Contents

1 Physical Background

1.1 Physical Basis of the Pockels Effect

The dielectric constants is used to describe electric fields in a medium. Often a linear approximation is used for the dependency between the dielectric displacement D and the electric field E, so the dielectric constant seems to be constant. Actually if the squared term is considered, while terms of higher order are ignored, the dielectric constant becomes

$$D = a_1 E + a_2 E^2 + ..., \text{ where } a_i \in \mathbb{R} \tag{1}$$

$$\implies \epsilon_r = \frac{\partial D}{\partial E} = a_1 + 2a_2 E + ... \tag{2}$$

So the dielectric constant is actually dependent on the applied electric field. This linear term is describing the Pockels effect, which will be observed in this experiment.

The pockels cell used in the experiment consists of four ADP (ammonium dihydrogen phosphate $NH_4H_2PO_4$) crystals. These crystals have no symmetric center otherwise the coefficient a_2 would be equal to zero and the pockels effect would not be measurable. The used Pockels cell is illustrated in fig. 2.

The index ellipsoid for a ADP crystal with an applied electric field which is orientated along the x_1 axis is given as

$$\frac{x_1^2}{n_1^2} + 2r_{41}x_2Ex_3 + \frac{x_2^2}{n_2^2} + \frac{x_r^2}{n_3^2} = 1, \tag{3}$$

where E is the applied electric field and r_{41} is the electo optical coefficient. Now a coordinate transformation of the form

$$x_2 = \frac{x_2' + x_3'}{\sqrt{2}} \qquad x_3 = \frac{x_2' - x_3'}{\sqrt{2}} \tag{4}$$

is made. Furthermore we introduce the definition

$$n_x^2 = \frac{1}{2}\left(\frac{1}{n_1^2} + \frac{1}{n_3^2}\right). \tag{5}$$

Now eq. (3) becomes

$$\frac{x_1^2}{n_1^2} + \frac{{x_3'}^2}{n_x^2}(1 - r_{41}En_x^2) + \frac{{x_2'}^2}{n_x^2}(1 + r_{41}En_x^2) + x_2'x_3'\left(\frac{1}{n_1^2} - \frac{1}{n_3^2}\right) = 1. \tag{6}$$

To simplify the term for refractive indices of the new coordinates x_2', x_3' we use the Taylor series to the third order. We get

$$n_{x_2'} = \frac{n_x}{\sqrt{1 + r_{41}En_x^2}} \approx n_x + \frac{1}{2}r_{41}En_x^3 \qquad \text{and} \tag{7}$$

$$n_{x_3'} = \frac{n_x}{\sqrt{1 - r_{41}En_x^2}} \approx n_x - \frac{1}{2}r_{41}En_x^3. \tag{8}$$

The birefringence causes a shift of phase which can be calculated by the formula

$$\Delta\varphi = kL(n_1 - n_{x_2'}), \tag{9}$$

where k is the wave number and L is the path length traveled by the light. Using eq. (7) and neglecting the natural birefringence $n_1 - n_x$ because we eliminated it by the given setup, the phase shift caused by the Pockels effect is given as

$$\Delta\varphi = \frac{\pi}{\lambda} r_{41} E n_x^3 l. \tag{10}$$

As mentioned earlier the used Pockels cell consists of four ADP crystals. Therefor the length L is given as four times the length of one crystal l. The electric field is applied by a capacitor-like setup so the field strength is approximately given by $E = U/d$. Now the electro optical coefficient can be calculated by

$$r_{41} = \frac{\lambda d}{U_{\lambda/2} \cdot 4l} \left(\frac{1}{2n_1^2} + \frac{1}{2n_3^2} \right)^{\frac{3}{2}}. \tag{11}$$

1.2 Physical Basis of the Faraday Effect

The Faraday effect describes the observed phenomena of linear polarized light passing an isotropic medium in a magnetic field and changing its angle of polarization because of this.

Linear polarized light can be described as a combination of two opposite circular polarized waves. When an electro-magnetic waves enters an isotropic medium the electrons of the material will be affected by the wave and rotate. The moving electrons in the material create small dipoles and as the two circular waves are opposite for one wave the magnetic field of the dipole will be in the same direction as the external field and for the other wave the dipole field will weaken the external field. This weakening and fortifying leads to one circular wave propagation through the material faster than the other. Therefore there is a phase between the two waves. Added up to a linear polarized wave the angle of polarization is different to the beginning.

With help of the Verdet constant V the angle of rotation can be described with

$$\alpha = V \cdot H \cdot l. \tag{12}$$

As seen in eq. (12) the angle α is directly proportional to the strenght H of the magnetic field and the length l of the material. For a non-constant magnetic field the material is devided into small slices $\frac{\mathrm{d}}{\mathrm{d}z}$ and integrating over the length of the material returns the angle α again:

$$\mathrm{d}\alpha = V \cdot H(z)\,\mathrm{d}z\,. \tag{13}$$

Calculation of the Magnetic Field of a Coil The magnetic field in the Faraday experiment is created by a coil. With use of Biot-Savart's law the magnetic field of a current loop can be calculated. The magnetic field $\mathrm{d}H$ in a piece of wire $\mathrm{d}\vec{l}$ at a distance $\vec{r}$ that is caused by the current I is

$$\mathrm{d}H = \frac{1}{4\pi} \frac{I\,\mathrm{d}\vec{l} \times \vec{r}}{r^3}. \tag{14}$$

Using this we can calculate the magnetic field of a loop with radius x in a point l'

$$\begin{aligned} \mathrm{d}H_z &= |\,\mathrm{d}\vec{H}\,| \sin\Theta \text{ with } \Theta \sphericalangle \vec{r}, \vec{l'} \\ &= \frac{1}{4\pi} \frac{I}{r^2} \sin\varphi \sin\Theta \;\mathrm{d}l \text{ with } \varphi \sphericalangle r,\ \mathrm{d}l \\ &= \frac{1}{4\pi} \frac{1}{r^2} \sin\Theta \; x\mathrm{d}\phi \end{aligned} \tag{15}$$

whereby it has already been considered that the x- and the y-component cancel out. With use of $\sin\Theta = x/r$ and integrating over dΦ we find:

$$H(l') = \frac{I}{2}\frac{x^2}{\sqrt{x^2 + l'^2}}. \tag{16}$$

As we are interested in the magnetic field of a coil, not a single current loop we now consider a coil as many loops on side of each other. Using the inner radius x_1 of the coil and the outer radius x_2, the number of twists N and the length of the coil ℓ we can weight the total current through the coil on the single loops:

$$\mathrm{d}I = I \cdot N\frac{\mathrm{d}x}{x_2 - x_1}\frac{\mathrm{d}l'}{\ell}. \tag{17}$$

Taking eq. (17) and plugging it into eq. (16) yields

$$\mathrm{d}H = \frac{1}{2}\frac{x^2}{\sqrt{x^2 + l'^2}}\mathrm{d}I = \frac{1}{2}\frac{x^2}{\sqrt{x^2 + l'^2}}\frac{NI}{(x_2 - x_1)\ell}\mathrm{d}x\,\mathrm{d}l' \tag{18}$$

Integrating eq. (18) over the coil brings:

$$\begin{aligned} H(z) &= \frac{NI}{2(x_2 - x_1)\ell}\int_{-z}^{\ell-z}\int_{x_1}^{x_2}\frac{x^2}{\sqrt{x^2 + l'^2}}\mathrm{d}x\,\mathrm{d}l' &(19)\\ &= \frac{NI}{2(x_2 - x_1)\ell}\left((\ell - z)\log\left(\frac{x_2+\sqrt{(\ell-z)^2+x_2^2}}{x_1+\sqrt{(\ell-z)^2+x_1^2}}\right) + z\log\left(\frac{x_2+\sqrt{z^2+x_2^2}}{x_1+\sqrt{z^2+x_1^2}}\right)\right). &(20)\end{aligned}$$

The magnetic field together with eq. (13) lets us calculate the angle alpha

$$\alpha = V\int_{\frac{\ell--l}{2}}^{\frac{\ell+l}{2}} H(z)\mathrm{d}z \tag{21}$$

by integrating over all slices.

2 Setup and Implementation

2.1 Setup

2.2 The setup for the Pockels measurement

The used setup consists primaly out of five parts. The analysed light comes from an HeNe-Laser and travels threw a polarisator to ensure we have linear polarised light. After that the light goes threw the Pockels cell the main part of the setup. Finally the light goes thre an other polarisator used as an analyser and gets detected by a photo diode. To do the measurement we use an oscilloscope and different voltage suppliers. The whole setup can be seen in fig. 1

For further discussion of the physical basis of the pockels effect we need to know what exactly is in the pockels cell and how the orientations are. To illustrate that it is shown in fig. 2.

The Pockels cell consists of four identical ADP crystals to which a electric field is applied using different polarisations to guarantee that the natural birefringence is eliminated but the Pockels effect is still measureable.

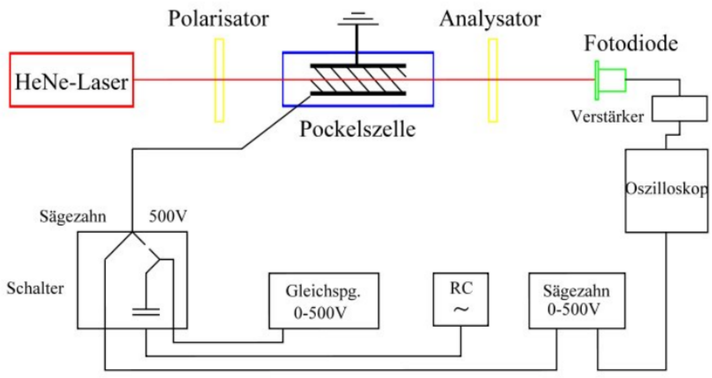

Figure 1: In this picture the setup for the measurement of the Pockels effect is illustratet ([Source 1]).

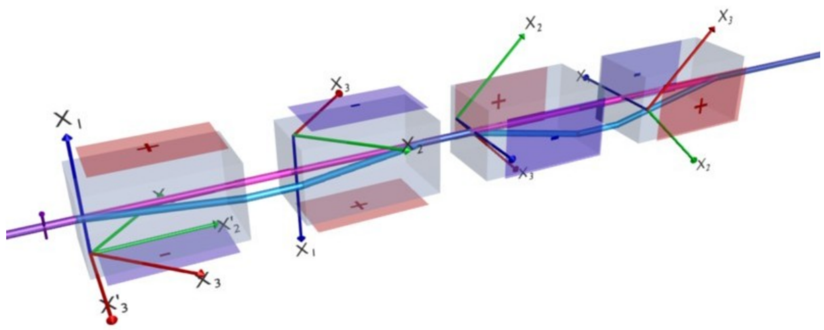

Figure 2: In this picture the used Pockels cell ist shown. In the following discussion of the physical basis the shown orientations are used ([Source 1]).

2.3 Setup of the Faraday Experiment

Main part of the Faraday experiment in fig. 3 is the current coil with the flint-glass stick inside. The light that is emitted by the lamp is linearly polarized and proceeds into the flit-glass stick. Because of the magnetic field the Faraday effect happens and the polarization angle changes. The light goes into the half-shade polarimeter and can be analyzed through the ocular.

Furthermore the current coil is connected with a generator and the current can be changed in small steps between $-5\,\mathrm{A}$ and $5\,\mathrm{A}$.

2.4 Implementation

2.5 Implementation of the Pockels Experiment

To measure the electro optical coefficient two independent methods were used. One is called the sawtooth method and one, since it is using a sine modulated direct current, is called modulated DC method.

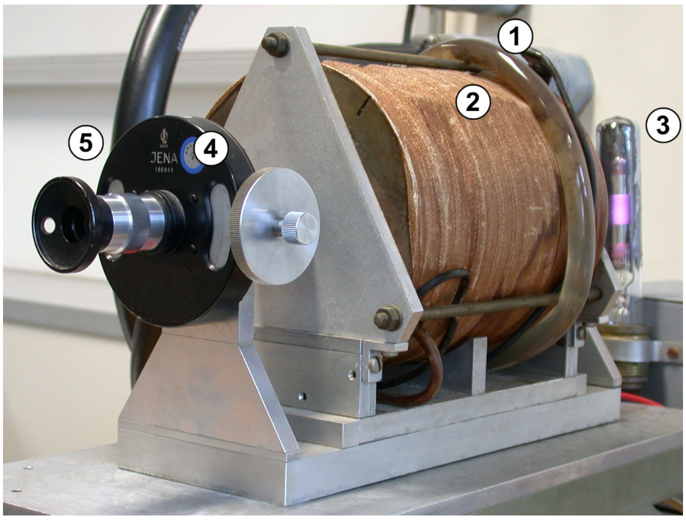

Figure 3: Setup of the Farady experiment: 1. Cooling system, 2. Coil with flint glass stick, 3. sodium-vapor lamp, 4.Analyzer of the half-shade polarimeter, 5. Ocular ([Source 1])

2.5.1 The Sawtooth Method

First of all the polarizer had to be adjusted in a way that the from the polarizer reflected beam was reflected in the beam that comes out of the laser. Now a sawtooth voltage was applied to the Pockels cell and displayed on the oscilloscope with a constant damping. This signal and the signal from the photo diode can be used to determine the voltage $U_{\lambda/2}$.

After that the damping factor was measured. To do so the signal of the sine voltage generator was measured directly and indirectly over the supplier at the same time.

2.5.2 The Sine Modulated Direct Current Method

In this part of the experiment a sine modulated direkt current was applied to the Pockels cell. Now the direct current was adjusted so the measured signal from the photo diode showed the doubled frequency of the input signal. The value of the direct current was noted. Now the polarization of the direct current was changed and the measured value was noted again.

2.6 Implementation of the Faraday Experiment

First of all before the experiment can be done the cooling system has to be switched on and also the lamp needs some time to get started. After about half an hour the temperature is supposed to be stable and the measurements can be taken.

For equal steps in $-5\,\mathrm{A}$ and $5\,\mathrm{A}$ four angles were to be measured.

Equally Dark For the calculation of the Verdet constant of flint-glass the angle where both sections of the half-shade polarimeter appear dark in the same way can be used. To find this angle the polarimeter was slowly turned and the angle of same-darkness was read of.

Equally Bright The equally-bright position can also be used to calculate the Verdet constant. As it was really difficult to determine this point instead the two angles were it was still slightly possible to separate the different sections. The idea was that later the angle in between can be used as the equally-bright position and it also holds sensible errors for the analysis.

Dark Outer and Dark Inner Section To determine the angle 2ϵ the angles where the inner section appeared the darkest and the angle where the outer section appeared the darkest were measured. This measurement did not feel very precise as it is difficult to decide whether something is the darkest it will become or not. Nevertheless as is was also not possible to measure outer borders so we did not use the method introduced for the equally-bright but simply tried to measure the best we could.

Each measurement was done for all currencies and the angles were noted.

3 Analysis

3.1 Analysis of the Pockels Measurement

3.1.1 Damping Measurement

To determine the damping factor Γ we measured the same sine signal once directly on the supplier and once over the current distributor. The so got data was fitted of the form

$$f(x) = A + B\sin(Cx + D). \tag{22}$$

The data and the fit are shown in fig. 4. The damping factor Γ was calculated by

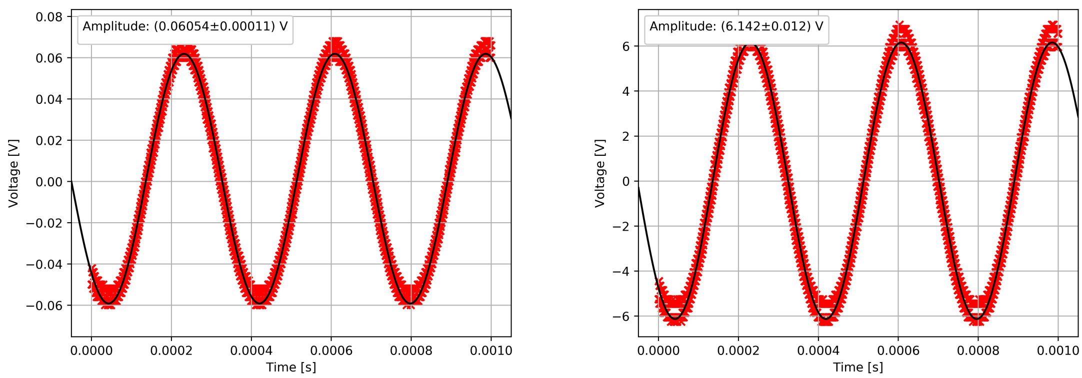

Figure 4: Plots of the damped and the undamped Signal. The amplitudes were estimated by a sine fit using the least squares method.

$$\Gamma = \frac{U_{\text{undamped}}}{U_{\text{damped}}} = 101.45 \tag{23}$$

The error of the damping factor was calculated by gaussian error propagation and determined to $s_\Gamma = 0.27$.

3.1.2 Analysis of the Sawtooth Method

In this measurement we used the program which reads out the oscilloscope to mark the points where the signal from the photo diode has its maximum respectively its minimum (In the period of time where the signal shows a sine function). Then the voltage of the sawtooth of these two points is measured and one can get the voltage $U_{\lambda/2}$ as the difference between the two values. To visualize the procedure the measurements of the oscilloscope have been saved. In fig. 5 one out eight measurement is displayed. The rest of the measurements can be found in the appendix.

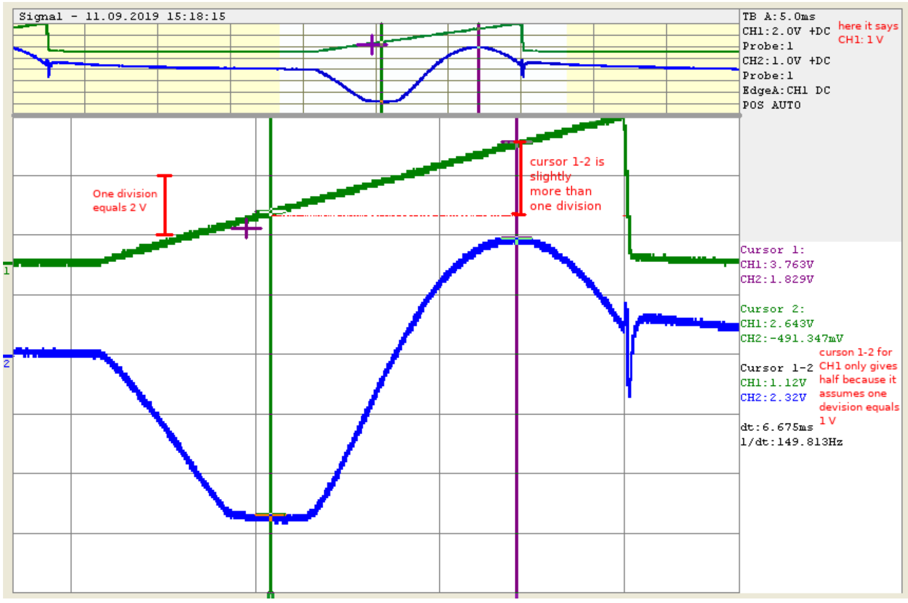

Figure 5: One measurement of the sawtooth method. The other measurements can be found in the appendix

The values displayed on the measuring program where exactly the half of sensible values so we assume that caused by the different measuring divisions of the oscilloscope that all the values have to be multiplied by a factor of two. A closer look to the raw data speaks for that assumption. To visualize the problem there are some visual additions in fig. 5.

The values of the half wave voltage $U_{\lambda/2}$ (which were manipulated in the way we mentioned before) are listed in table 1.

Measurement	Voltage [V]
1	2,24
2	1,92
3	1,28
4	1,76
5	1,28
6	1,48
7	1,76
8	2,24

Table 1: In this tables the determined half wave voltages of every single measurement are listed.

For the calculation of the electro optical coefficient the mean and the unbiased standard derivation of the measured voltages is used. So for the damped half wave voltage the value

$$U_{\lambda/2}^{\text{damped}} = (1{,}7 \pm 0{,}4)\,\text{V} \tag{24}$$

is determined. To calculate the undamped value for the half wave voltage we get

$$U_{\lambda/2}^{\text{undamped}} = (170 \pm 40)\,\text{V}. \tag{25}$$

Using eq. (11) we get for the electro optical coefficient

$$r_{41} = (33 \pm 7)\,\frac{\text{pm}}{\text{V}} \tag{26}$$

while the error was calculated using gaussian error propagation.

3.1.3 The Sine Modulated Direct Current Method

The voltage at which the diode signal showed the doubled frequency of the input signal applied to the pockels cell for the positive polarization was measured to

$$U_{+} = (196 \pm 1)\,\text{V}. \tag{27}$$

For the opposite polarization we observed a voltage of

$$U_{-} = (-56 \pm 2)\,\text{V}. \tag{28}$$

Both errors were estimated due to the quality of the diode signal. Since the signal for the negative polarization was quite more noisy the estimated error is bigger. For the half wave voltage we get

$$U_{\lambda/2} = U_{+} - U_{-} = (252 \pm 2)\,\text{V} \tag{29}$$

while the error was calculated by gaussian error propagation. The measurements are shown in the appendix. For the electro optical coefficient we get

$$r_{41} = (22{,}37 \pm 0{,}18)\,\frac{\text{pm}}{\text{V}} \tag{30}$$

3.2 Analysis of the Faraday Experiment

To analyze the experiment first of all some preparation of the taken data had to be done. For the later linear fit angles of 178° do not make sense, so every angle over 90° was modified by −180° for the equally-bright and the 2ϵ measurements.

Moreover for the equally-bright measurements the actual angles were calculated with help of the borders to

$$\alpha_{\text{bright}} = \alpha_{\text{min}} + \frac{\alpha_{\text{max}} - \alpha_{\text{min}}}{2} \tag{31}$$

with an error of

$$s_{\alpha_{\text{bright}}} = \frac{\alpha_{\text{min}} - \alpha_{\text{max}}}{2}. \tag{32}$$

3.2.1 Calculating the Integral Needed to Determine the Verdet Constant

To determine the Verdet constant out of the measured data it is necessary to calculate the integral given in eq. (21). Using the given data for the coil ([Source 2]) and the Python function `scipy.integrate.quad` we find

$$\begin{aligned} \ell &= 175\,\text{mm} \\ x_1 &= 10\,\text{mm} \\ x_2 &= 75\,\text{mm} \\ l &= 150\,\text{mm} \\ N &= 3600 \\ \int_{\frac{\ell-l}{2}}^{\frac{\ell+l}{2}} \frac{H(z)}{I}\text{d}z &= 2554{,}85. \end{aligned} \tag{33}$$

`scipy.integrate.quad` also gives an error of 1,4 on the calculated integral which is extremly small so it is not going to be considered in the analysis.

The manual suggested to try another method for calculating the magnetic field by using

$$H = \frac{NI}{\ell}. \tag{34}$$

Using this formula and running the same methods as for calculating in eq. (33) we find:

$$\int_{\frac{\ell-l}{2}}^{\frac{\ell+l}{2}} \frac{H}{I}\text{d}z = l\frac{N}{\ell} = 3085.7. \tag{35}$$

The so calculated value is about 21 % away from the accurate one, so in the further analysis we will stick to the first value.

3.2.2 Determining the Verdet Constant out of the Equally-Dark Measurements

To determine the Verdet constant the measured angle is plotted against the current in the coil. With `scipy.optimize.curve_fit` a linear fit of the form $f = a + bx$ is made.

Using the slope of the fit, the in eq. (33) calculated magnetic field and eq. (21) the Verdet constant can be found with

$$V = -\frac{b}{2554.85}. \tag{36}$$

For the error on V the square root of the diagonal entry of the covariance matrix is used. As the value given by the manufacture has the unit $\frac{{}' \mathrm{cm}}{\mathrm{Oe}}$ the calculated value needs to be transformed. Thus we use

$$\begin{aligned} 1^\circ &= 60' \\ 1\,\mathrm{A} &= \frac{4\pi}{10}\frac{1}{\mathrm{Oe\,cm}}. \end{aligned} \tag{37}$$

The error on the unit converted value is calculated in the same way.

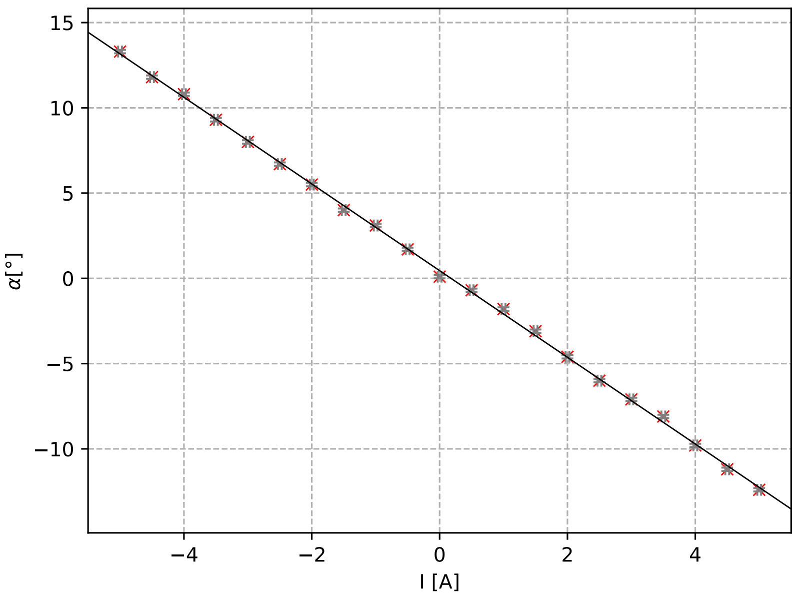

Figure 6: Linear fit of the equally-dark measurement. The displayed errorbars are based on the estimated errors for I and α_{dark}

Following the above described procedure with the data displayed in fig. 6 we get the following parameters:

$$\begin{aligned} b_{\mathrm{dark}} &= (-2{,}542 \pm 0{,}013)\,\frac{\circ}{\mathrm{A}} \\ V_{\mathrm{dark}} &= (4{,}75 \pm 0{,}03) \cdot 10^{-2}\,\frac{'}{\mathrm{Oe\,cm}}. \end{aligned} \tag{38}$$

3.2.3 Determining the Verdet Constant out of the Equally-Bright Measurement

The procedure for the equally-bright measurement is more or less the same with the small difference that the errors for the measured angle have been determined out of the taken data. Nevertheless the fit is made with `scipy.optimize.curve_fit` which also

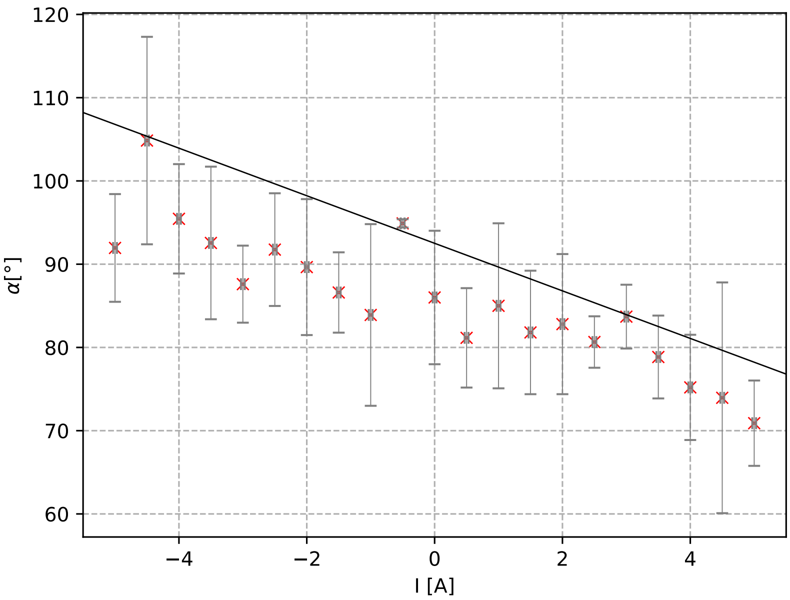

Figure 7: Linear fit of the equally-bright measurement. The displayed errorbars are determined out of the data.

takes errors for the y-values. With data and fit from fig. 7 a second value for the Verdet constant is calculated:

$$\begin{aligned} b_{\text{bright}} &= (-2{,}857 \pm 0{,}013)\,\frac{^\circ}{\text{A}}\,, \\ V_{\text{bright}} &= (5{,}3 \pm 1{,}1)\cdot 10^{-2}\,\frac{'}{\text{Oe cm}}. \end{aligned} \tag{39}$$

3.2.4 Determining 2ϵ

The polarimeter shift can be found by subtracting the two angles of inner (β) and outer (γ) maximum darkness. To get a better value the mean is taken and the error is calculated with gaussian error propagation where the estimated error of β and γ is used. Doing so we get:

$$\begin{aligned} 2\epsilon &= \gamma - \beta \\ s_{2\epsilon} &= \sqrt{0.4^2 + 0.4^2} \\ \bar{2\epsilon} &= \frac{1}{n}\sum 2\epsilon = (11{,}94 \pm 0{,}03)^\circ \text{ with} \\ s_{\bar{2\epsilon}} &= \frac{s_{2\epsilon}}{\sqrt{n}}. \end{aligned} \tag{40}$$

4 Discussion

4.1 Summarizing and Discussing the Pockels Experiment

In the Pockels experiment we measured the electro optical coefficient for the used Pockels cell with two different methods. These methods yielded different values. These values are

$$r_{41}^{\text{sawtooth}} = (33 \pm 7)\,\frac{\text{pm}}{\text{V}} \tag{41}$$

$$r_{41}^{\text{modulated DC}} = (22{,}37 \pm 0{,}18)\,\frac{\text{pm}}{\text{V}}. \tag{42}$$

If you compare these results with the given value of $23{,}4\,\frac{\text{pm}}{\text{V}}$ you see that the first measurement yielded a value within 2 standard deviations from the given value which is not least caused by the big standard deviation. The measurement with the sine modulated direct current yielded a value for the electro optical coefficient which is much closer to the given one but the error on that measurement is way smaller so that it is within 6 standard deviations. It has to be noticed that the given value for the electro optical coefficient is a specification given by the producer of the probe so it can change within time caused by corrosion. Furthermore the electro optical coefficient is dependent on the temperature and the given value was measured at 21 °C so the deviation may be caused by the different temperature.

Additionally the sensible result of the sawtooth method shows that we might have interpreted the error of the used measuring program right in a way that it displayed half the value which was measured.

To sum up, the measurements yielded reasonable results so it can be assumed that the measurement was carried out properly and the methods are appropriate to measure the electro optical coefficient of a probe.

4.2 Summarising and Discussing the Faraday Experiment

In the Faraday experiments two different measurements were use to determine the Verdet constant V of flint-glass. Using the equally-dark method we found

$$V_{\text{dark}} = (4{,}74 \pm 0{,}03) \cdot 10^{-2}\,\frac{'}{\text{Oe cm}}. \tag{43}$$

The equally-bright method leads to

$$V_{\text{bright}} = (5{,}3 \pm 1{,}1) \cdot 10^{-2}\,\frac{'}{\text{Oe cm}}. \tag{44}$$

The manufacturs value for the Verdet constant of flint-glass is $V_{\text{flint}} = 0{,}05\,\frac{'}{\text{Oe cm}}$ so both measurements are very close to the expected value. One may notice that the error for equally-dark is much smaller than for equally-brigth. This was done on purpose because the equal-dark was way easier to measure and even if the equally-brigth measurement has a quite good absolute value the uncertainity is definetly to hight to make a sensible statement about the Verdet constant. Moreover one will notice one point with really small error in the equally-bright plot that shifts the whole linear funktion up. Even though that point is out of range of the others it was not kicked out for the fit because of its small error.

Furthermore out of the data of maximum inner and outer darkness the shift of the polarimeter was found as

$$2\epsilon = (11{,}94 \pm 0{,}03)^\circ. \tag{45}$$

5 Appendix

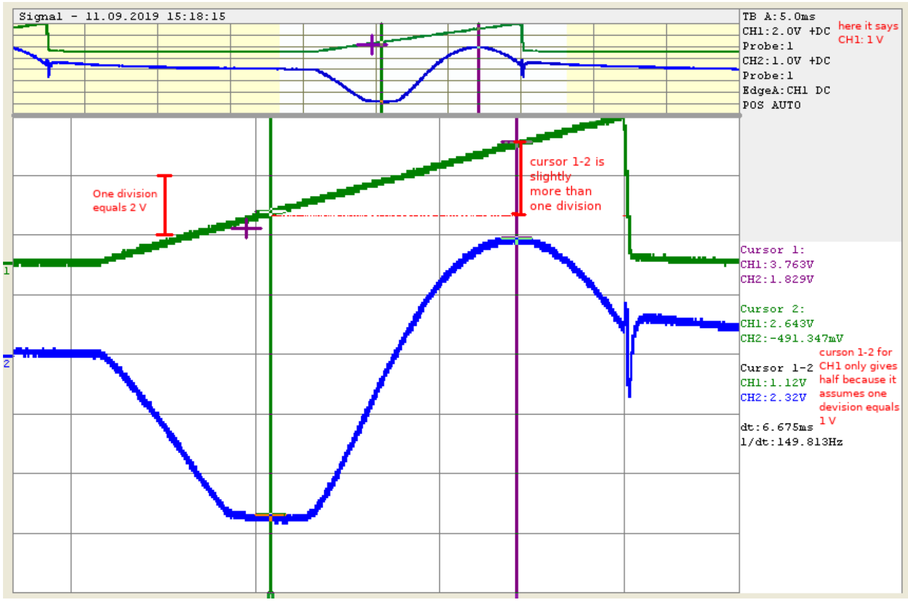

Figure 8: Measurement 0using the sawtooth method.

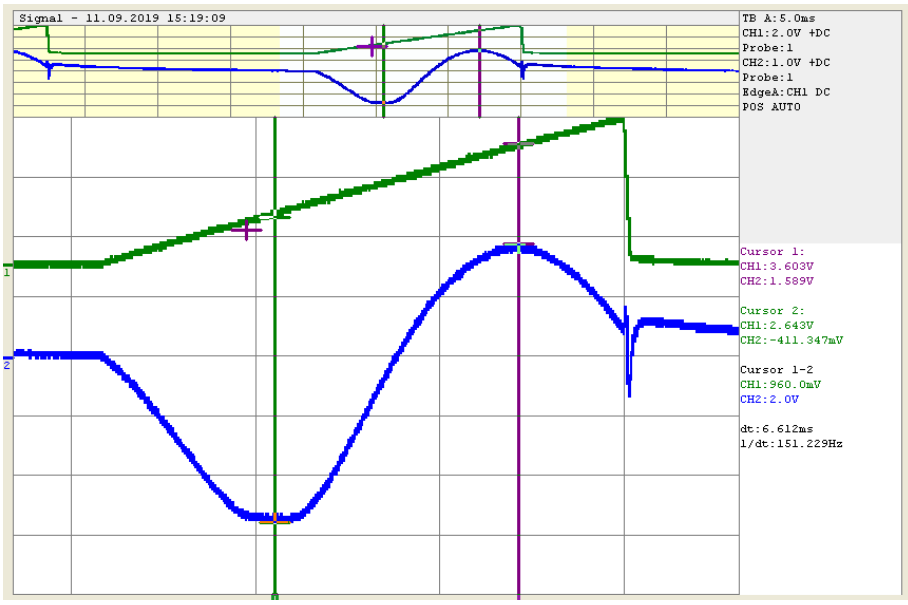

Figure 9: Measurement 1using the sawtooth method.

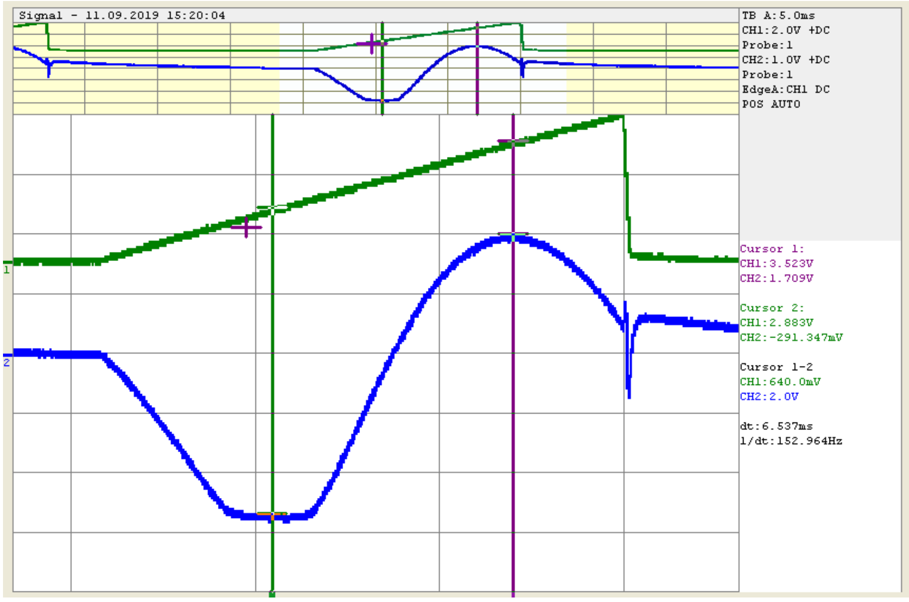

Figure 10: Measurement 2using the sawtooth method.

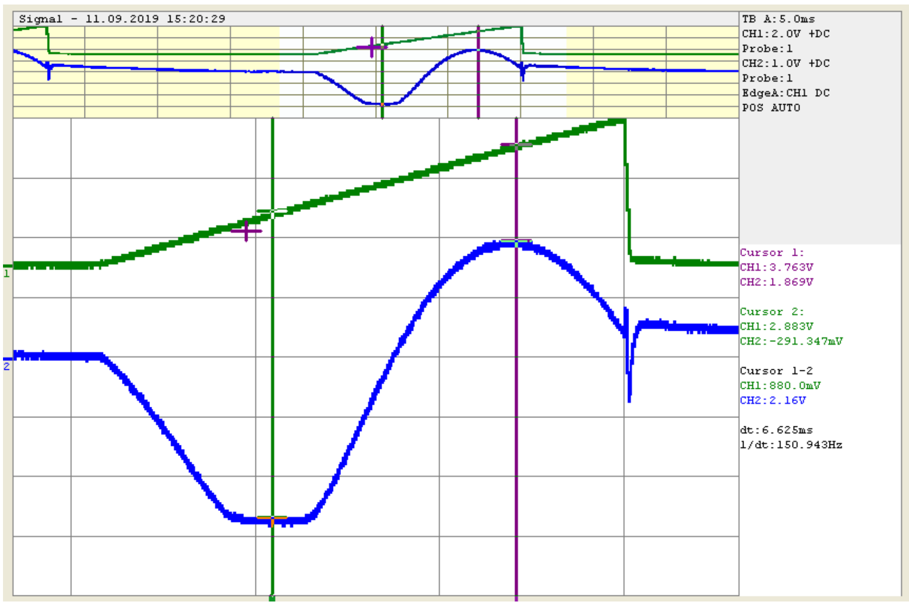

Figure 11: Measurement 3using the sawtooth method.

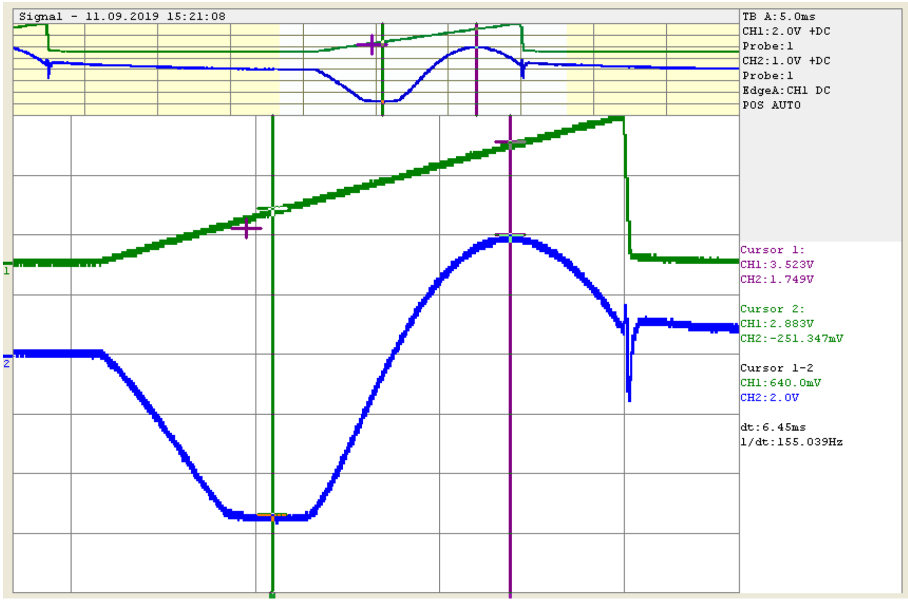

Figure 12: Measurement 4using the sawtooth method.

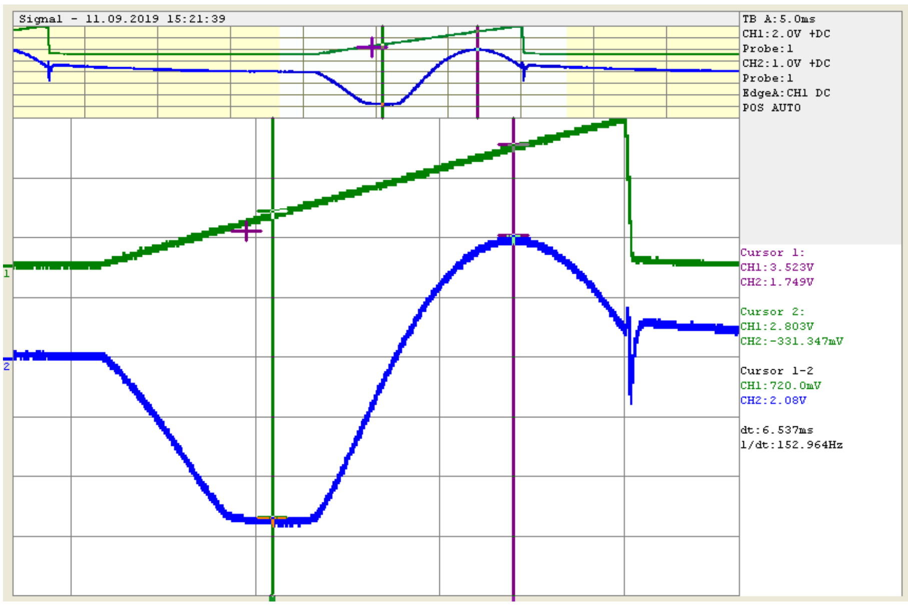

Figure 13: Measurement 5using the sawtooth method.

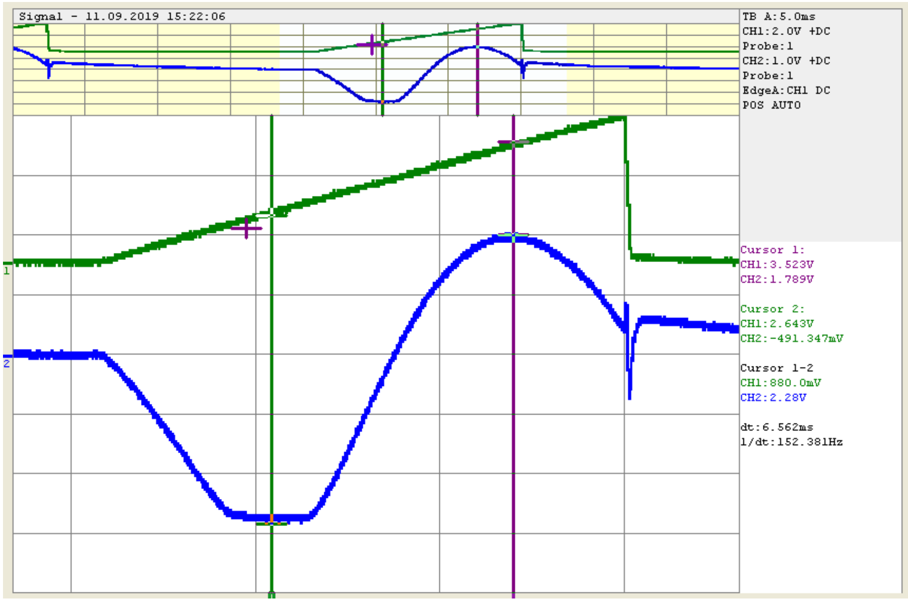

Figure 14: Measurement 6using the sawtooth method.

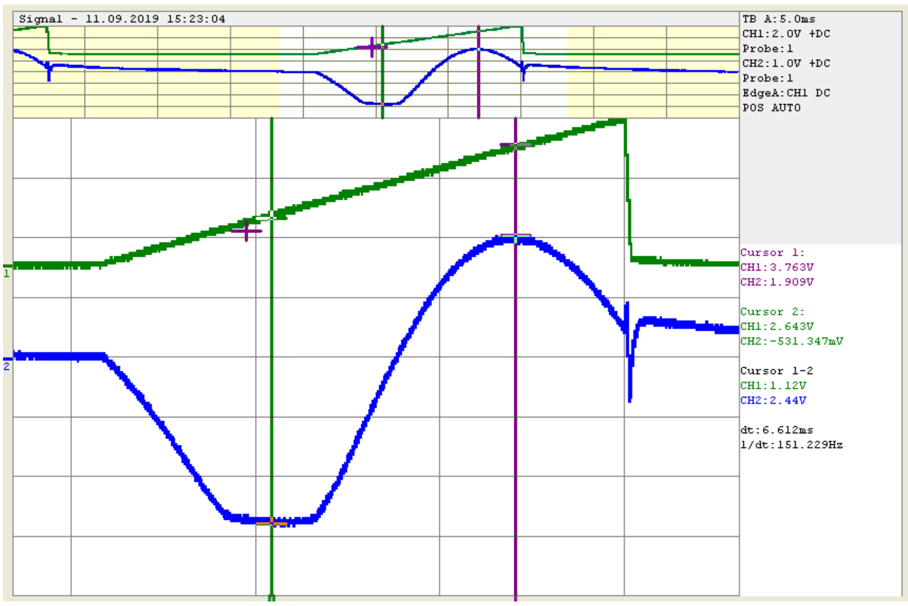

Figure 15: Measurement 7using the sawtooth method.

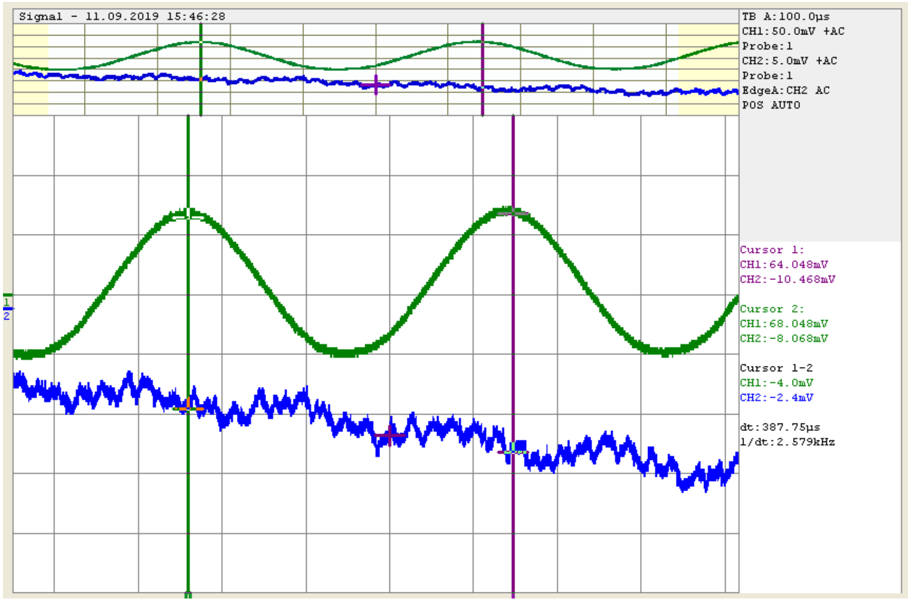

Figure 16: U_{-}-Measurement of the sine modulated direct current method

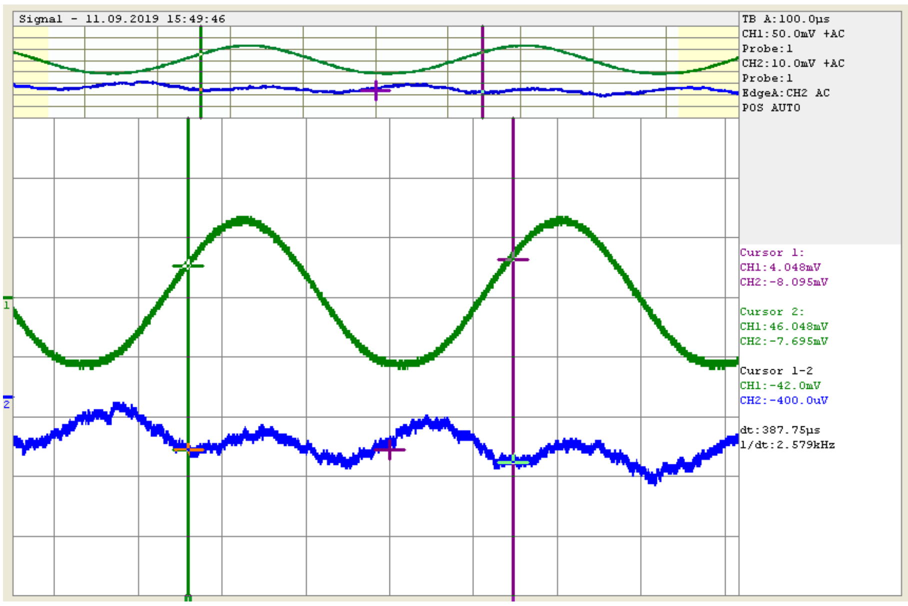

Figure 17: U_{+}-Measurement of the sine modulated direct current method

List of Figures

References

[Source 1] *"Versuchsanleitungen zum Physiklabor für Anfänger*innen, Teil 2"* Stand 02/2019.

[Source 2] *"Elektrooptischer Effekt und Faraday-Effekt, Zulassungsarbeit zur wissenschaftlichen Prüfung für das Lehramt an Gymnasien, Bernd Hermann, Januar 1977"*

Faraday - Effekt

°(16,5 °C)
*(12,2 °C)
+(11,7 °C)
⊠ (11,6 °C)

innen dunkel | außen dunkel

	I [A]	α^{min}_{dunkel} [°]	α^{max}_{dunkel} [°]	α^{min}_{hell} [°]	α^{max}_{hell} [°]	β [°]	γ [°]
°	0	0,2	0,2	76,2	99,8	176,3	5,8
	0.50	179,1	179,1	74,2	93,9	173,1	4,4
*	1	2	2	79,1	90,8	172,0	7,4
+	1.50	176,8	176,8	80,1	90,5	170,0	2,2

⊠	I [A]	α^{min}_{dunkel} [°]	α^{max}_{dunkel} [°]	α^{min}_{hell} [°]	α^{max}_{hell} [°]	β [°]	γ [°]
	0	0,1	0,1	78	94	173,9	8,4
	0.50	179,3	179,3	75,2	87,1	173	6,9
	1	178,2	178,2	75,1	94,9	171,1	6
	1.50	176,9	176,9	74,4	89,2	167,6	3,6
	2	175,4	175,4	74,4	91,2	169,1	0
	2.50	174	174	77,6	83,7	169,8	179,3
	3	172,9	172,9	78,9	88,5	167	1,2
	3.50	171,9	171,9	73,9	83,8	163,5	177,3
	4	170,2	170,2	68,9	81,5	165,4	176
	4,50	168,8	168,8	60,1	87,8	161,5	173,7
	5	167,6	167,6	65,8	76	161,7	176,2

I [A]	α^{min}_{dunkel} [°]	α^{max}_{dunkel} [°]	α^{min}_{hell} [°]	α^{max}_{hell} [°]	β [°]	γ [°]
-0,5	1,7	1,7	94,9 ↔	76,5	175,9	10,3
-1	3,1	3,1	73	94,8 ~~[illegible]~~	6,4	7,6
-1,5	4	4	81,8	91,4	178,7	10,9
-2	5,5	5,5	81,6	97,8	179,4	13,9
-2,5	6,7	6,7	85	98,5	1	12
-3	8	8	83	82,2	3,6	4,5
-3,5	9,3	9,3	83,4	101,7	3	10,8
-4	10,8	10,8	88,9	102	0,6	17,8
-4,5	11,8	11,8	92,4	117,3	5,6	20,6
-5	13,3	13,3	98,4 ↔	85,5	8,8	19,5

Fehler

I	α_d^{min}	α_d^{max}	α	α	β	γ
±0,03A	±0,1°	±0,1°	±0,5°	±0,5°	±0,4°	±0,4°

Temp ± 7°C
(10 - 17°C)