $\frac{(0.828)^2}{1-(0.172)^2}=0.706$ or $\boxed{70.6\%}$.

P25.50 (a) As the mirror turns through angle θ, the angle of incidence increases by θ and so does the angle of reflection. The incident ray is stationary, so the reflected ray turns through angle 2θ. The angular speed of the reflected ray is $2\omega_m$. The speed of the dot of light on the circular wall is $\boxed{2\omega_m R}$.

(b) The two angles marked θ in the figure to the right are equal because their sides are perpendicular, right side to right side and left side to left side.

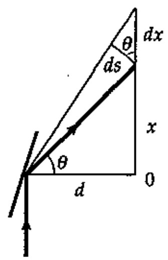


FIG. P25.50

We have $\cos\theta=\frac{d}{\sqrt{x^2+d^2}}=\frac{ds}{dx}$

and $\frac{ds}{dt}=2\omega_m\sqrt{x^2+d^2}$.

So $\frac{dx}{dt}=\frac{ds}{dt}\frac{\sqrt{x^2+d^2}}{d}=\boxed{2\omega_m\frac{x^2+d^2}{d}}$.

P25.51 Define n_1 to be the index of refraction of the surrounding medium and n_2 to be that for the prism material. We can use the critical angle of 42.0° to find the ratio $\frac{n_2}{n_1}$:

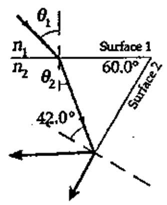


FIG. P25.51

$$n_2\sin 42.0°=n_1\sin 90.0°.$$

So, $\frac{n_2}{n_1}=\frac{1}{\sin 42.0°}=1.49$.

Call the angle of refraction θ_2 at the surface 1. The ray inside the prism forms a triangle with surfaces 1 and 2, so the sum of the interior angles of this triangle must be 180°.

Thus, $(90.0°-\theta_2)+60.0°+(90.0°-42.0°)=180°$.

Therefore, $\theta_2=18.0°$.

Applying Snell's law at surface 1, $n_1\sin\theta_1=n_2\sin 18.0°$

$\sin\theta_1=\left(\frac{n_2}{n_1}\right)\sin\theta_2=1.49\sin 18.0°$ $\boxed{\theta_1=27.5°}$.

***P25.52** The picture illustrates optical sunrise. At the center of the earth,

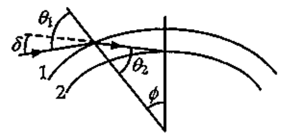


FIG. P25.52

$\cos\phi=\frac{6.37\times10^6\text{ m}}{6.37\times10^6\text{ m}+8\,614}$
$\phi=2.98°$
$\theta_2=90-2.98°=87.0°$

At the top of the atmosphere

$n_1\sin\theta_1=n_2\sin\theta_2$
$1\sin\theta_1=1.000\,293\sin 87.0°$
$\theta_1=87.4°$

Deviation upon entry is

$\delta=|\theta_1-\theta_2|$
$\delta=87.364°-87.022°=0.342°$

Sunrise of the optical day is before geometric sunrise by $0.342°\left(\frac{86\,400\text{ s}}{360°}\right)=82.2$ s. Optical sunset occurs later too, so the optical day is longer by $\boxed{164\text{ s}}$.

P25.53 (a) For polystyrene *surrounded by air*, internal reflection requires

$$\theta_3 = \sin^{-1}\left(\frac{1.00}{1.49}\right) = 42.2°.$$

Then from geometry, $\theta_2 = 90.0° - \theta_3 = 47.8°$.

From Snell's law, $\sin\theta_1 = 1.49 \sin 47.8° = 1.10$.

This has no solution.

Therefore, total internal reflection $\boxed{\text{always happens}}$.

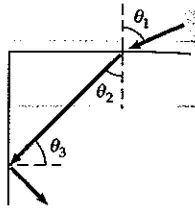


FIG. P25.53

(b) For polystyrene *surrounded by water*, $\theta_3 = \sin^{-1}\left(\frac{1.33}{1.49}\right) = 63.2°$

and $\theta_2 = 26.8°$.

From Snell's law, $\theta_1 = \boxed{30.3°}$.

(c) $\boxed{\text{No internal refraction is possible}}$

since the beam is initially traveling in a medium of lower index of refraction.

P25.54 $\delta = \theta_1 - \theta_2 = 10.0°$ and $n_1 \sin\theta_1 = n_2 \sin\theta_2$

with $n_1 = 1$, $n_2 = \frac{4}{3}$.

Thus, $\theta_1 = \sin^{-1}(n_2 \sin\theta_2) = \sin^{-1}[n_2 \sin(\theta_1 - 10.0°)]$.

(You can use a calculator to home in on an approximate solution to this equation, testing different values of θ_1 until you find that $\theta_1 = \boxed{36.5°}$. Alternatively, you can solve for θ_1 exactly, as shown below.)

We are given that $\sin\theta_1 = \frac{4}{3}\sin(\theta_1 - 10.0°)$.

This is the sine of a difference, so $\frac{3}{4}\sin\theta_1 = \sin\theta_1 \cos 10.0° - \cos\theta_1 \sin 10.0°$.

Rearranging, $\sin 10.0° \cos\theta_1 = \left(\cos 10.0° - \frac{3}{4}\right)\sin\theta_1$

$\frac{\sin 10.0°}{\cos 10.0° - 0.750} = \tan\theta_1$ and $\theta_1 = \tan^{-1}(0.740) = \boxed{36.5°}$.

P25.55 $\tan\theta_1 = \frac{4.00 \text{ cm}}{h}$

and $\tan\theta_2 = \frac{2.00 \text{ cm}}{h}$

$$\tan^2\theta_1 = (2.00 \tan\theta_2)^2 = 4.00 \tan^2\theta_2$$

$$\frac{\sin^2\theta_1}{1-\sin^2\theta_1} = 4.00\left(\frac{\sin^2\theta_2}{1-\sin^2\theta_2}\right). \quad (1)$$

Snell's law in this case is: $n_1 \sin\theta_1 = n_2 \sin\theta_2$

$\sin\theta_1 = 1.333 \sin\theta_2$.

Squaring both sides, $\sin^2\theta_1 = 1.777 \sin^2\theta_2$. (2)

Substituting (2) into (1), $\frac{1.777\sin^2\theta_2}{1-1.777\sin^2\theta_2} = 4.00\left(\frac{\sin^2\theta_2}{1-\sin^2\theta_2}\right)$.

Defining $x = \sin^2\theta$, $\frac{0.444}{1-1.777x} = \frac{1}{1-x}$.

Solving for x, $0.444 - 0.444x = 1 - 1.777x$ and $x = 0.417$.

From x we can solve for θ_2: $\theta_2 = \sin^{-1}\sqrt{0.417} = 40.2°$.

Thus, the height is $h = \frac{2.00 \text{ cm}}{\tan\theta_2} = \frac{2.00 \text{ cm}}{\tan 40.2°} = \boxed{2.36 \text{ cm}}$.

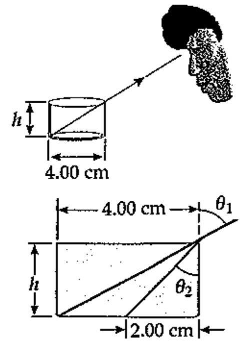


FIG. P25.55

P25.56 Observe in the sketch that the angle of incidence at point P is γ, and using triangle OPQ:

$$\sin\gamma = \frac{L}{R}.$$

Also, $\cos\gamma = \sqrt{1-\sin^2\gamma} = \frac{\sqrt{R^2-L^2}}{R}$.

Applying Snell's law at point P, $1.00 \sin\gamma = n \sin\phi$.

Thus, $\sin\phi = \frac{\sin\gamma}{n} = \frac{L}{nR}$

and $\cos\phi = \sqrt{1-\sin^2\phi} = \frac{\sqrt{n^2R^2-L^2}}{nR}$.

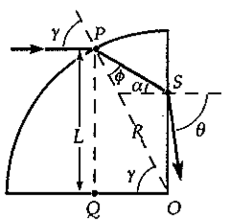


FIG. P25.56

From triangle OPS, $\phi + (\alpha + 90.0°) + (90.0° - \gamma) = 180°$ or the angle of incidence at point S is $\alpha = \gamma - \phi$. Then, applying Snell's law at point S

continued on next page

gives $1.00\sin\theta = n\sin\alpha = n\sin(\gamma-\phi)$

or $\sin\theta = n[\sin\gamma\cos\phi - \cos\gamma\sin\phi] = n\left[\left(\frac{L}{R}\right)\frac{\sqrt{n^2R^2-L^2}}{nR} - \frac{\sqrt{R^2-L^2}}{R}\left(\frac{L}{nR}\right)\right]$

$$\sin\theta = \frac{L}{R^2}\left(\sqrt{n^2R^2-L^2}-\sqrt{R^2-L^2}\right)$$

and $\theta = \boxed{\sin^{-1}\left[\frac{L}{R^2}\left(\sqrt{n^2R^2-L^2}-\sqrt{R^2-L^2}\right)\right]}$.

P25.57 As shown in the sketch, the angle of incidence at point A is:

$$\theta = \sin^{-1}\left(\frac{d/2}{R}\right) = \sin^{-1}\left(\frac{1.00\text{ m}}{2.00\text{ m}}\right) = 30.0°.$$

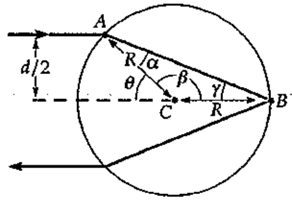


FIG. P25.57

If the emerging ray is to be parallel to the incident ray, the path must be symmetric about the centerline CB of the cylinder. In the isosceles triangle ABC,

$$\gamma = \alpha \quad \text{and} \quad \beta = 180° - \theta.$$

Therefore, $\alpha + \beta + \gamma = 180°$

becomes $2\alpha + 180° - \theta = 180°$

or $\alpha = \frac{\theta}{2} = 15.0°$.

Then, applying Snell's law at point A,

$$n\sin\alpha = 1.00\sin\theta$$

or $n = \frac{\sin\theta}{\sin\alpha} = \frac{\sin 30.0°}{\sin 15.0°} = \boxed{1.93}$.

P25.58

$\sin\theta_1$	$\sin\theta_2$	$\frac{\sin\theta_1}{\sin\theta_2}$
0.174	0.131	1.330 4
0.342	0.261	1.312 9
0.500	0.379	1.317 7
0.643	0.480	1.338 5
0.766	0.576	1.328 9
0.866	0.647	1.339 0
0.940	0.711	1.322 0
0.985	0.740	1.331 5

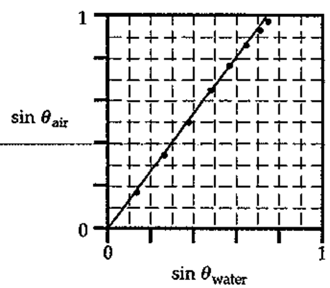


FIG. P25.58

The straightness of the graph line demonstrates Snell's proportionality.

The slope of the line is $\bar{n} = 1.327\,6 \pm 0.01$

and $n = \boxed{1.328 \pm 0.8\%}$.

P25.59 (a) Given that $\theta_1 = 45.0°$ and $\theta_2 = 76.0°$.

Snell's law at the first surface gives

$$n\sin\alpha = 1.00\sin 45.0°. \quad (1)$$

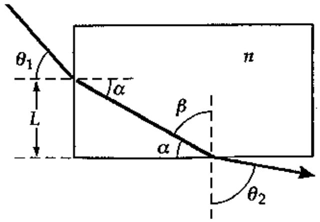


FIG. P25.59

Observe that the angle of incidence at the second surface is

$$\beta = 90.0° - \alpha.$$

Thus, Snell's law at the second surface yields

$$n\sin\beta = n\sin(90.0° - \alpha) = 1.00\sin 76.0°$$

or $n\cos\alpha = \sin 76.0°$. (2)

Dividing Equation (1) by Equation (2), $\tan\alpha = \frac{\sin 45.0°}{\sin 76.0°} = 0.729$

or $\alpha = 36.1°$.

Then, from Equation (1), $n = \frac{\sin 45.0°}{\sin\alpha} = \frac{\sin 45.0°}{\sin 36.1°} = \boxed{1.20}$.

(b) From the sketch, observe that the distance the light travels in the plastic is $d = \frac{L}{\sin\alpha}$. Also, the speed of light in the plastic is $v = \frac{c}{n}$, so the time required to travel through the plastic is

$$\Delta t = \frac{d}{v} = \frac{nL}{c\sin\alpha} = \frac{1.20(0.500\text{ m})}{(3.00\times10^8\text{ m/s})\sin 36.1°} = 3.40\times10^{-9}\text{ s} = \boxed{3.40\text{ ns}}.$$

***P25.60** Consider an insulated box with the imagined one-way mirror forming one face, installed so that 90% of the electromagnetic radiation incident from the outside is transmitted to the inside and only a lower percentage of the electromagnetic waves from the inside make it through to the outside. Suppose the interior and exterior of the box are originally at the same temperature. Objects within and without are radiating and absorbing electromagnetic waves. They would all maintain constant temperature if the box had an open window. With the glass letting more energy in than out, the interior of the box will rise in temperature. But this is impossible, according to Clausius's statement of the second law. This reduction to a contradiction proves that it is impossible for the one-way mirror to exist.

ANSWERS TO EVEN PROBLEMS

P25.2 see the solution

P25.4 25.5°; 442 nm

P25.6 (a) 474 THz; (b) 422 nm; (c) 200 Mm/s

P25.8 22.5°

P25.10 (a) 1.52; (b) 417 nm; (c) 474 THz; (d) 198 Mm/s