

Pockels effect

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Abstract

Article studies birefringence and Pockels effect on LiNbO₃ 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.

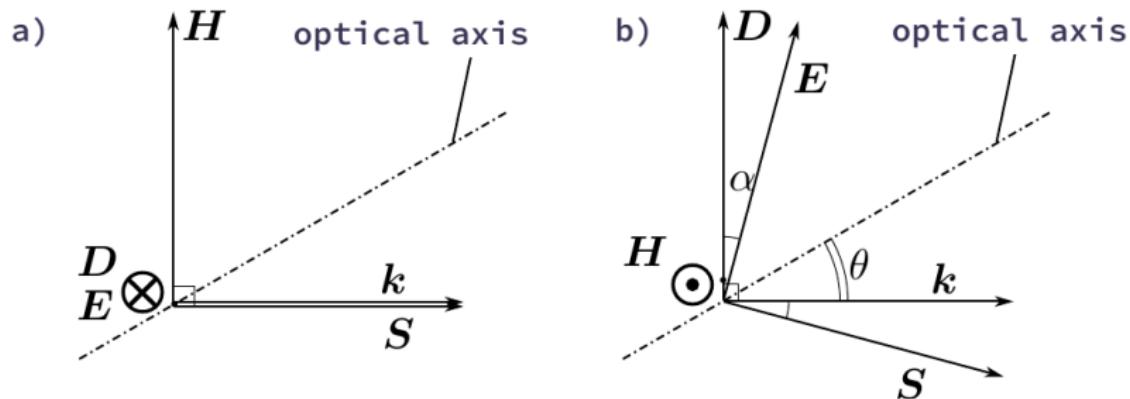


Figure: Ordinary (n_o) and extraordinary (n_e) waves scheme.

Malus' law

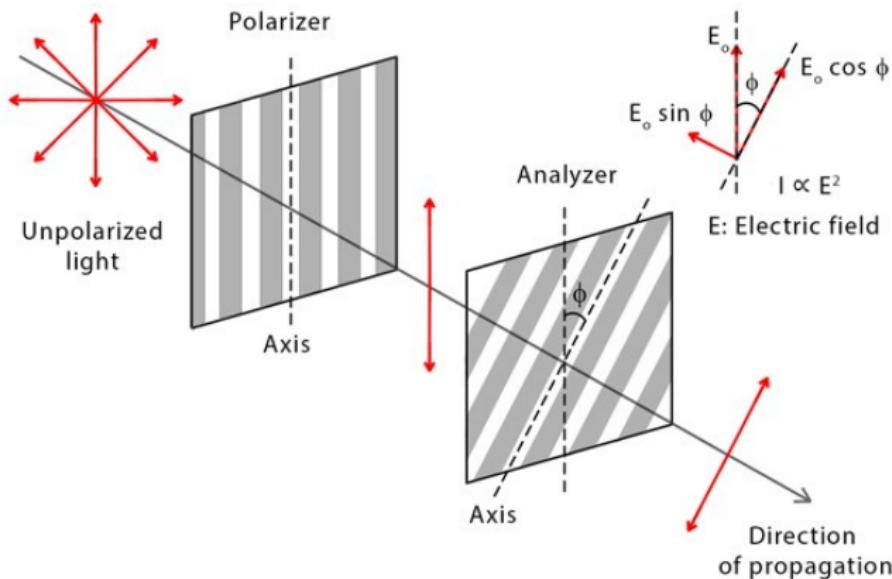


Figure: Malus' law on system of analyzer and polarizer

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

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

Scatter plate

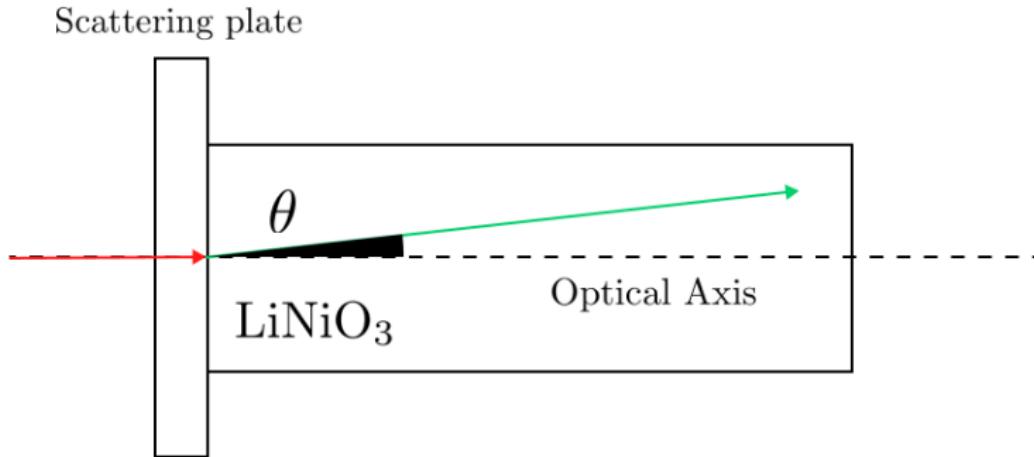


Figure: Ray propagation

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

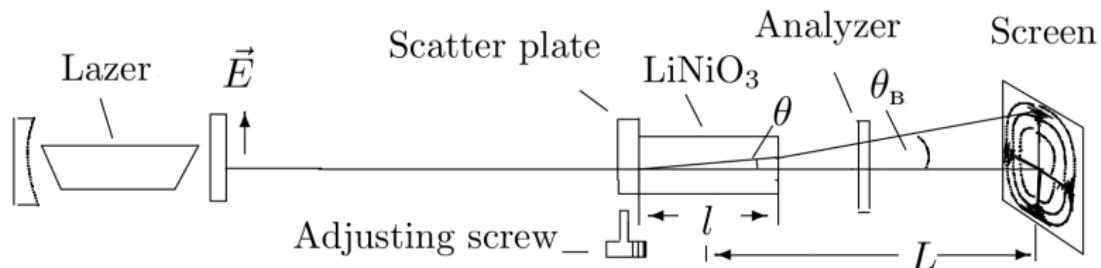


Figure: Experimental setup

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 – LiNbO₃ crystal length.

Conoscopic interference patterns

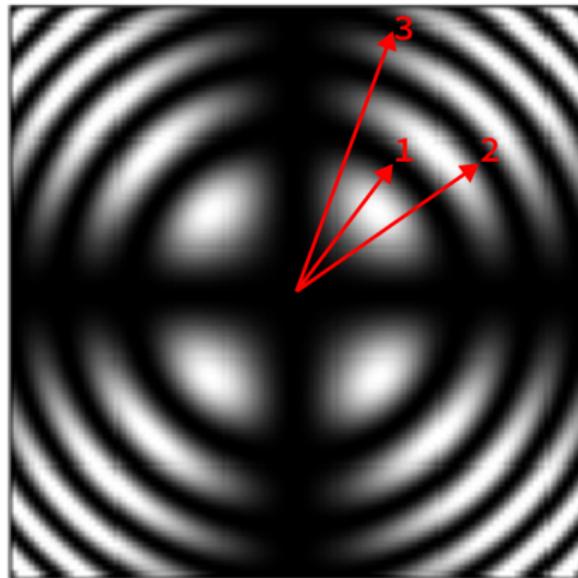


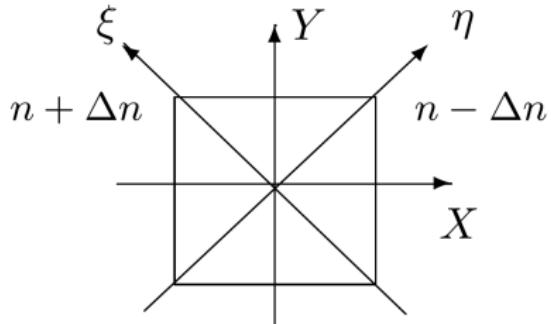
Figure: Conoscopic interference pattern with the dark "maltese cross"

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

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

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:

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

Measurements and Results

Experimental Setup

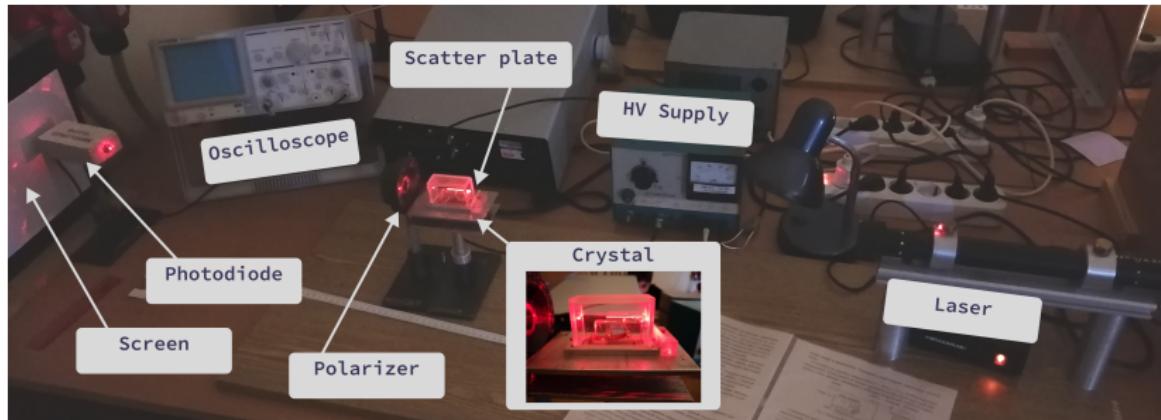


Figure: Photo of experimental setup

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

Interference Patterns

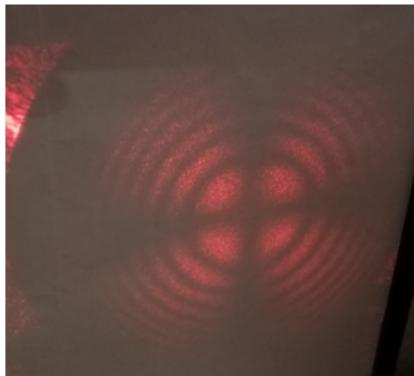


Figure: Interference pattern

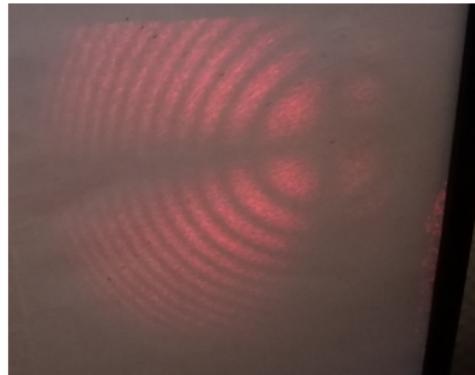


Figure: Additional lines

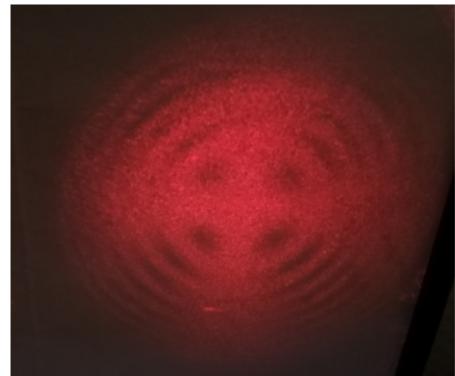


Figure: Inverted interference pattern

”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

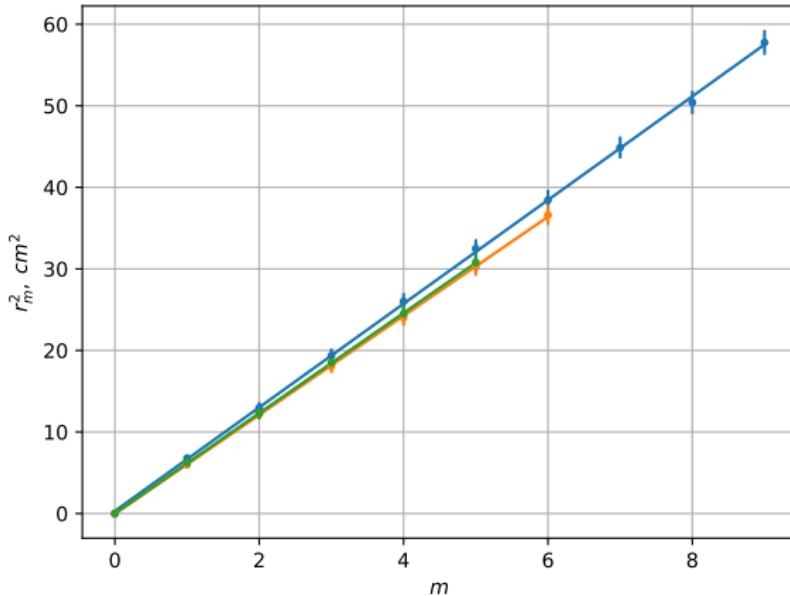


Figure: Inverted interference pattern

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

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

Pockels Effect



Figure: $U = 0$

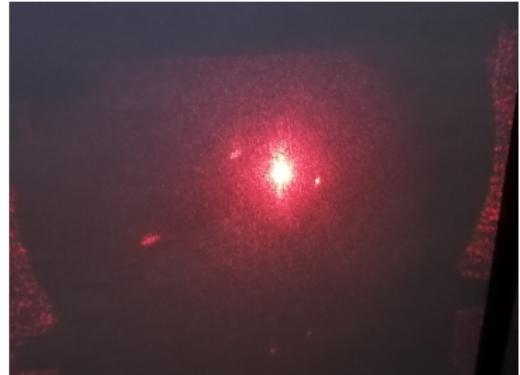


Figure: $U = U_{\lambda/2}$

m	U, kV	
	\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:

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

Circular Polarization

Figure: Brightness invariance of circularly-polarised light

Lissajous figures

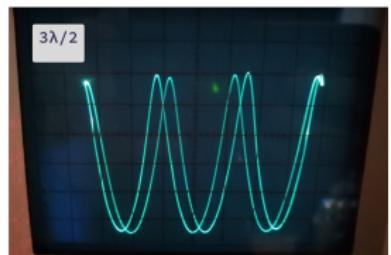
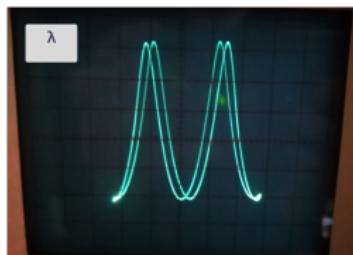
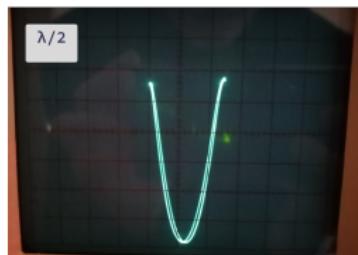
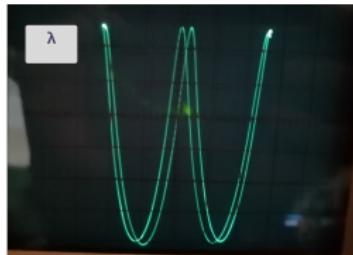


Figure: Lissajous figures for \parallel (top) and \perp (bottom) polarizations

Lissajous figures transformation

Figure: Effect of polarizer rotation on lissajous figures

Conclusion

Birefringence 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:

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

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!