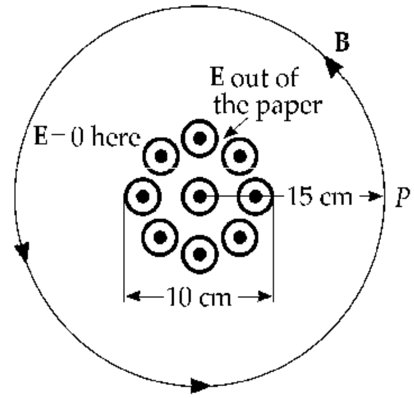
24.1 We use the extended form of Ampere's law, Equation 24.7. Since no moving charges are present,



$$I = 0$$

and we have $$\oint \mathbf{B} \cdot d\boldsymbol{\ell} = \mu_0 \epsilon_0 \frac{d\Phi_E}{dt}$$

In order to evaluate the integral, we make use of the symmetry of the situation. Symmetry requires that no particular direction from the center can be any different from any other direction. Therefore, the must be *circular symmetry* about the central axis. We know the magnetic field lines are circles about the axis. Therefore, as we travel around such a magnetic field circle, the magnetic field remains constant in magnitude. Setting aside until later the determination of the *direction* of **B**, we integrate $\oint \mathbf{B} \cdot d\boldsymbol{\ell}$ around the circle

at $$R = 0.15 \text{ m}$$

to obtain $$2\pi RB$$

Differentiating the expression $$\Phi_E = AE$$

we have $$\frac{d\Phi_E}{dt} = \left(\frac{\pi d^2}{4}\right)\frac{dE}{dt}$$

Thus, $$\oint \mathbf{B} \cdot d\boldsymbol{\ell} = 2\pi RB = \mu_0 \epsilon_0 \left(\frac{\pi d^2}{4}\right)\frac{E}{dt}$$

Solving for B gives $$B = \frac{\mu_0 \epsilon_0}{2\pi R}\left(\frac{\pi d^2}{4}\right)\frac{dE}{dt}$$

Substituting numerical values, $$B = \frac{\left(4\pi \times 10^{-7} \text{ H/m}\right)\left(8.85 \times 10^{-12} \text{ F/m}\right)\left[\pi (0.10 \text{ m})^2\right](20 \text{ V/m} \cdot \text{s})}{2\pi (0.15 \text{ m})(4)}$$

$$B = \boxed{1.85 \times 10^{-18} \text{ T}}$$

In Figure 24.1, the direction of the *increase* of the electric field is out the plane of the paper. By the right-hand rule, this implies that the direction of **B** is *counterclockwise*. Thus, the direction of **B** at P is upwards.

***24.3** (a) Since the light from this star travels at $3.00\times10^8\ \text{m/s}$

the last bit of light will hit the Earth in $\dfrac{6.44\times10^{18}\ \text{m}}{3.00\times10^8\ \text{m/s}} = 2.15\times10^{10}\ \text{s} = 680\ \text{years}$

Therefore, it will disappear from the sky in the year $2002+680 = \boxed{2.68\times10^3\ \text{C.E.}}$

The star is 680 light-years away.

(b) $\Delta t = \dfrac{\Delta x}{v} = \dfrac{1.496\times10^{11}\ \text{m}}{3\times10^8\ \text{m/s}} = \boxed{499\ \text{s}} = 8.31\ \text{min}$

(c) $\Delta t = \dfrac{\Delta x}{v} = \dfrac{2\left(3.84\times10^8\ \text{m}\right)}{3\times10^8\ \text{m/s}} = \boxed{2.56\ \text{s}}$

(d) $\Delta t = \dfrac{\Delta x}{v} = \dfrac{2\pi\left(6.37\times10^8\ \text{m}\right)}{3\times10^8\ \text{m/s}} = \boxed{0.133\ \text{s}}$

(e) $\Delta t = \dfrac{\Delta x}{v} = \dfrac{10\times10^3\ \text{m}}{3\times10^8\ \text{m/s}} = \boxed{3.33\times10^{-5}\ \text{s}}$

24.5 (a) $f\lambda = c$

or $f(50.0\ \text{m}) = 3.00\times10^8\ \text{m/s}$

so $\boxed{f = 6.00\times10^6\ \text{Hz} = 6.00\ \text{MHz}}$

(b) $\dfrac{E}{B} = c$

or $\dfrac{22.0}{B_{\text{max}}} = 3.00\times10^8$

so $\mathbf{B}_{\text{max}} = \boxed{-73.3\mathbf{k}\ \text{nT}}$

(c) $k = \dfrac{2\pi}{\lambda} = \dfrac{2\pi}{50.0} = 0.126\ \text{m}^{-1}$

and $\omega = 2\pi f = 2\pi\left(6.00\times10^6\ \text{s}^{-1}\right) = 3.77\times10^7\ \text{rad/s}$

$\mathbf{B} = \mathbf{B}_{\text{max}}\cos(kx-\omega t) = \boxed{-73.3\cos\left(0.126x - 3.77\times10^7 t\right)\mathbf{k}\ \text{nT}}$

24.7 (a) $B = \frac{E}{c} = \frac{100\ \text{V/m}}{3.00 \times 10^8\ \text{m/s}} = 3.33 \times 10^{-7}\ \text{T} = \boxed{0.333\ \mu\text{T}}$

(b) $\lambda = \frac{2\pi}{k} = \frac{2\pi}{1.00 \times 10^7\ \text{m}^{-1}} = \boxed{0.628\ \mu\text{m}}$

(c) $f = \frac{c}{\lambda} = \frac{3.00 \times 10^8\ \text{m/s}}{6.28 \times 10^{-7}\ \text{m}} = \boxed{4.77 \times 10^{14}\ \text{Hz}}$

24.16 $S = I = \frac{U}{At} = \frac{Uc}{V} = uc$ $\qquad \frac{\text{Energy}}{\text{Unit Volume}} = u = \frac{I}{c} = \frac{1000\ \text{W/m}^2}{3.00 \times 10^8\ \text{m/s}} = \boxed{3.33\ \mu\text{J/m}^3}$

24.19 Power output = (power input)(efficiency)

Thus, $\text{Power input} = \frac{\text{Power out}}{\text{eff}} = \frac{1.00 \times 10^6\ \text{W}}{0.300} = 3.33 \times 10^6\ \text{W}$

and $A = \frac{\mathcal{P}}{I} = \frac{3.33 \times 10^6\ \text{W}}{1.00 \times 10^3\ \text{W/m}^2} = \boxed{3.33 \times 10^3\ \text{m}^2}$

***24.22** $\text{Power} = SA = \frac{E_{\text{max}}^2}{2\mu_0 c}\left(4\pi r^2\right)$

Solving for r, $r = \sqrt{\frac{\mathcal{P}\mu_0 c}{2\pi E_{\text{max}}^2}} = \sqrt{\frac{(100\ \text{W})\mu_0 c}{2\pi(15.0\ \text{V/m})^2}} = \boxed{5.16\ \text{m}}$

24.48 (a) $\mathcal{P} = SA$: $\qquad \mathcal{P} = \left(1340\ \text{W/m}^2\right)\left[4\pi\left(1.496 \times 10^{11}\ \text{m}\right)^2\right] = \boxed{3.77 \times 10^{26}\ \text{W}}$

(b) $S = \frac{cB_{\text{max}}^2}{2\mu_0}$ so $\qquad B_{\text{max}} = \sqrt{\frac{2\mu_0 S}{c}} = \sqrt{\frac{2\left(4\pi \times 10^{-7}\ \text{N/A}^2\right)\left(1340\ \text{W/m}^2\right)}{3.00 \times 10^8\ \text{m/s}}} = \boxed{3.35\ \mu\text{T}}$

$S = \frac{E_{\text{max}}^2}{2\mu_0 c}$ so $\qquad E_{\text{max}} = \sqrt{2\mu_0 c S} = \sqrt{2\left(4\pi \times 10^{-7}\right)\left(3.00 \times 10^8\right)(1340)} = \boxed{1.01\ \text{kV/m}}$

24.24 (a) $\mathcal{P} = (S_{av})A = (6.00\ \text{W/m}^2)(40.0\times10^{-4}\ \text{m}^2) = 2.40\times10^{-2}\ \text{J/s}$

In one second, the total energy U impinging on the mirror is 2.40×10^{-2} J. The momentum p transferred *each second* for total reflection is

$$p = \frac{2U}{c} = \frac{2(2.40\times10^{-2}\ \text{J})}{3.00\times10^{8}\ \text{m/s}} = \boxed{1.60\times10^{-10}\ \text{kg}\cdot\text{m/s}}$$

(b) $F = \dfrac{dp}{dt} = \dfrac{1.60\times10^{-10}\ \text{kg}\cdot\text{m/s}}{1\ \text{s}} = \boxed{1.60\times10^{-10}\ \text{N}}$

24.32 $f = \dfrac{c}{\lambda} = \dfrac{3.00\times10^{8}\ \text{m/s}}{5.50\times10^{-7}\ \text{m}} = \boxed{5.45\times10^{14}\ \text{Hz}}$

***24.33** (a) $f\lambda = c$ gives $(5.00\times10^{19}\ \text{Hz})\lambda = 3.00\times10^{8}\ \text{m/s}$: $\boxed{\lambda = 6.00\times10^{-12}\ \text{m} = 6.00\ \text{pm}}$

(b) $f\lambda = c$ gives $(4.00\times10^{9}\ \text{Hz})\lambda = 3.00\times10^{8}\ \text{m/s}$: $\boxed{\lambda = 0.075\ \text{m} = 7.50\ \text{cm}}$

24.34 (a) $\lambda = \dfrac{c}{f} = \dfrac{3.00\times10^{8}\ \text{m/s}}{1150\times10^{3}\ \text{s}^{-1}} = 261\ \text{m}$ so $\dfrac{180\ \text{m}}{261\ \text{m}} = \boxed{0.690\ \text{wavelengths}}$

(b) $\lambda = \dfrac{c}{f} = \dfrac{3.00\times10^{8}\ \text{m/s}}{98.1\times10^{6}\ \text{s}^{-1}} = 3.06\ \text{m}$ so $\dfrac{180\ \text{m}}{3.06\ \text{m}} = \boxed{58.9\ \text{wavelengths}}$

24.40 Let the first sheet have its axis at angle θ to the original plane of polarization, and let each further sheet have its axis turned by the same angle.

The first sheet passes intensity $I_{\max}\cos^2\theta$

The second sheet passes $I_{\max}\cos^4\theta$

and the n^{th} sheet lets through $I_{\max}\cos^{2n}\theta \geq 0.90 I_{\max}$ where $\theta = 45°/n$

Try different integers to find $\cos^{2\times5}\left(\dfrac{45°}{5}\right) = 0.885$ $\cos^{2\times6}\left(\dfrac{45°}{6}\right) = 0.902$

(a) So $n = \boxed{6}$

(b) $\theta = \boxed{7.50°}$

24.51 Think of light going up and being absorbed by the bead, which presents face area πr_b^2.

If we take the bead to be perfectly absorbing, the light pressure is $P = \frac{S_{av}}{c} = \frac{I}{c} = \frac{F_\ell}{A}$

(a) $$F_\ell = F_g$$

so $$I = \frac{F_\ell c}{A} = \frac{F_g c}{A} = \frac{mgc}{\pi r_b^2}$$

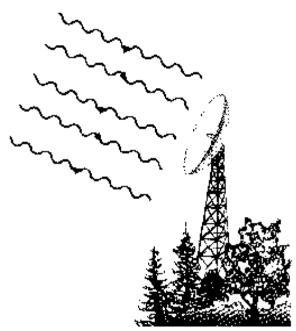
From the definition of density, $$\rho = \frac{m}{V} = \frac{m}{\frac{4}{3}\pi r_b^3}$$

so $$\frac{1}{r_b} = \left(\frac{\frac{4}{3}\pi\rho}{m}\right)^{1/3}$$

Substituting for r_b, $$I = \frac{mgc}{\pi}\left(\frac{4\pi\rho}{3m}\right)^{2/3} = gc\left(\frac{4\rho}{3}\right)^{2/3}\left(\frac{m}{\pi}\right)^{1/3} = \boxed{\frac{4\rho gc}{3}\left(\frac{3m}{4\pi\rho}\right)^{1/3}}$$

(b) $\mathcal{P} = IA$ $$\mathcal{P} = \boxed{\frac{4\pi r^2 \rho gc}{3}\left(\frac{3m}{4\pi\rho}\right)^{1/3}}$$

24.52 (a) $B_{max} = \frac{E_{max}}{c} = \boxed{6.67 \times 10^{-16}\ \text{T}}$



(b) $S_{av} = \frac{E_{max}^2}{2\mu_0 c} = \boxed{5.31 \times 10^{-17}\ \text{W/m}^2}$

(c) $\mathcal{P} = S_{av}A = \boxed{1.67 \times 10^{-14}\ \text{W}}$

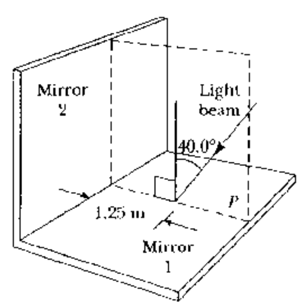
(d) $F = PA = \left(\frac{S_{av}}{c}\right)A = \boxed{5.56 \times 10^{-23}\ \text{N}}$ ($\cong$ the weight of 3000 H atoms!)

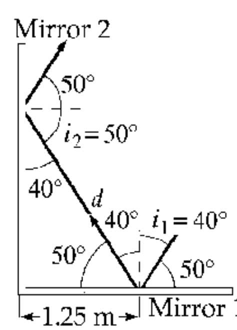
25.9 (a) From geometry, $1.25\ \text{m} = d \sin 40.0°$

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

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

or parallel to the incident ray



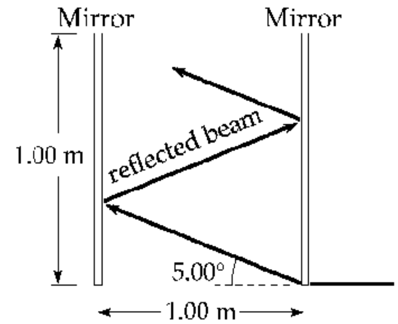


25.11 The incident light reaches the left-hand mirror at distance

$$(1.00\text{ m})\tan 5.00° = 0.0875\text{ m}$$

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

$$2(0.0875\text{ m}) = 0.175\text{ m}$$



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

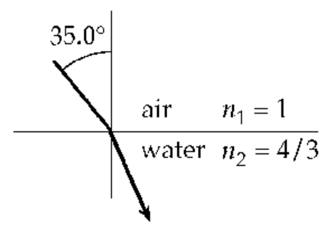
Since $$\frac{1.00\text{ m}}{0.175\text{ m}} = 5.72$$

the light reflects **five times from the right-hand mirror and six times from the left.**

25.1 Using Snell's law, $$\sin\theta_2 = \frac{n_1}{n_2}\sin\theta_1$$

$$\theta_2 = \boxed{25.5°}$$

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



25.2 (a) $$f = \frac{c}{\lambda} = \frac{3.00\times 10^8\text{ m/s}}{6.328\times 10^{-7}\text{ m}} = \boxed{4.74\times 10^{14}\text{ Hz}}$$

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

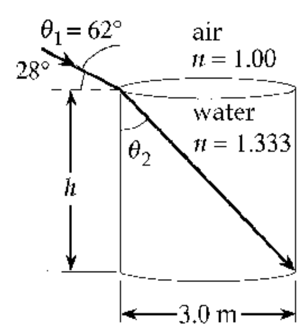
(c) $$v_{\text{glass}} = \frac{c_{\text{air}}}{n} = \frac{3.00\times 10^8\text{ m/s}}{1.50} = 2.00\times 10^8\text{ m/s} = \boxed{200\text{ Mm/s}}$$

25.8 $$\sin\theta_1 = n_w \sin\theta_2$$

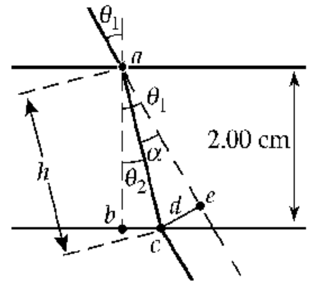
$$\sin\theta_2 = \frac{1}{1.333}\sin\theta_1 = \frac{1}{1.333}\sin(90.0° - 28.0°) = 0.662$$

$$\theta_2 = \sin^{-1}(0.662) = 41.5°$$

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



25.13 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

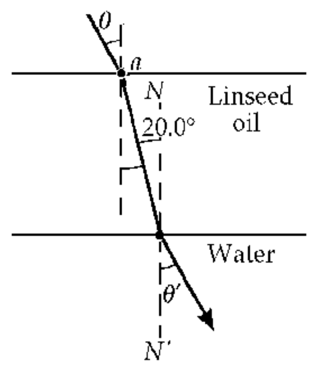
$$\cos\theta_2 = \frac{2.00 \text{ cm}}{h}$$

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

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

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

25.15 Applying Snell's law at the air-oil interface,



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

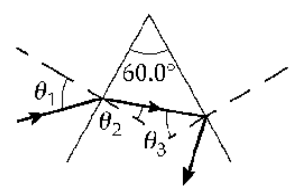
yields $\boxed{\theta = 30.4°}$

Applying Snell's law at the oil-water interface

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

yields $\boxed{\theta' = 22.3°}$

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



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

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 $\theta_1 > \boxed{27.9°}$

25.25 $n \sin\theta = 1$. From Table 25.1,

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

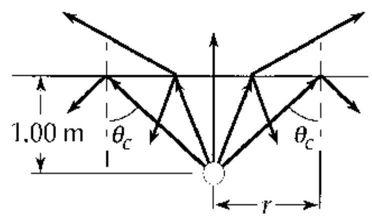
(b) $\theta = \sin^{-1}\left(\frac{1}{1.66}\right) = \boxed{37.0^\circ}$

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

***25.32** For total internal reflection, $n_1 \sin\theta_1 = n_2 \sin 90.0^\circ$

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

25.35 For water, $\sin\theta_c = \frac{1}{4/3} = \frac{3}{4}$



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

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

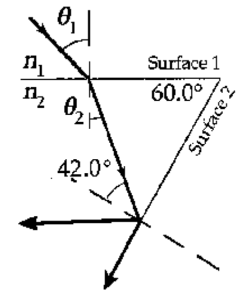
$d = (2.00\text{ m})\tan 48.6^\circ = \boxed{2.27\text{ m}}$

***25.42** (a) $\frac{S_1'}{S_1} = \left[\frac{n_2 - n_1}{n_2 + n_1}\right]^2 = \left[\frac{1.52 - 1.00}{1.52 + 1.00}\right]^2 = \boxed{0.0426}$

(b) If medium 1 is glass and medium 2 is air, $\frac{S_1'}{S_1} = \left[\frac{n_2 - n_1}{n_2 + n_1}\right]^2 = \left[\frac{1.00 - 1.52}{1.00 + 1.52}\right]^2 = 0.0426$

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

25.45 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 n_2 / n_1:



$$n_2 \sin 42.0° = n_1 \sin 90.0°$$

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°.

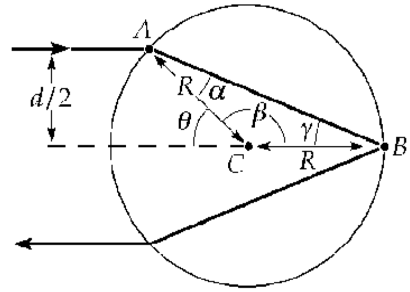
Thus, $$(90.0° - \theta_2) + 60.0° + (90.0° - 42.0°) = 180°$$

Therefore, $$\theta_2 = 18.0°$$

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

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

***25.52** As shown in the sketch, the angle of incidence at point A is:



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

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,

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

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