Pockels effect

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Abstract

Laboratory work describes birefringence and Pockels effect on $LiNbO_3$ crystal. Interference patterns are examined. Difference of refractive indices $n_e - n_o$ and characteristic value of $U_{\lambda/2}$ are estimated.

Birefringence

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

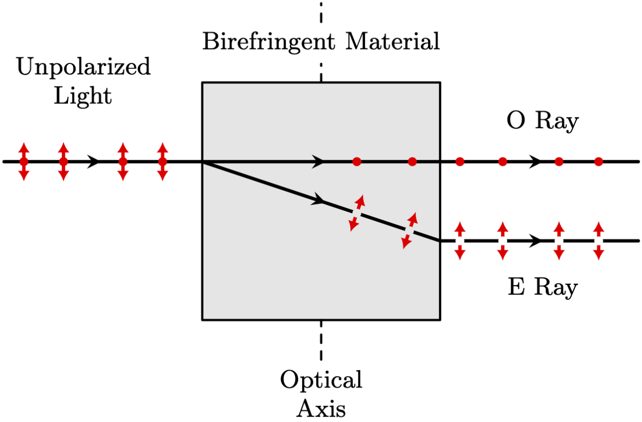


Figure: Ordinary (n_o) and extraordinary (n_e) waves scheme.

Analyzer

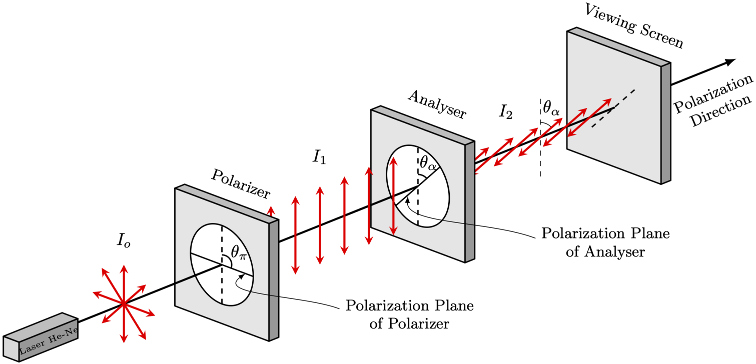


Figure: Usage of analyzer

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

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

Scatter plate

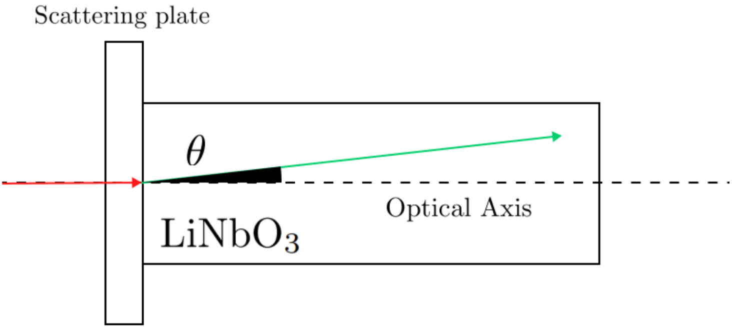


Figure: Ray propogation

Ordinary: Refractive index stays the same: $n_o(\theta) = n_o$

Extraordinary: Refractive index can be assumed from:

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

Interference observation

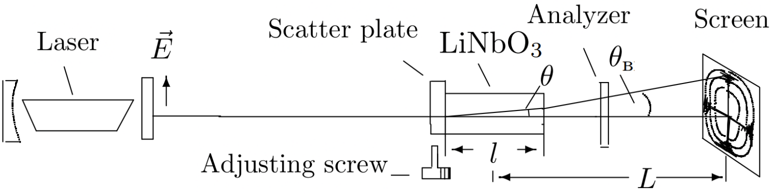


Figure: Experimental setup

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 – $LiNiO_3$ crystal length.

Conoscopic interference patterns

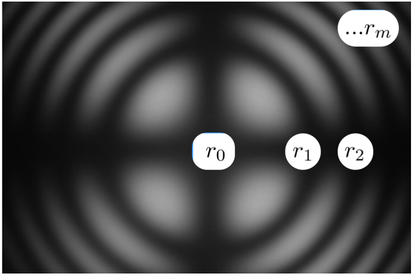


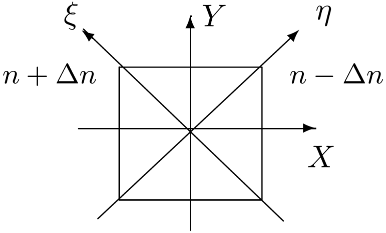
Figure: Conoscopic interference pattern with the dark "maltese cross"

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:

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

Experimental setup

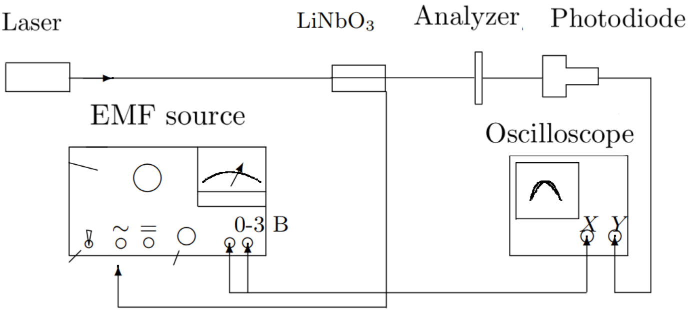


Figure: Experimental setup for observing the Pockels effect

Measurements and Results

Experimental setup

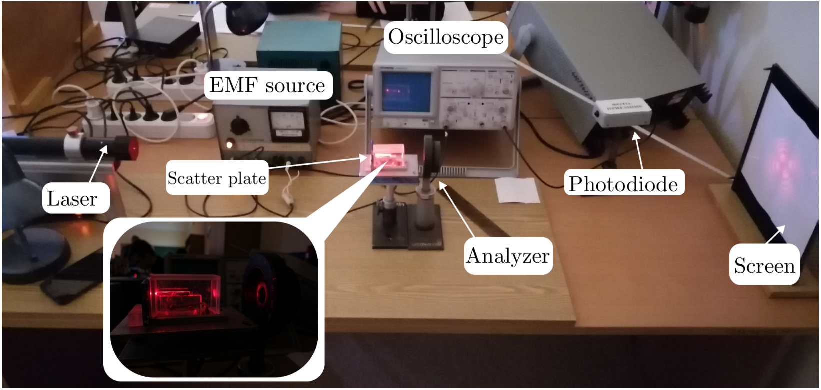


Figure: Photo of the experimental setup.

Conoscopic interference patterns

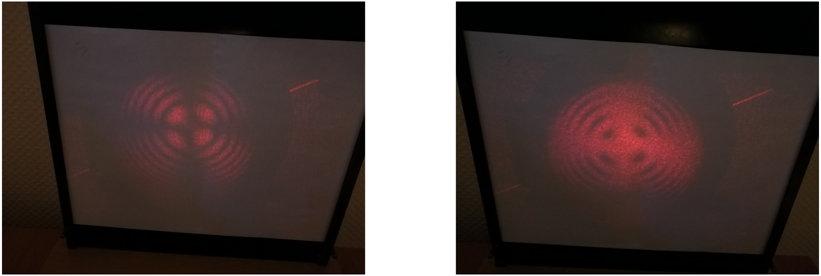


Figure: Dark (left) and light (right) "maltese cross" patterns. When the polarizer is rotated by 90 degrees, the cross pattern changes to a bright cross on a dark background.

Dark rings

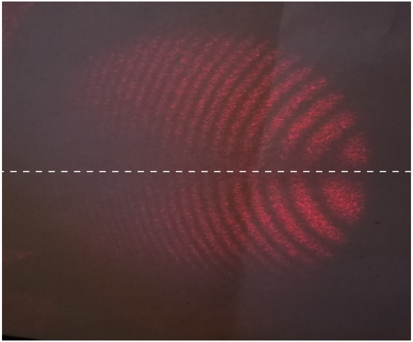


Figure: Conoscopic interference patterns rings

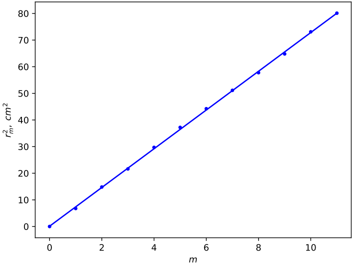


Figure: Linearization $r_m^2(m)$

From the series $r_m(m)$ we can calculate the birefringence difference using slope:

$$\Delta n = n_o - n_e = \frac{\lambda}{l}\frac{(n_o L)^2}{\frac{\partial r_m^2}{\partial m}} = (0.098 \pm 0.004)$$

Half-wave voltage

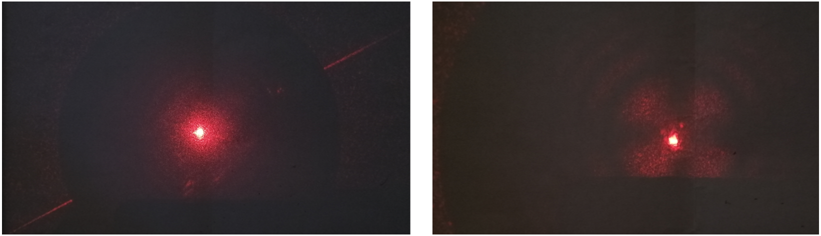


Figure: Photo of the maximum (left) and minimum (right) spot brightness observed with a change in voltage U.

	U, kV	
	$\uparrow\uparrow$	$\leftarrow\uparrow$
$U_{\lambda/2}$	0.45	0.45
U_{λ}	0.94	0.93
$U_{3\lambda/2}$	1.38	1.35

The error is determined both by the division value of the voltmeter and by the eye of the experimenter: $\sigma_U \approx 0.06$ kV

Quarter-wave voltage

Oscilloscope

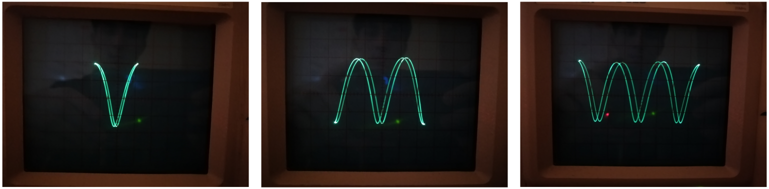


Figure: Photo waveforms for parallel polarizations.

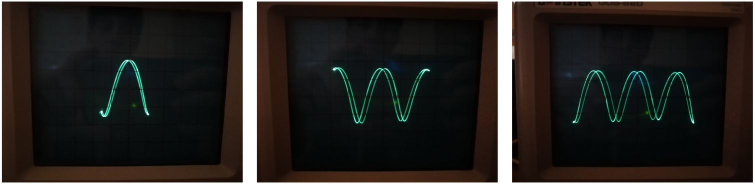


Figure: Photo waveforms for perpendicular polarizations.

Results

Investigated the interference of scattered light passing through the crystal. Determined birefringence difference:

$$\Delta n = (0.098 \pm 0.004)\ .$$

$$\text{reference value for } \lambda = 0.63\ \mu m \ \ n_o - n_e = 0.08 \div 0.11$$

Observed the change in the nature of the polarization of light when an electric field was applied to a crystal. Estimated half-wave voltage:

$$U_{\lambda/2} = (0.45 \pm 0.06)\ \text{kV}$$