

# Pockels effect

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## Abstract

Article studies birefringence and Pockels effect on LiNbO<sub>3</sub> 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.

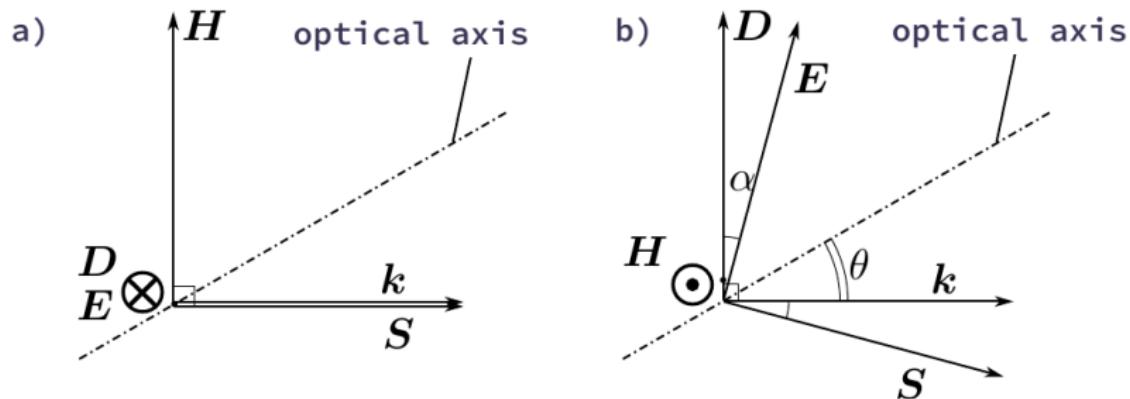


Figure: Ordinary ( $n_o$ ) and extraordinary ( $n_e$ ) waves scheme.

# Scatter plate

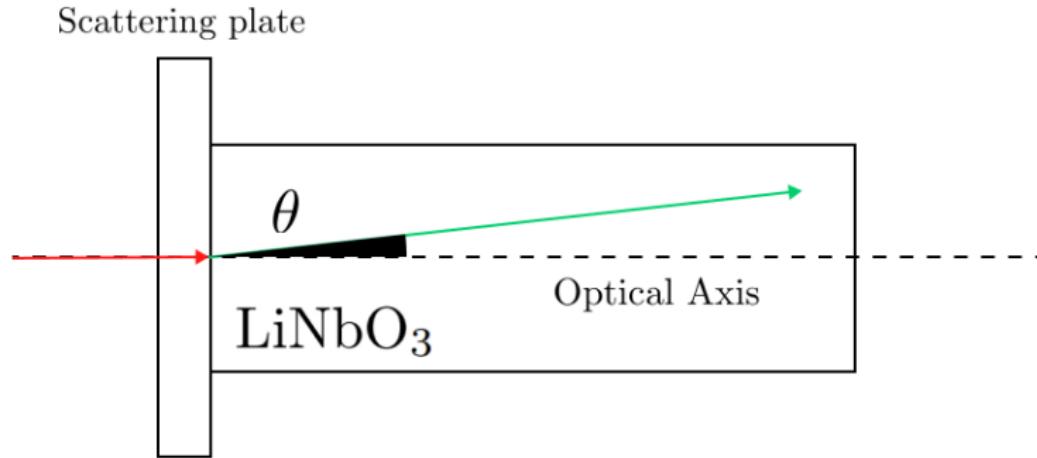


Figure: Ray propagation

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

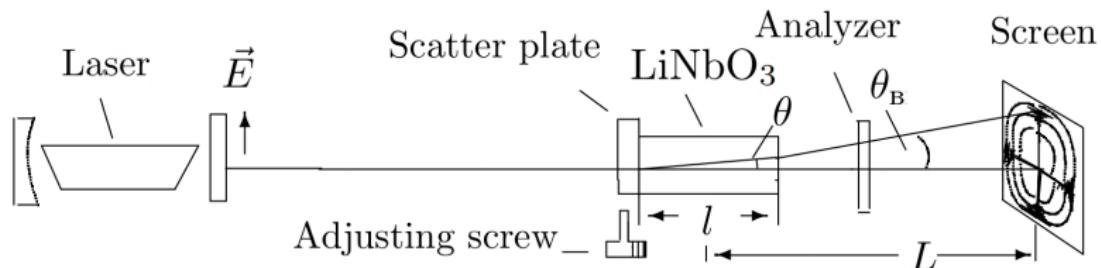


Figure: Experimental setup

Phase shift between ordinary and extraordinary waves can be estimated:

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

where  $\lambda$  – wavelength,  $l$  –  $\text{LiNbO}_3$  crystal length.

# Application of analyzer

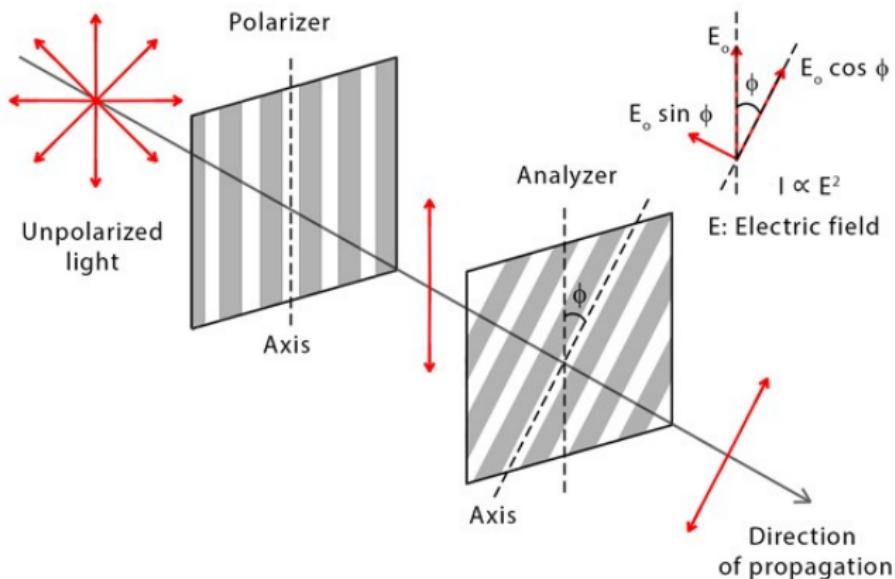


Figure: System of analyzer and polarizer

Using analyzer we can project differently polarized light on required axis.

## Conoscopic interference patterns

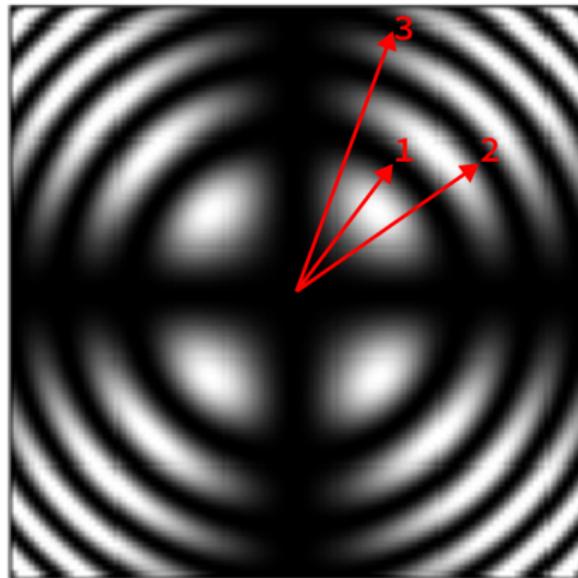


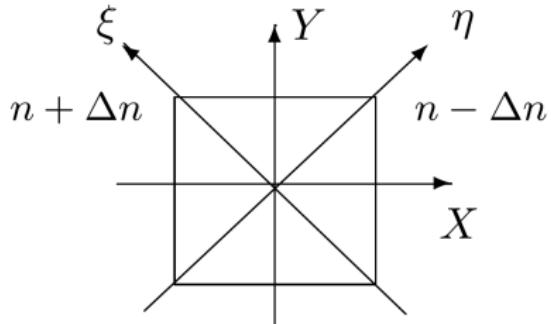
Figure: Conoscopic interference pattern with the dark "maltese cross"

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  $\text{LiNbO}_3$  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  $E_\xi$  and  $E_\eta$ :

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

where  $l$ ,  $d$  – crystal length, width,  $A$  – constant for crystal. Decomposing light electric field to  $E_\xi$  and  $E_\eta$ , 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

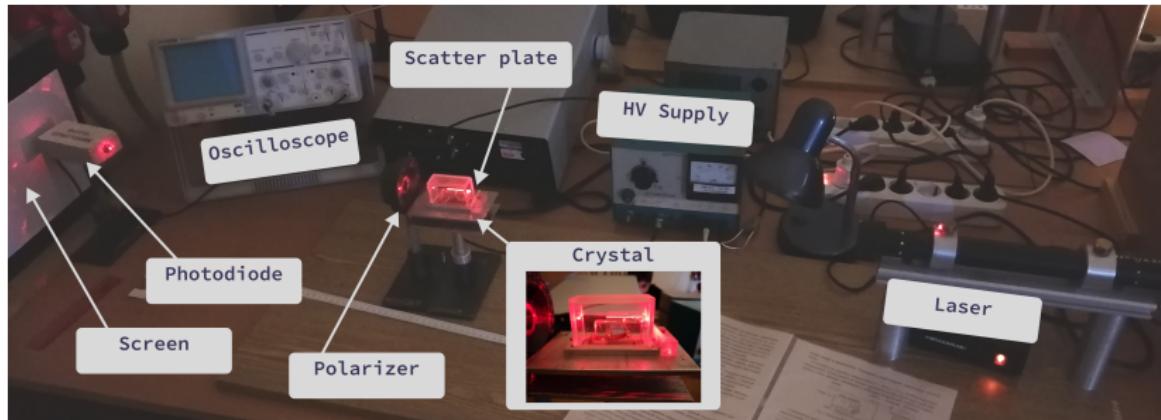


Figure: Photo of experimental setup

- 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

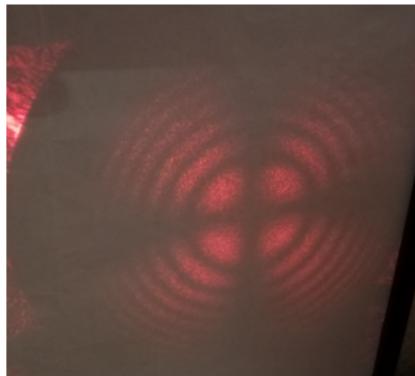


Figure: Interference pattern

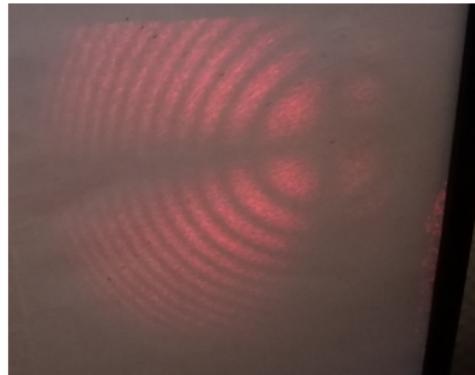


Figure: Additional lines

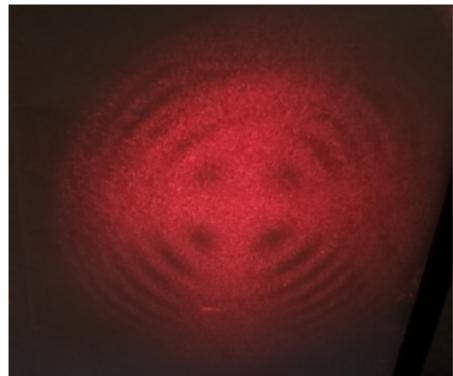
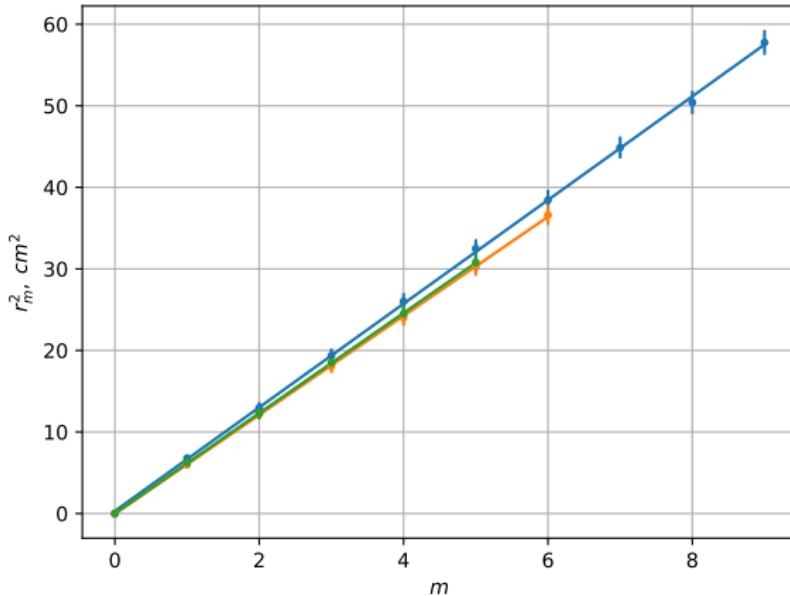


Figure: Inverted interference pattern

”Dark circles” conoscopic pattern with ”maltese cross”. Rotating polarizer by  $90^\circ$  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:  $U = 0$

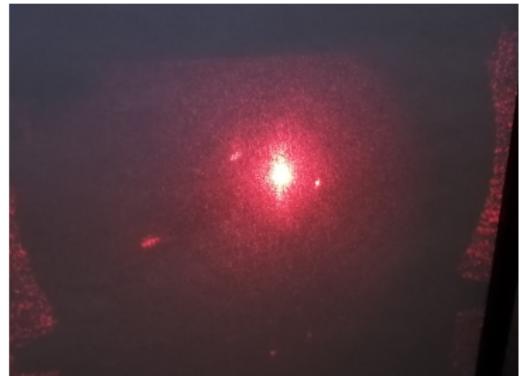


Figure:  $U = U_{\lambda/2}$

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

Applying voltage on  $\text{LiNbO}_3$  crystal  
we observe Pockels effect.  
Measuring voltages we get:

$$U_{\lambda/2} = (0.45 \pm 0.03) \text{ kV.}$$

# Circular Polarization

Figure: Brightness invariance of circularly-polarised light

# Lissajous figures

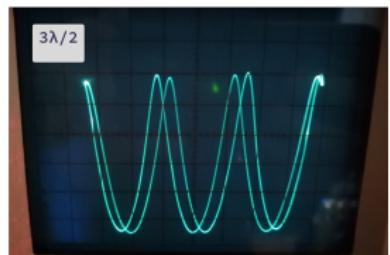
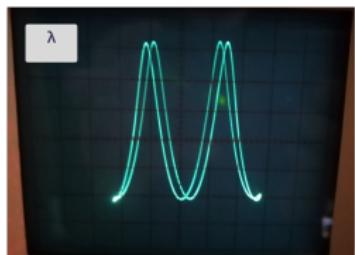
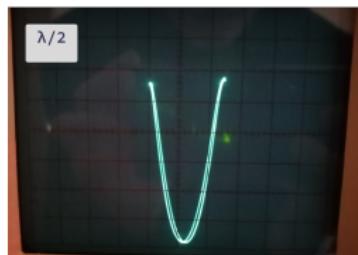
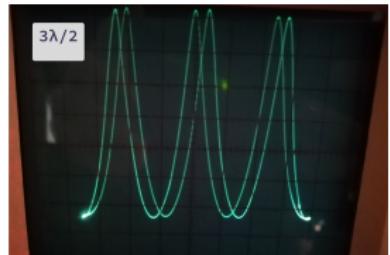
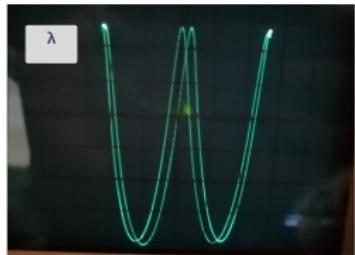


Figure: Lissajous figures for  $\parallel$  (top) and  $\perp$  (bottom) polarizations

# Lissajous figures transformation

Figure: Effect of polarizer rotation on lissajous figures

## Conclusion

Birefringence was observed. Difference of refractive indices for ordinary and extraordinary waves ( $\text{LiNbO}_3$  – 'negative' crystal):

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

Reference value (for  $\lambda = 630$  nm, depends on crystal composition)<sup>1</sup> :

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

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

$$U_{\lambda/2} = (0.45 \pm 0.03) \text{ kV} \quad \Rightarrow \quad E_{\lambda/2} = (150 \pm 9) \text{ kV/m.}$$

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<sup>1</sup> Refractive indices of lithium niobate as a function of wavelength and composition Journal of Applied Physics 73, 3472 (1993)

Thank you for your attention!