Pockels effect

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Abstract

Article studies birefringence and Pockels effect on $LiNbO_3$ crystal. Theoretical description of effects provided. Interference patterns are examined. Difference of refractive indices $n_e - n_o$ is estimated numerically. Pockels effect is observed. Characteristic values of $U_{\lambda/2}$, $E_{\lambda/2}$ are evaluated.

Birefringence

In materials refractive index can depend on the polarization and direction of light propagation.

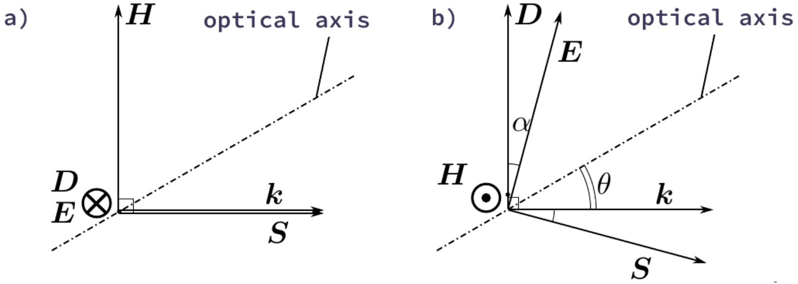


Figure: Ordinary (n_o) and extraordinary (n_e) waves scheme.

Malus' law

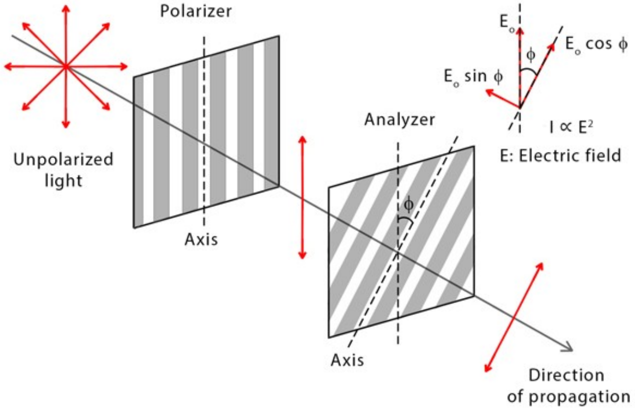


Figure: Malus' law on system of analyzer and polarizer

To describe polarization, analyzer and Malus' law is used:

$$I(\theta_i) = I_0 \cos^2 \theta.$$

Scatter plate

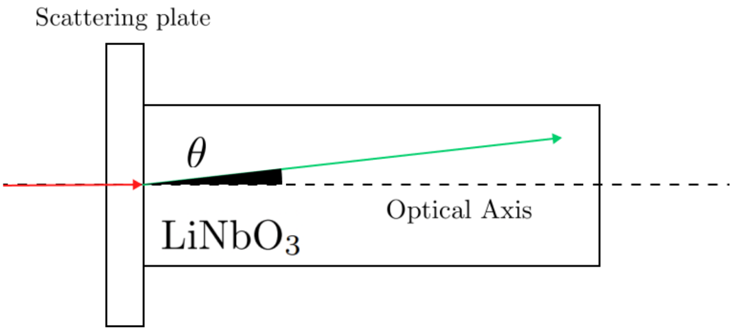


Figure: Ray propogation

For ordinary wave n stays the same: $n_o(\theta) = n_o$.
Extraordinary wave:

$$\frac{1}{n_e^2(\theta)} = \frac{\cos^2\theta}{n_o^2} + \frac{\sin^2\theta}{n_e^2} \implies n_e^2(\theta) \approx n_o - (n_o - n_e)\theta^2.$$

Interference observation

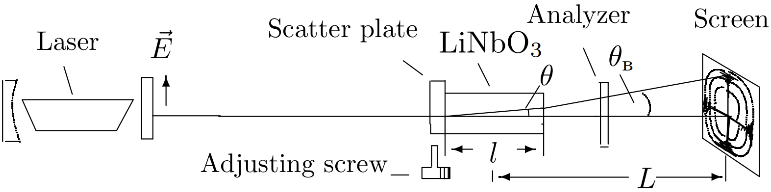


Figure: Experimental setup

Phase shift between ordinary and extraordinary waves can be estimated:

$$\Delta\varphi = \frac{2\pi}{\lambda} l(n_o - n_e)\theta^2,$$

where λ – wavelength, l – $LiNbO_3$ crystal length.

Conoscopic interference patterns

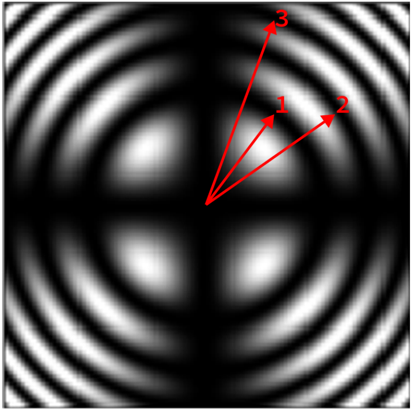


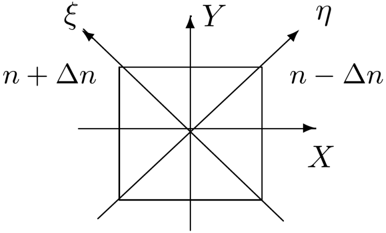
Figure: Conoscopic interference pattern with the dark "maltese cross"

The radius of the nth ring can be calculated by equating: $\Delta\varphi = 2\pi m$

$$r_m^2 = \frac{\lambda}{l}\frac{(n_o L)^2}{(n_o - n_e)} m, \quad m = 1, 2...,$$

where L – distance from crystal to the screen.

Pockels effect



Applying voltage to crystal of $LiNbO_3$ converts it from uniaxial to biaxial. Biaxial crystal has 'fast' $(n_0 - \Delta n)$ and 'slow' $(n_0 + \Delta n)$ axes.

Figure: Biaxial structure of crystal

Phase shift of E_ξ and E_η:

$$\Delta\varphi = \frac{4\pi}{\lambda}\frac{l}{d}AU,$$

where l, d – crystal length, width, A – constant for crystal. Decomposing light electric field to E_ξ and E_η, evaluating phase shift and projecting on X-axis we get:

$$E_{\text{out}} = E_0 e^{\omega t - kl}\sin\left(\frac{\Delta\varphi}{2}\right) \qquad I_{\text{out}} = I_0 \sin^2\left(\frac{\pi}{2}\frac{U}{U_{\lambda/2}}\right).$$

Measurements and Results

Experimental Setup

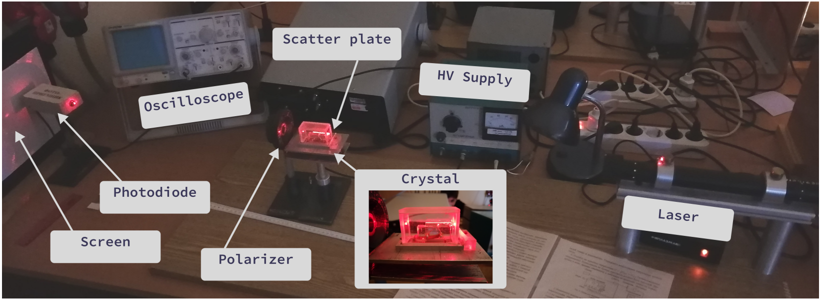


Figure: Photo of experimental setup

- Crystal dimensions: 3 mm $\times$ 3 mm $\times$ 26 mm.
- Laser wavelength $\lambda = 630$ nm.
- HV Supply range: $0 - 1.5$ kV.
- Distance between crystal and screen $L = 72$ cm.

Interference Patterns

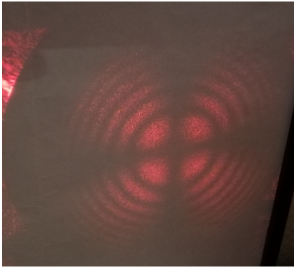


Figure: Interference pattern

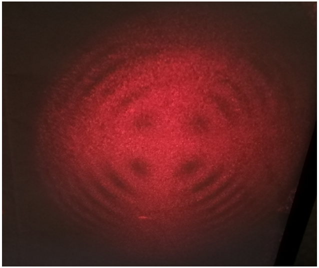


Figure: Inverted interference pattern

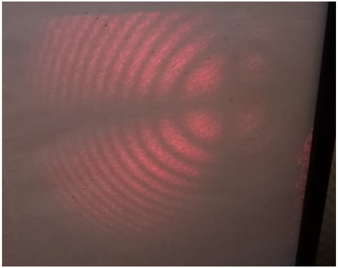


Figure: Additional lines

"Dark circles" conoscopic pattern with "maltese cross". Rotating polarizer by 90° we obtain inverted pattern. Moving polarizer in cross-axis provides more lines to observe.

Dark circles

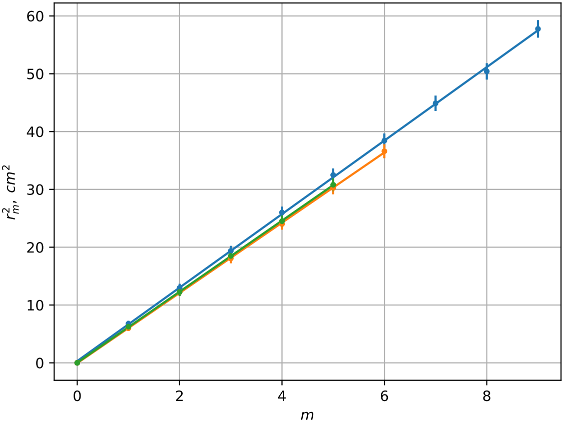


Figure: Inverted interference pattern

Using slope coefficient and formula for circles' radius we get:

$$n_0 - n_e = 0.115 \pm 0.005.$$

Pockels Effect

Figure: $U = 0$

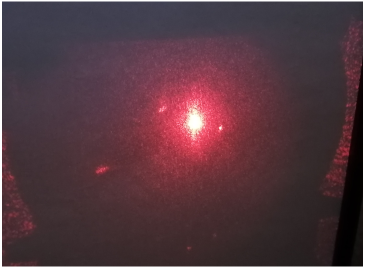


Figure: $U = U_{\lambda/2}$

	U, kV	
m	$\perp$	$\parallel$
1	0.45	0.45
2	0.90	0.87
3	1.38	1.35

Applying voltage on $LiNbO_3$ crystal we observe Pockels effect.
Measuring voltages we get:

$$U_{\lambda/2} = (0.45 \pm 0.02)\ \mathrm{kV}.$$

Circular Polarization

Figure: Brightness invariance of circularly-polarised light

Lissajous figures

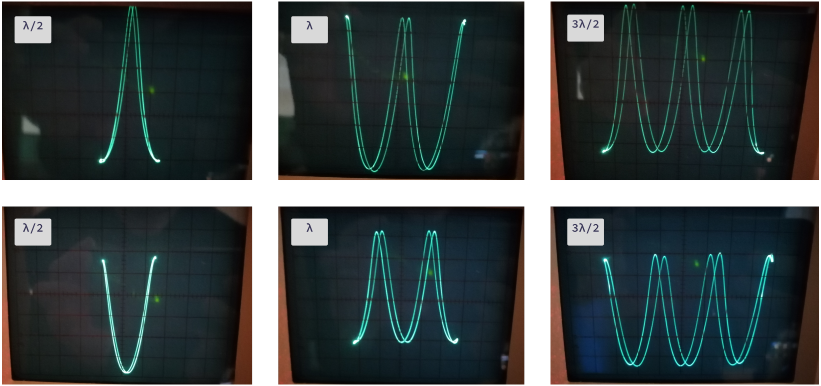


Figure: Lissajous figures for $\parallel$ (top) and $\perp$ (bottom) polarizations

Lissajous figures transformation

Figure: Effect of polarizer rotation on lissajous figures

Conclusion

Birefrigence was observed. Difference of refractive indices for ordinary and extraordinary waves ($LiNbO_3$ – 'negative' crystal):

$$n_e - n_o = -(0.115 \pm 0.005).$$

Reference value (for $\lambda = 630$ nm, depends on crystal composition)[1] :

$$n_e - n_o = 0.07 \div 0.12.$$

Pockels effect was examined. $U_{\lambda/2}$ was measured:

$$U_{\lambda/2} = (0.45 \pm 0.02)\ \mathrm{kV} \quad \Rightarrow \quad E_{\lambda/2} = (150 \pm 6)\ \mathrm{kV/m}.$$

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[1] Refractive indices of lithium niobate as a function of wavelength and composition Journal of Applied Physics 73, 3472 (1993)

Thank you for your attention!