Electro-optick Effect

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1 Introdution & Goals

Transparent materials can be described by a parameter, n, the refractive index, that describes the speed of propagation of light in the solid via:

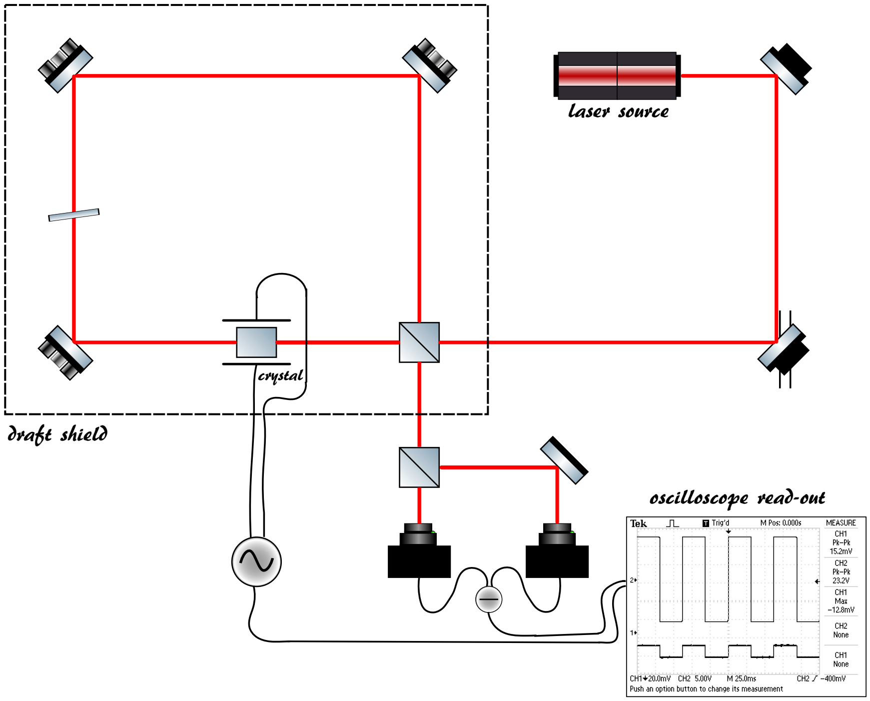
$$v = \frac{c}{n}.$$

While n is generally taken to be constant independent of anything but the material's properties and the frequency of the light, some material's refractive index show a dependence on local electric fields. The linear effect ($\Delta n \propto E_{applied}$) is known as the Pockel's Effect and is the dependency shown by the substance examined in this lab, Lithium Niobate ($LiNbO_3$). The goal of this lab is to calculate the value of r for two different orientations of the Lithium Niobate sample, according to:

$$\Delta n = \frac{r n_0^3 E_{applied}}{2}.$$

2 Procedure

The setup utilized a single-beam Sagnac interferometer, as oriented below.



The Helium-Neon laser used in the experiment was oriented as to have equal intensities of light in both polarizations traveling the interferometer[1]. The electro-optic sample in the shape of a rectangular prism was placed in the path of the beam between a parallel plate capacitor, which was connected to an AC voltage source. An AC voltage was applied to the capacitor containing the sample. The output signals corresponding to the different polarization states traveling through the crystal were entered into a difference calculator. This difference signal was tunable with a single plate of glass that could be rotated as to affect the phase of one of the polarizations. The difference in output signals was plotted along side the applied voltage on the oscilloscope.

With the setup established, the procedure is as follows:

1. Set zero crossing point of difference signal with tuner plate[2]
2. Apply AC voltage source to crystal
3. Record change in difference signal

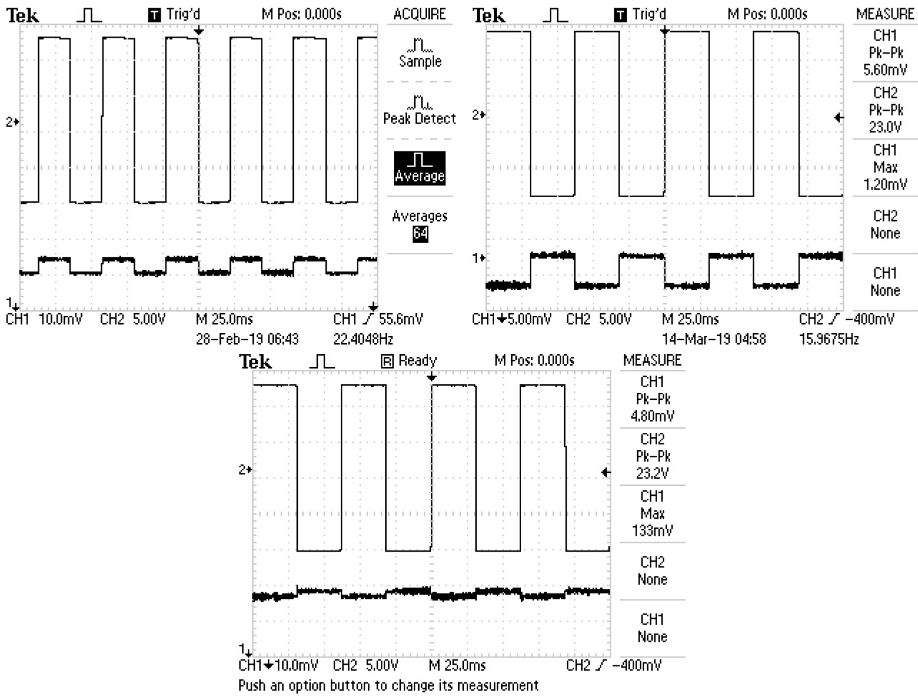
One may then change the orientation of the crystal to acquire different proportionality coefficients, as different axes of the crystal exhibit different quantities of responsiveness to applied voltages.

3 Data

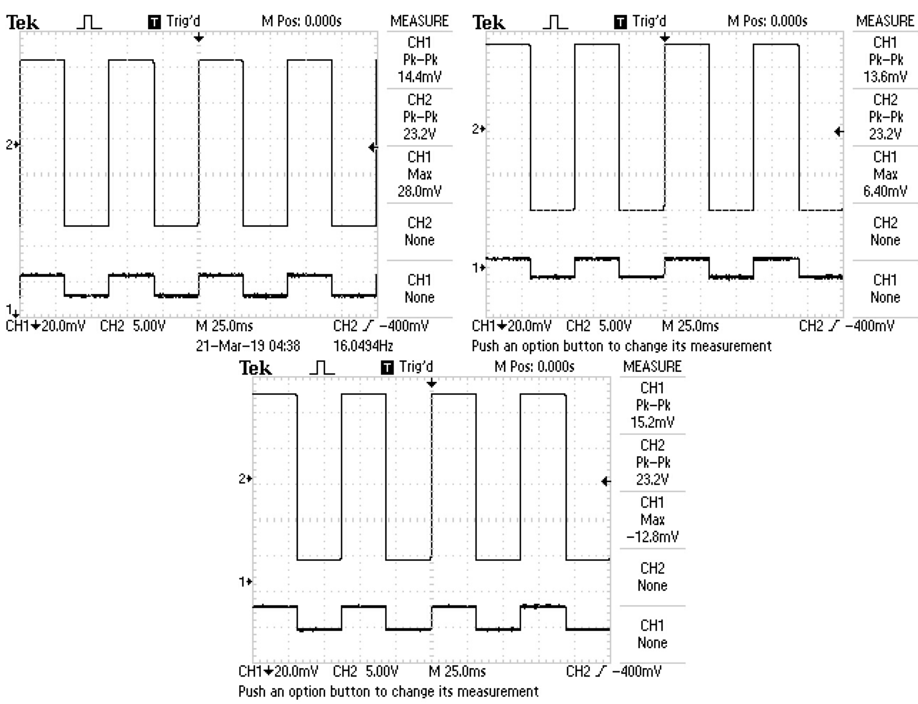
The length of the sample in the shape of a rectangular prism was $(0.0015)m$, with a width of $(.8 \times 10^{-3})m$. The wavelength of the Helium Neon laser in vacuum, λ_0, is $(6.328 \times 10^{-7})m$. The amplitude of the square wave voltage applied to the sample was $11.2V$. The accepted refractive index of lithium niobate for λ_0 is 2.29. An averaged oscilloscope screen print for each test is displayed below, three for each orientation.

[1]The beam is split into two perpendicularly polarized beams by the first beam splitting cube of the interferometer.
[2]To maximize sensitivity of difference signal to phase difference.

Averaged data collected for orientation 1 of the crystal is shown below.



Averaged data collected for orientation 2 of the crystal is shown below[3].



[3] Note the different scale on which the difference signal (Ch. 2) is plotted.

The collected data is gathered in the table below. All values are in Volts, V.

Table 1: Collected Data for Orientation 1

VMax	DelV
0.50	0.0050
0.72	0.0056
0.38	0.0042

Table 2: Collected Data for Orientation 2

VMax	DelV
0.44	0.0160
0.52	0.0136
0.59	0.0160

4 Analysis

The difference in phase is calculated by the ratio of the observed voltage difference against the maximum difference of voltage, as shown below.

$\Delta\phi = \pi\frac{\Delta V}{V_{max}}$

This corresponds to a difference in phase, Δn, as calculated according to the relationship below.

$\Delta\phi = \frac{2\pi}{\lambda} \cdot \Delta nL$

The relevant linear coefficient of electro-optic behavior is then found via the relationship:

$\Delta n = \frac{rn_0^3E}{2} \rightarrow r = \frac{2\Delta n}{n_0^3E}$.

Using collected data values to calculate $\Delta\Phi$, Δn, and r_{33} gives the values below. $\Delta\Phi$ is in radians and r values are in meters per Volt, $\frac{m}{V}$.

Table 3: Analysis Values for Orientation 1

V_{max}	ΔV	$\frac{\Delta V}{V_{max}}$	$\Delta\Phi$	Δn	r_1
500.0×10^{-3}	5.000×10^{-3}	10.00×10^{-3}	31.42×10^{-3}	2.109×10^{-6}	12.55×10^{-12}
720.0×10^{-3}	5.600×10^{-3}	7.778×10^{-3}	24.43×10^{-3}	1.641×10^{-6}	9.758×10^{-12}
380.0×10^{-3}	4.200×10^{-3}	11.05×10^{-3}	34.72×10^{-3}	2.331×10^{-6}	13.87×10^{-12}

Table 4: Analysis Values for Orientation 2

V_{max}	ΔV	$\frac{\Delta V}{V_{max}}$	$\Delta\Phi$	Δn	r_2
440.0×10^{-3}	16.00×10^{-3}	36.36×10^{-3}	114.2×10^{-3}	7.670×10^{-6}	45.62×10^{-12}
520.0×10^{-3}	13.60×10^{-3}	26.15×10^{-3}	82.16×10^{-3}	5.517×10^{-6}	32.81×10^{-12}
590.0×10^{-3}	16.00×10^{-3}	27.12×10^{-3}	85.20×10^{-3}	5.720×10^{-6}	34.02×10^{-12}

These values give values of $r_1 = [(1.2 \pm .2) \times 10^{-11}]\frac{V}{m}$ and $r_2 = [(3.7 \pm .8) \times 10^{-11}]\frac{V}{m}$.

4.1 Comparison to Accepted Values

Comparing to the average of the free crystal values for $\lambda = 633nm$ presented in Weis[WG85], our calculated value of r_1 is closest to the accepted value of r_{13}. Similarly, r_2 is closest to r_{33} or r_{51}. Values are shown below in units of $\times 10^{-12}\frac{m}{V}$.

$$r_{13} = 10.45$$

$$r_{33} = 33.1$$

$$r_{51} = 32$$

Comparing the accepted value of $r_{13} = 10.45$ to that of $r_1 = 12$ gives a percent difference of 13.8%. Comparing the accepted value of $r_{33} = 33.1$ and $r_{51} = 32$, respectively, to that of $r_2 = 37$ gives percent differences of 11.1% and 14.5%. All values overlap with the range given by the uncertainty.

5 Conclusion

The value for r were found to be $r_1 = [(1.2 \pm .2) \times 10^{-11}]\frac{V}{m}$ and $r_2 = [(3.7 \pm .8) \times 10^{-11}]\frac{V}{m}$. Comparing to values in [WG85], gives percent differences of 13.8% between our found value for r_1 and Weis' value for r_{13}, and is within the uncertainty range of our experiment. Similar comparisons gives percent differences of 11.1% and 14.5% between our found value of r_2 and Weis' values for r_{33} and r_{51}, respectively. Both of these values of r are also within our uncertainty range of r_2.

Sources of error include the graphical nature of the oscilloscope output, so if ranges were not set correctly, values may have been rounded, though scales were set appropriately as to avoid such error. The averaging of oscilloscope output data may have also affected the difference values obtained. Noise was also an exceptionally challenging impediment to accurate or observable values, so a draft shield was added to minimize noise as much as possible.

References

[WG85] RS Weis and TK Gaylord. Lithium niobate: summary of physical properties and crystal structure. *Applied Physics A*, 37(4):191–203, 1985.