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CHAPTER 34

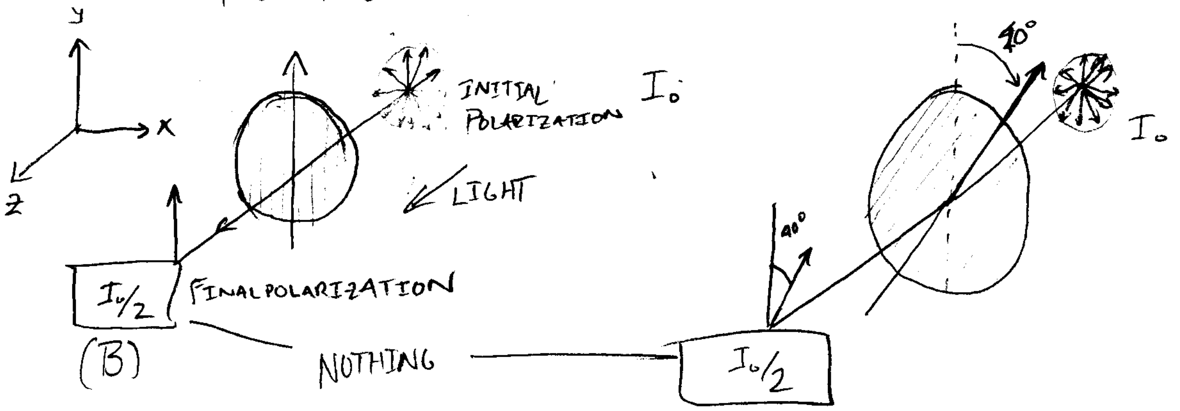
E + M WAVES

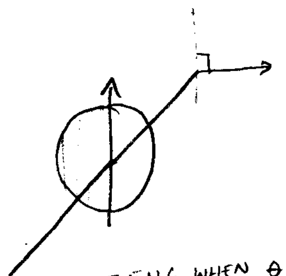
QUESTIONS: 3, 9, 13, 15

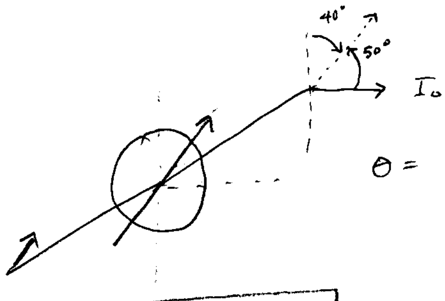
PROBLEMS: 2, 4, 8, 19, 27, 39, 58, 67, 77, 84, 85

Q3

(A) IT TURNS OUT THAT UNPOLARIZED LIGHT CONSISTS OF RANDOMLY POLARIZED LIGHT (THINK SUPERPOSITION PRINCIPLE). THE EFFECT OF THE POLARIZER IS TO PICK ONE OF THOSE RANDOM DIRECTIONS AND LET IT THROUGH. THE EFFECT OF ROTATING THE POLARIZER ONLY CHANGES THE DIRECTION OF POLARIZATION FOR THE LIGHT THAT GETS THROUGH $\boxed{\text{NOT THE INTENSITY}}$. SINCE ALL INITIAL RANDOM DIRECTIONS HAVE SAME AVERAGE INTENSITY. YOU HAVE NOW CREATED POLARIZED LIGHT. WITH







$\theta = 90° - 40° = 50°$

$I = 0$ (NOTHING WHEN $\theta = 90°$)

$I = I_0 \cos^2 90° = 0$

$\boxed{I = 0}$ —— INCREASE —— $\boxed{I = I_0 \cos^2 50°}$

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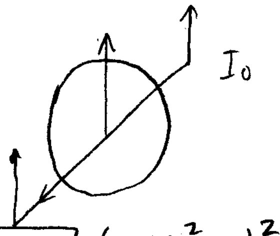
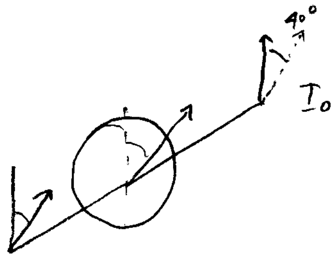
(C)





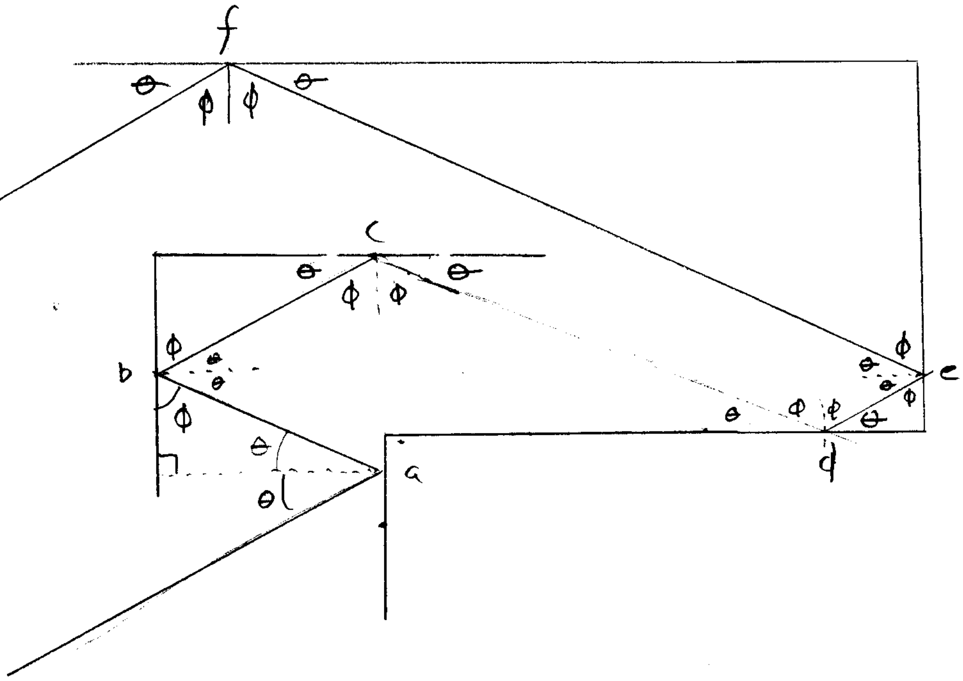
$\boxed{I = I_0}$ $\left((\cos 0)^2 = 1^2\right)$

ALL GETS THROUGH

$\boxed{I = I_0 \cos^2(40°)}$

DECREASE

Q9

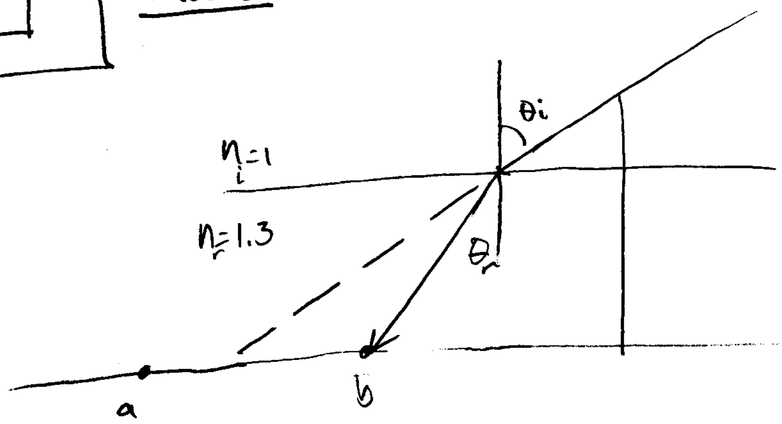


$\theta = 30°$

$\phi = 90 - \theta = 60°$

a) $\theta = 30°$
b) $\theta = 30°$
c) $\phi = 60°$
d) $\phi = 60°$
e) $\theta = 30°$
f) $\phi = 60°$

Q13



ACCORDING TO SNELL

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

$$\frac{\sin\theta_i}{\sin\theta_r} = \frac{n_r}{n_i} = \frac{1.3}{1} = 1.3$$

$\sin\theta_i = 1.3 \sin\theta_r$

SO $\sin\theta_i > \sin\theta_r$

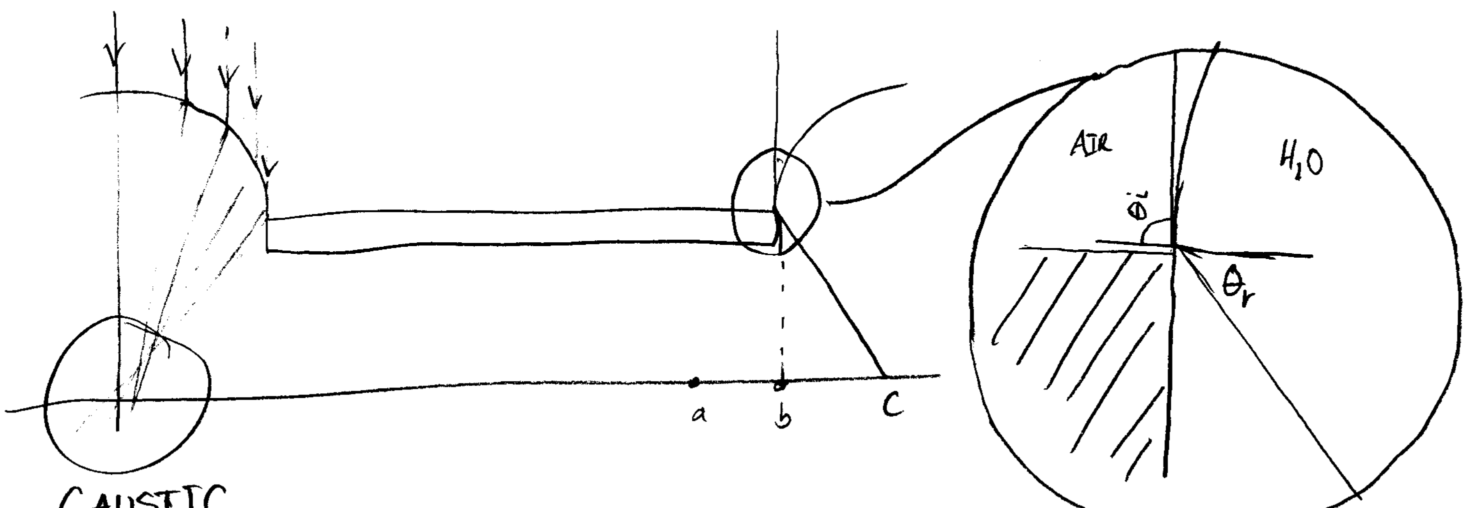
$\Rightarrow$ $\boxed{\theta_i > \theta_r}$

SEE DRAWING...

a) $\boxed{b}$

b) blue gets bent more, red bent less. So $\boxed{\text{BLUE IS CLOSER}}$

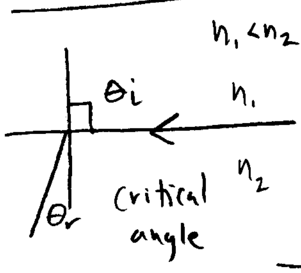
c) $\boxed{C}$



$\theta_i = 90°$ ish

Q15

you can only get total internal reflection when you go from a high index of refraction to a lower index of refraction (H_2O to Air, Fiber optic to Air, $n = 1.5$ to $n = 1.4$, $n = 1.5$ to $n = 1.3$)



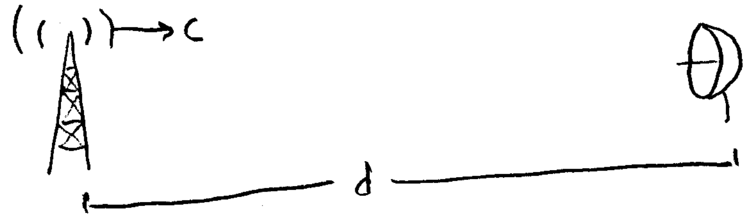
$\boxed{\text{LIGHT CAN ONLY GET TRAPPED IN THE SLOWEST MEDIUM, } N = 1.5}$

PROBLEMS

P2

radio waves are light, light moves at c, the speed of light.

a)



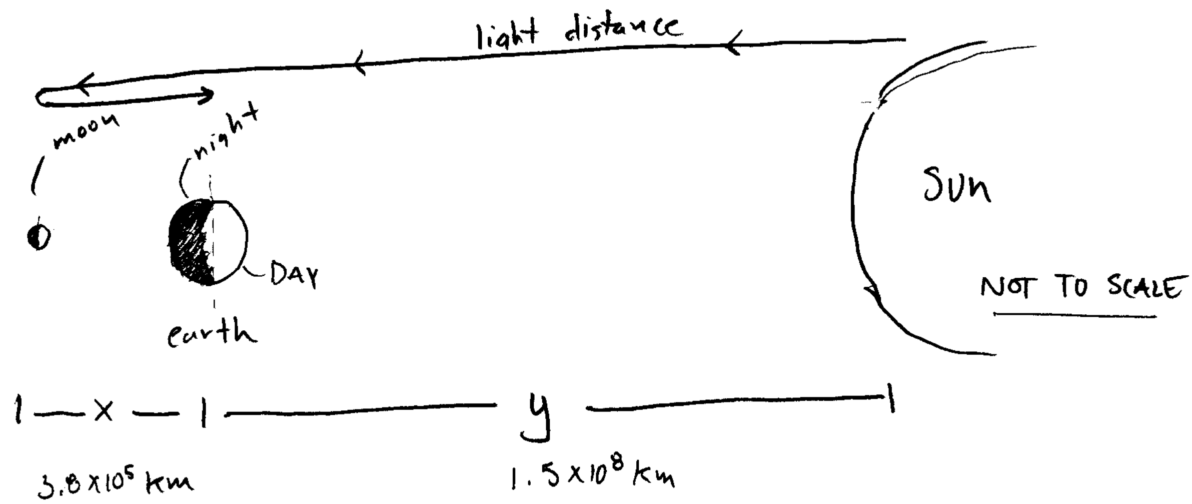
$d = rt$ $\qquad$ $d = 150\ \text{km}$

$t = \dfrac{d}{r}$ $\qquad$ $r = c = 3\times10^{8}\ \text{m/s}$

$$t = \frac{\overset{50}{\cancel{150}} \times 10^{\cancel{3}}\ \cancel{\text{m}}}{\cancel{3} \times 10^{\cancel{8}\,5}\ \cancel{\text{m}}/\text{s}} = \frac{50\ \text{s}}{1\times10^{5}} = 50\times10^{-5}\ \text{s} = 0.5\ \text{ms}$$

(a) $\boxed{t = .5\ \text{ms}}$ $(5\times10^{-4}\ \text{s})$

(b)



$d = rt$, $d = (x+y) + x = 2x + y$, $c = 3\times10^{8}\ \text{m/s} = 3\times10^{5}\ \frac{\text{km}}{\text{s}}$

$$t = \frac{d}{r} = \frac{2x+y}{c} = \frac{2(3.8\times10^{5}\ \text{km}) + 1.5\times10^{8}\ \text{km}}{3\times10^{5}\ \text{km/s}}$$

$$t = \frac{7.6 \times \cancel{10^{5}}\ \text{km}}{3\times\cancel{10^{5}}\ \frac{\text{km}}{\text{s}}} + \frac{\overset{.5}{\cancel{1.5}}\times10^{\cancel{8}\,3}\ \text{km}}{\cancel{3}\times\cancel{10^{5}}\ \text{km/s}} = \frac{7.6}{3} + .5\times10^{3} = \underbrace{\frac{7.6}{3}}_{2\times\text{Earth-moon}} + \underbrace{500}_{\text{Sun-earth}} = \boxed{502.5\ \text{s} = t}$$

~ 8.5 min

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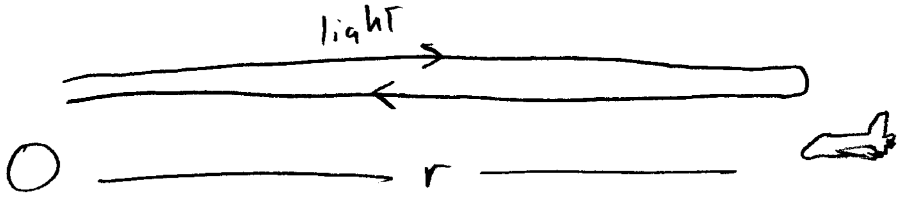
(c)



$r = 1.3 \times 10^9$ km

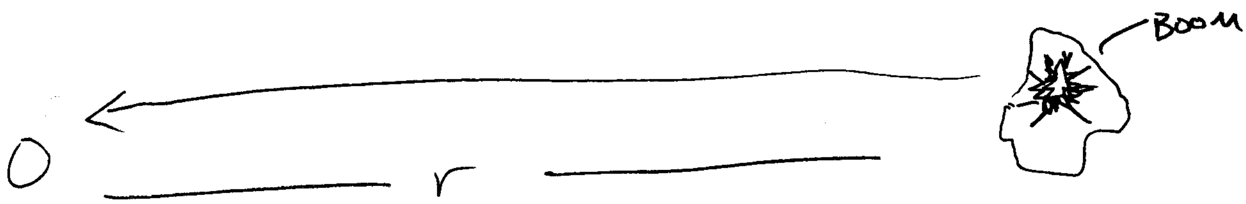
$$t = \frac{d}{r} = \frac{2r}{c} = \frac{2(1.3 \times 10^{\cancel{9}\,4}\,\cancel{km})}{3 \times \cancel{10^8}\,\cancel{km}/s} = 1.3\left(\frac{2}{3}\right) \times 10^4\ s$$

$$= .86 \times 10^4\ s$$

$$\boxed{t = 8.6 \times 10^3\ s}$$

$$= 866\ s \approx 14.5\ min$$

(d)



$r = 6500$ c-yr

$d = rt$

$$t = \frac{d}{r} = \frac{6500\ \cancel{c}\text{-yr}}{\cancel{c}} = \boxed{\underset{\text{light travel time}}{6500\ yr} = t}$$

So if they saw it in 1054 AD, it happened in

$$1054 - 6500 = \boxed{5446\ BC}$$

SEE FIGURE 34-2 PP 843

P4

(a) about $\boxed{510\ nm}$ and $\boxed{610\ nm}$

(b) most sensitive is at $\boxed{555\,nm = \lambda}$

$$f\lambda = c, \quad T = \frac{1}{f}, \quad f = \frac{c}{\lambda}$$

$$f = \frac{c}{\lambda} = \frac{3\times 10^{\cancel{8}\,17}\ \cancel{m}/s}{555\times \cancel{10^{-9}}\ \cancel{m}} = \frac{3}{555}\times 10^{17}\ s^{-1} = .0054\times 10^{17}\ s^{-1}$$

$$\boxed{f = 5.4\times 10^{14}\ Hz}$$

$$T = \frac{1}{f} = \frac{1}{5.4}\frac{1}{10^{14}} = \boxed{1.85\times 10^{-15}\ s = T}$$

P8

well you know $\omega = \frac{1}{\sqrt{LC}}$ ← capacitance

speed of light

and also that $\omega = 2\pi f$ and $f\lambda = c$

so we can solve for λ in terms of ω

$$\lambda = \frac{c}{f} = \frac{2\pi c}{\omega} = \frac{2\pi c}{1/\sqrt{LC}} = \frac{2\pi\ 3\times 10^{8}\ m/s}{1/\sqrt{(.253\times 10^{-6} H)(25\times 10^{-12} F)}} = 4.74\ m$$

$$\boxed{\lambda = 4.74\ m}$$

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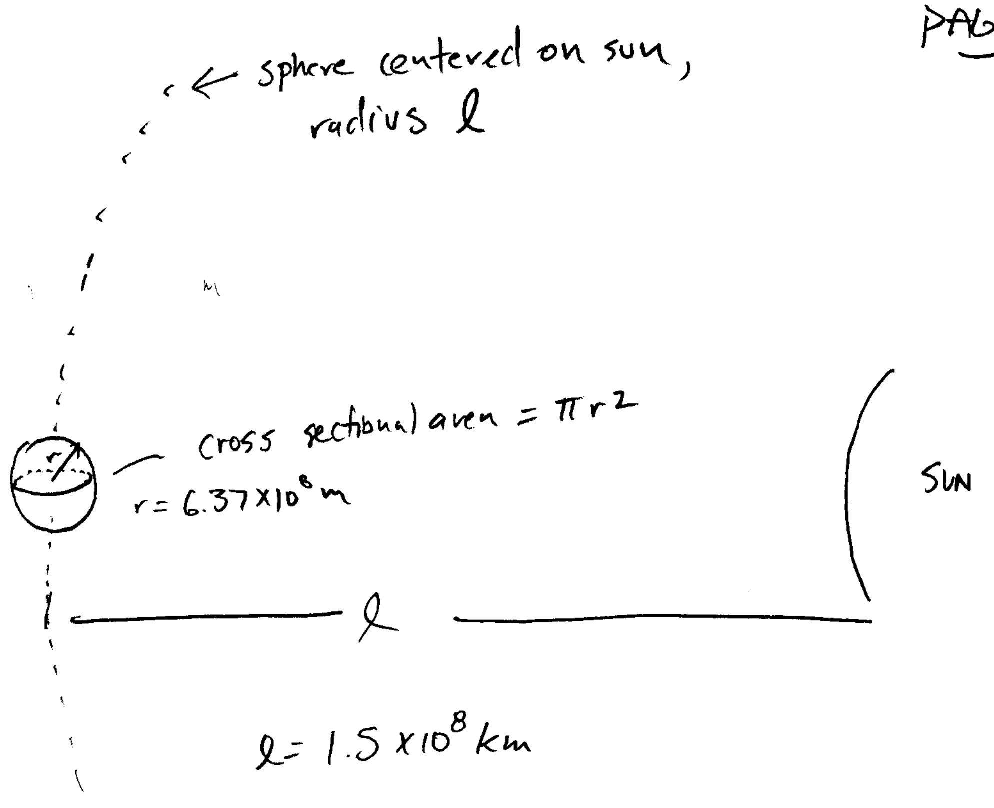
P 19



SO TOTAL POWER EMITTED OVER ENTIRE ℓ sphere, earth gets πr^2 of that total area hence

$$\frac{\text{Area of earth disk}}{\text{Area of } \ell \text{ sphere}} = \frac{\pi r^2}{4\pi \ell^2} = \frac{1}{4}\left(\frac{r}{\ell}\right)^2 = \frac{1}{4}\left(\frac{6.37 \times 10^6 \, \cancel{m}}{1.5 \times 10^{11} \, \cancel{m}}\right)^2$$

$$= \frac{1}{4}\left(4.2 \times 10^{-5}\right)^2$$

$$\boxed{= 4.5 \times 10^{-10}}$$

P 27

$S = \frac{1}{\mu_0} \mathbb{E} \times \mathbb{B}$ describes energy flux $S_{rms} = 1.4 \text{ kW/m}^2$

and we know that $\frac{E}{B} = c$ so $E = cB$, $B = \frac{1}{c} E$

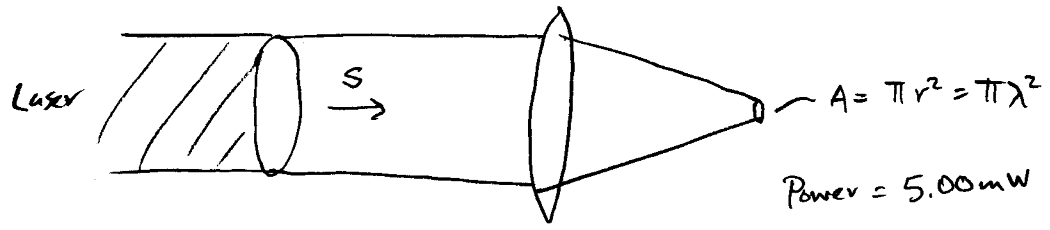
$$S_{rms} = \frac{1}{\mu_0} E_{rms} B_{rms} = \frac{1}{\mu_0} E\left(\frac{1}{c} E\right) = \frac{1}{\mu_0 c} E^2 = \frac{1}{\mu_0 c} (cB)^2 = \frac{c}{\mu_0} B^2$$

$B_{rms} = \sqrt{\frac{\mu_0 S}{c}} = \frac{1}{\sqrt{2}} B_m$ $\qquad E_{rms} = \sqrt{\mu_0 c S} = \frac{1}{\sqrt{2}} E_m$

$\mu_0 = 4\pi \times 10^{-7}$ $\qquad B_m = 3.03 \times 10^{-6}$ T $\qquad \boxed{E_m = 910 \text{ V/m}}$

P39

$\lambda = 633\,nm$



$$I = \frac{\text{Power}}{\text{Area}} = \frac{5 \times 10^{-3}\,W}{\pi\,(633 \times 10^{-9}\,m)^2} = \boxed{3.9 \times 10^{12}\,W/m^2 = I} \quad (a)$$

pressure given by

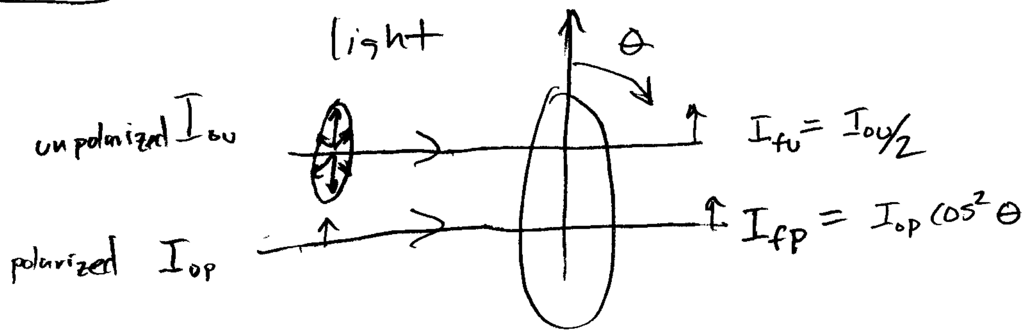
$$P_r = \frac{I}{c} = \frac{3.9 \times 10^{12}}{3 \times 10^{8}} = \boxed{1.3 \times 10^{4}\,N/m^2 = P_r} \quad (b)$$

definition of pressure

$$\frac{F}{A} = P_r \Rightarrow F = P_r A = 1.3 \times 10^4\,N/m^2 \left(\pi\,(633 \times 10^{-9})^2\right)$$

$$\boxed{F = 1.61 \times 10^{-14}\,N}$$

P58



I_{max}: For $\cos\theta = 1$ we get max transmission

I_{min}: for $\cos\theta = 0$ min transmission

they say $5\,I_{min} = I_{max}$

$$I_o = I_{ou} + I_{op}$$

$$I_f = I_{fu} + I_{fp}$$

$$I_{min} = I_{FU} + \cancel{I_{fp}}^{\,0}\ (\cos^2 90 = 0)$$

$$I_{max} = I_{FU} + I_{fp}\ (\cos^2 90 = 1)$$

$$5\,I_{FU} = I_{FU} + I_{FP} \qquad 4 I_{FU} = I_{FP} \Rightarrow 4\left(\frac{I_{ou}}{2}\right) = I_{op}$$

$\boxed{\text{2 times as much polarized}}$ $\qquad \boxed{2\,I_{ou} = I_{op}}$

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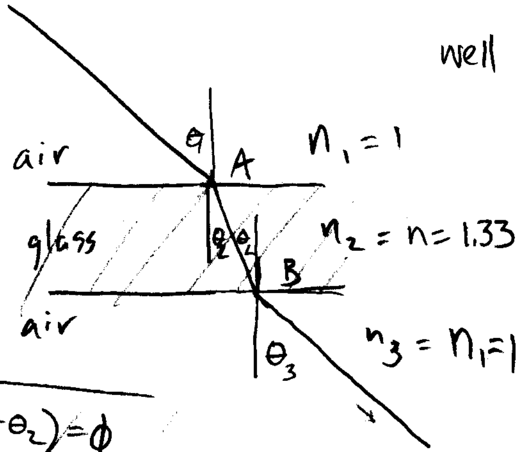


well $n_1 \sin\theta_1 = n_2 \sin\theta_2$ at A

$n_2' \sin\theta_2 = n_3 \sin\theta_3$

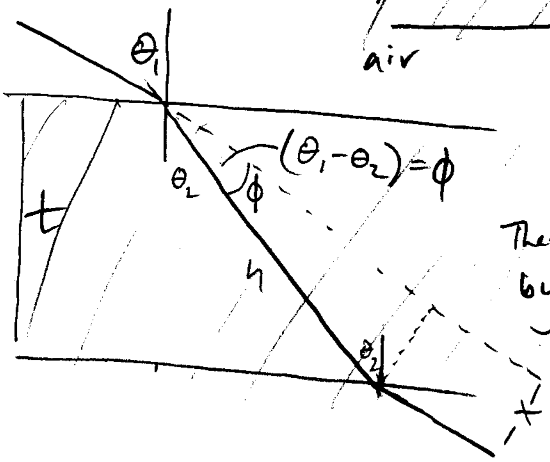
but $n_3 = n_1$

so $n_1 \sin\theta_1 = n_3 \sin\theta_3$

$\cancel{n_1} \sin\theta_1 = \cancel{n_1} \sin\theta_3$

$\sin\theta_1 = \sin\theta_3$

$\Rightarrow \boxed{\theta_1 = \theta_3}$



These two angles equal by geometry

$\sin\phi = x/h$, $\quad h = \dfrac{t}{\cos\theta_2}$ (hypotenuse) $\quad$ note $\cos x \approx 1$ for $x \ll 1$, $\sin x \approx x$ (taylor expand...)

want x in terms of θ_1

so $\quad x = h\sin\phi = \dfrac{t \sin\phi}{\cos\theta_2}$ $\quad$ and note: $\sin\theta_2 = \dfrac{n_1}{n_2}\sin\theta_1$

if θ_1 small then so is ϕ since $\phi = \theta_1 - \theta_2 \Rightarrow \theta_1, \theta_2 \ll 1$

so $\quad \sin\phi = \sin(\theta_1 - \theta_2) = \sin\theta_1 \cancel{\cos\theta_2}^{\,1} - \sin\theta_2 \cancel{\cos\theta_1}^{\,1}$

so $\quad x = \dfrac{t(\sin\theta_1 - \sin\theta_2)}{\cancel{\cos\theta_2}^{\,1}} \approx t\left(\theta_1 - \dfrac{n_1}{n_2}\cancel{\sin}\theta_1\right)$

$= t\left(\theta_1 - \dfrac{n_1}{n_2}\theta_1\right) = \boxed{t\left(\dfrac{n-1}{n}\right)\theta_1 = x}$

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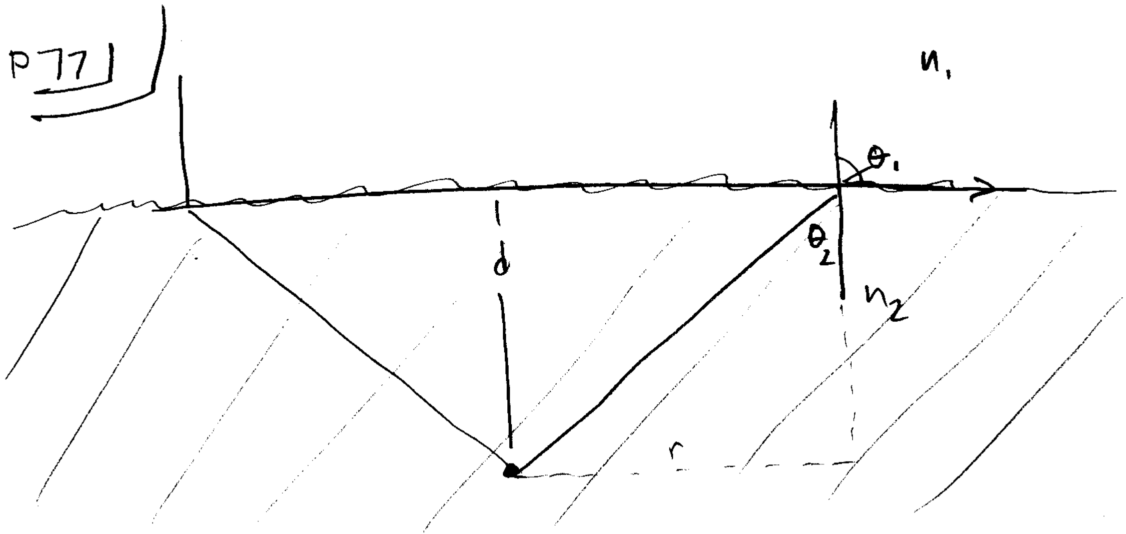

$d = 80$ cm

for total internal reflection $\theta_1 = 90°$ so

$$n_1 \cancel{\sin\theta_1}^{1} = n_2 \sin\theta_2$$

$$\sin\theta_2 = \frac{n_1}{n_2} = \frac{1}{1.33} \qquad \theta_2 = \arcsin\left(\frac{1}{1.33}\right) = 48.8°$$

and now diameter $= 2r$

$$r/d = \tan\theta_2 \qquad r = d\tan\theta_2$$

$$\boxed{\text{diameter} = 2d\tan\theta_2} = \boxed{182 \text{ cm}}$$

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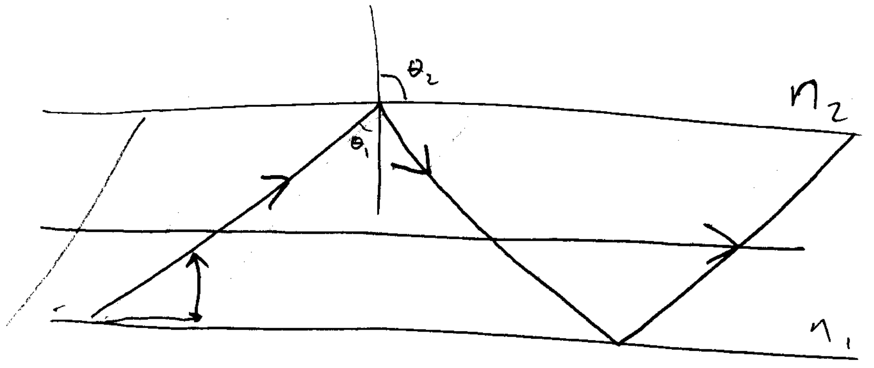
P 84

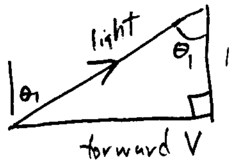


$n_1 = 1.58$
$n_2 = 1.53$

$n_1 \sin\theta_1 = n_2 \cancel{\sin\theta_2}^{\,1}$ at critical angle

$\sin\theta_1 = \frac{n_2}{n_1}$

Break velocity into vectors



$V_x = V \sin\theta_1$

light travels at v where $v = \frac{c}{n}$

for straight light

$$x = v t_1 = \frac{c t_1}{n_1} \qquad t_1 = \frac{n_1 x}{c}$$

for reflected light (forward v)

$$x = v \sin\theta_1 t_2 \qquad t_2 = \frac{n_1 x}{c \sin\theta_1}$$

for $x = L$

$$\Delta t = t_2 - t_1 = \frac{n x}{c \sin\theta_1} - \frac{n_1 x}{c} = \frac{n_1 L}{c}\left(\frac{1}{\sin\theta_1} - 1\right)$$

$$= \frac{n_1 L}{c}\left(\frac{n_1}{n_2} - 1\right) = \boxed{\frac{L}{c}\frac{n_1}{n_2}\left(n_1 - n_2\right) = \Delta t}$$

b) $\Delta t = \frac{300\text{ m}}{3\times10^8\text{ m/s}} \frac{1.58}{1.53}(1.58 - 1.53) = \boxed{5.16\times10^{-8}\text{ s} = .5\text{ns} = \Delta t}$

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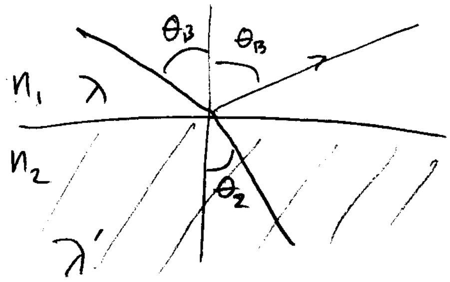
P85

$$\theta_B = \arctan\left(\frac{n_2}{n_1}\right)$$



$n_{air} = 1$

$n_{H_2O} \approx 1.33$

Brewsters angle is the angle at which the light is totally polarized

sort of...

so $\theta_B = \arctan n_{H_2O} \approx \boxed{53° = \theta_B}$ where $n_{H_2O} = \frac{c}{V_{medium}}$

and $c = f\lambda$

$v = f\lambda'$

$$\theta_B = \arctan \frac{\lambda}{\lambda'}$$

$$n_{H_2O} = \frac{\cancel{f}\lambda}{\cancel{f}\lambda'}$$

<u>does depend on wavelength</u>