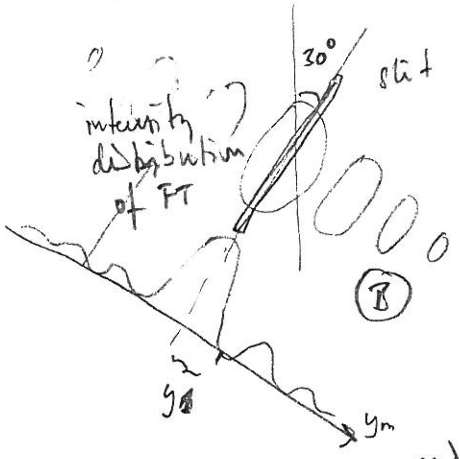
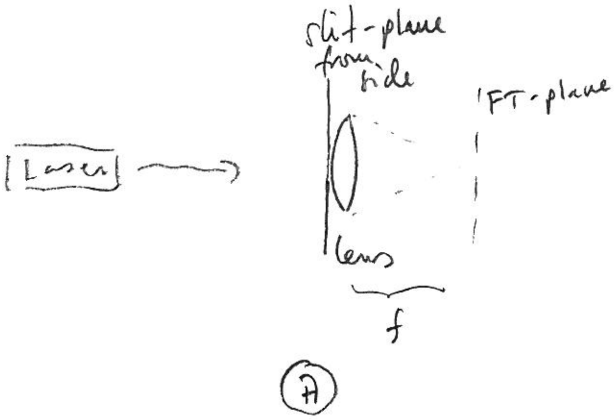
A-1.





C From e.g. Pedrotti $y_m = \dfrac{m\lambda f}{b}$ $\qquad y_1 = \dfrac{1 \cdot 1064 \cdot 10^{-9}\,m \cdot 0.5\ m}{0.00025\ m} = 2.1\ mm$

$\Rightarrow$ distance between minima $2 \times y_1$ $\qquad$ ans. 4.2 mm

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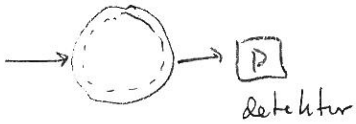
A-2.



with water (transparent) one obtains intensity I_0.
with beer ; probably absorbing

$$0.5\, I_0 = I_0 \cdot e^{-\alpha \cdot x} \qquad x = 7\ cm$$

α absorption koefficient

$\Rightarrow \ln 0.5 = -\alpha \cdot 7\ cm \quad \Rightarrow \alpha = \dfrac{\ln 2}{7}\ cm^{-1}$ $\qquad$ ans. $0.099\ cm^{-1}$

A-3.

$$d_{eff}? \begin{cases} \hat{x}: & d_{15} \cdot E_x E_z \\ \hat{y}: & d_{15} \cdot E_y E_z \\ \hat{z}: & d_{15} \cdot E_x^2 + d_{15} E_y^2 + d_{33} E_z^2 \end{cases}$$

as usual $\hat{e}_o: (-\sin\phi, \cos\phi, 0)$
$\hat{e}_e: (\cos\phi\cos\theta, \sin\phi\cos\theta, -\sin\theta)$

$oo \to e: \cos\phi\cos\theta \cdot (d_{15} \cdot 0) + \sin\phi\cos\theta\, (d_{15} \cdot 0) + (-\sin\theta) \cdot (d_{15} \sin^2\phi + d_{15}\cos^2\phi + 0)$

$= -d_{15}\sin\theta$

$ee \to o: -\sin\phi(d_{15}\cos\phi\cos\theta(-\sin\theta)) + \cos\phi\, d_{15} \cdot \sin\phi\cos\theta(-\sin\theta) =$

$+ d_{15} \sin\phi\cos\phi\sin\theta\cos\theta - d_{15}\sin\phi\cos\phi\sin\theta\cos\theta = 0$

$$\text{ans.} \begin{cases} oo \to e: & -d_{15}\sin\theta \\ ee \to o: & 0 \end{cases}$$

A-4:

$$(\bar{b}\times\bar{c})\cdot\bar{a}-\bar{c}\cdot(\bar{a}\times\bar{b}) = \bar{a}\cdot(\bar{b}\times\bar{c})-(\bar{a}\times\bar{b})\cdot\bar{c} = \left(\epsilon_{rst}\, b_s c_t\right)\cdot a_r - \left(\varepsilon_{kij}\, a_i b_j\right) c_k$$

$$= a_r\, b_s\, \epsilon_{rst}\, c_t - a_i\, \epsilon_{kij}\, b_j\, c_k$$

$\therefore$ A2

$$(\bar{c}\times\bar{a})\times\bar{b} = \left(\varepsilon_{ijk}\, c_j a_k\right)\times\bar{b} = \epsilon_{ris}\, b_s\, \epsilon_{ijk}\, c_j a_k = \epsilon_{isr}\, \epsilon_{ijk}\, b_s c_j a_k =$$

$$= \left(\delta_{sj}\,\delta_{rk} - \delta_{sk}\,\delta_{rj}\right) c_j a_k b_s \qquad \therefore \quad B3$$

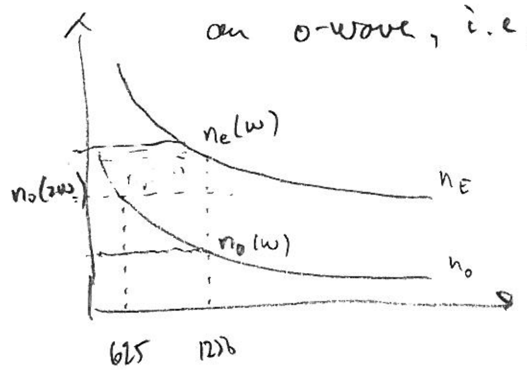
$$\bar{c}\times(\bar{a}\times\bar{b}) = \epsilon_{ijk}\, c_j\, (\bar{a}\times\bar{b})_k = \epsilon_{ijk}\, c_j\, \epsilon_{krs}\, a_r b_s =$$

$$= \epsilon_{krs}\, \underset{r\to j}{a_r}\, \underset{s\to k}{b_s}\, \underset{j\to s}{c_j}\, \epsilon_{ijk} = \epsilon_{\underset{i}{k}jk}\, a_j b_k c_s\, \epsilon_{\underset{r}{i}\underset{i}{s}k} = \epsilon_{ijk}\, a_j b_k c_s\, \epsilon_{rsi}$$

$k\to i$, $i\to r$

$$= \epsilon_{rsi}\, a_j b_k c_s\, \epsilon_{ijk} \qquad \therefore \quad C1$$

A-5: A) From the figure it is evident that the only way is to use a e-wave as pump to generate an o-wave, i.e, $ee\to o$.

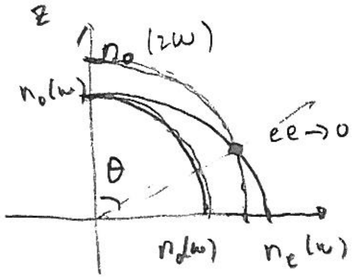


B) From figure

$n_o(2\omega) = 2.19$ (625 nm)

$n_o(\omega) = 2.14$ (1250 nm)

$n_e(\omega) = 2.22$ (1250 nm)



$$\underbrace{\frac{1}{n_o^2(2\omega)}}_{\text{o-wave @ } 2\omega} = \underbrace{\frac{\cos^2\theta_{pm}}{n_o^2(\omega)} + \frac{\sin^2\theta_{pm}}{n_e^2(\omega)}}_{\text{e-wave @ } \omega} \quad \leftarrow \text{condition for phase matching}$$

$$\Rightarrow \sin^2\theta_{pm} = \frac{n_e^2(\omega)}{n_o^2(2\omega)}\cdot\left[\frac{n_o^2(\omega)-n_o^2(2\omega)}{n_o^2(\omega)-n_e^2(\omega)}\right] \Rightarrow \boxed{\text{ans: } \theta_{pm} = \pm 53^\circ}$$

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investigate $KNbO_3$

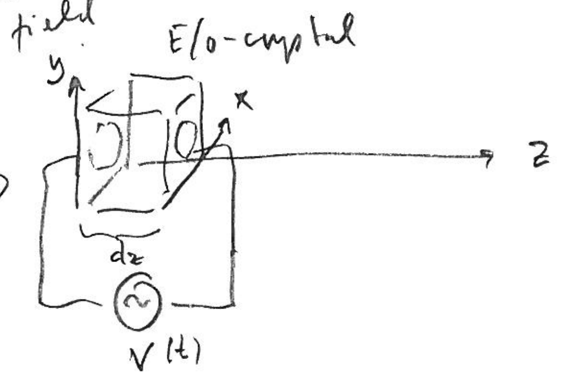
A):

$$\Delta\eta_{ij} = \begin{pmatrix} 0 & 0 & r_{13} \\ 0 & 0 & r_{23} \\ 0 & 0 & r_{33} \\ 0 & r_{42} & 0 \\ r_{51} & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} E_x \\ E_y \\ E_z \end{pmatrix} = \begin{pmatrix} r_{13}E_z & 0 & r_{51}E_x \\ 0 & r_{23}E_z & r_{42}E_y \\ r_{51}E_x & r_{42}E_y & r_{33}E_z \end{pmatrix}$$

quasi-static field

incoming vertical (or horizontal) polarized light

propagate along $\hat{z}$



when voltage $V(t)$ is applied along z (E_z) $\Delta\eta_{xx}$ & $\Delta\eta_{yy}$ experiences phase-shift. For vertically polarized light

$$\begin{pmatrix} \frac{1}{n_x^2} + r_{13}E_z & 0 \\ 0 & \frac{1}{n_y^2} + r_{23}E_z \end{pmatrix} \begin{pmatrix} 0 \\ D_y \end{pmatrix} - \frac{1}{n^2}\begin{pmatrix} 0 \\ D_y \end{pmatrix} = 0$$

$$\left(\left(\frac{1}{n_y^2} + r_{23}E_z\right) - \frac{1}{n^2}\right) D_y = 0$$

$$\frac{1}{n^2} = \frac{1}{n_y^2} + r_{23}E_z \Rightarrow n^2 = \frac{1 \cdot n_y^2}{\left(\frac{1 n_y^2}{n_y^2} + r_{23}E_z n_y^2\right)} = n_y^2 \cdot \frac{1}{(1 + r_{23}E_z n_y^2)}$$

$$n = n_y \frac{1}{\sqrt{1 + r_{23}E_z n_y^2}} \simeq n_y \cdot \left(1 - \frac{1}{2} r_{23}E_z n_y^2\right)$$

so D_y is phase-shifted

ans. A

B) $$e^{i\frac{2\pi}{\lambda}\cdot\left(n_y - \underbrace{\tfrac{1}{2}r_{23}E_z n_y^3}_{\text{phase-shift}}\right)\cdot z}$$

$$\frac{2\pi}{\lambda}\cdot\frac{1}{2}\cdot r_{23}\underbrace{\frac{V}{d_z}}_{\text{E-field}}\cdot n_y^3 = \frac{\pi}{2} \Rightarrow \boxed{V_{\frac{\pi}{2}} = \frac{\lambda}{2 n_y^3 r_{23}}}$$

ans. $V_{\frac{\pi}{2}} = 19.27\ kV$

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B-7

A) for $\theta = 0$ it is noted that the matrix is

$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \end{pmatrix}$$

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this looks like the QWP fast axis horizontal

$$\theta = 45^\circ \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}$$

$$\theta = 90^\circ \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

this looks like the QWP fast axis vertical

it seems to be a QWP. Then LPV or LPH should give CP when 45° rotated

$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix} \begin{pmatrix} 1 \\ 1 \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} 1 \\ 0 \\ 0 \\ 1 \end{pmatrix} \quad \text{OK}$$

it must be a QWP.

$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix} \begin{pmatrix} 1 \\ -1 \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} 1 \\ 0 \\ 0 \\ -1 \end{pmatrix} \quad \text{OK}$$

B-2

$\theta = 45^\circ$

$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix} \begin{pmatrix} 2 \\ -1 \\ 1 \\ 0 \end{pmatrix} = \begin{pmatrix} 2 \\ 0 \\ 1 \\ -1 \end{pmatrix}$$

with QWP 45° from the horizontal

component ← this is transferred to

LCP.   45° LP is unchanged

$\theta = 90^\circ$

$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \end{pmatrix} \begin{pmatrix} 2 \\ -1 \\ 1 \\ 0 \end{pmatrix} = \begin{pmatrix} 2 \\ -1 \\ 0 \\ 1 \end{pmatrix}$$

Here, since the QWP is with fast/slow axes along vertical/horizontal; the latter → LP (45°) does not change. However, the component becomes RCP.

P-8 cont.

B) Intensities.
circ pol is composed of equal amount of s- and p-pol. light (5 mW each). Due to Brewster condition all light p-pol continues through the crystal along e-wave, and all exits at the 2nd face.

o-wave ?

Use Fresnel eq.

$$r_{TE} = \frac{E_r}{E} = \frac{\cos\theta - n_o \cdot \cos\theta_o}{\cos\theta + n_o \cos\theta_o}$$

(with def. as in Fi,)

$$= \frac{\cos 55.7 - 1.5 \cdot \cos 33.4}{\cos 55.7 + 1.5 \cdot \cos 33.4} = \frac{0.5635 - 1.2523}{0.5635 + 1.2523}$$

$$= \frac{-492}{1297} \simeq 0.379$$

$$r_{TE}^2 = \frac{E_r^2}{E^2} = 0.1439$$

$\Rightarrow$ $0.1439 \cdot 5\,mW = 0.72\ mW$ is reflected (s-polarized)

the rest 4.28 mW is transmitted with polarization along y (o-wave)