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1 Short overview of the experiment

In this experiment we try to confirm the Raman-Nath theory of diffraction.
Therefore we examine the angles and the intesities of diverse interference patterns which are produced by a He-Ne-LASER and different gratings.
the experiment is split into five tasks.

1. Determine the grating constant of a Sin-grating from the distance of the 1^{st} maximum.
2. Identify the grating constant and the resolution of 5 different amplitude gratings
3. Calculate the aperture function for the 1^{st} grating from the measured intensities.
4. Calculate the ratio between the slit width and the grating constant from the aperture function.
5. (a) Measure the intensity distribution for a phase grating depending on the Voltage on the ultrasonic oscillating quartz.
   (b) Compare the results to the Raman-Nath theory
   (c) Identify the sonic wavelength.

2 Theoretical Background

In the following chapter, all the equations used, can be found in [1]

2.1 Diffraction

The scattering of electromagnetic waves on geometrical objects, like slits or gratings, is called Diffraction. This effect can not be explained by refraction or reflection but by the principle of Huygens which states, that every point on a wave-front is equivalent to a spherical wave. Due to those geometrical objects, non-homogeneities occur which leads to the observed interferences.
For diffraction experiments it is important to distinguish between the Fresnel- and the Fraunhofer-arrangements. This experiment makes use of the Fraunhofer-arrangement. Which means, that the spacing between the light source an the detector can be considered as infinite. This is being realised by two lenses, so that the laser beams are parallel and so the wave-front structure can be thought of as a plane. For the angles of the maxima on the screen for a grating with a grating constant K the following formula applies:

$$\sin(\Theta_m) = \frac{m \cdot \lambda}{K} \tag{1}$$

The Fresnel-arrangement on the other hand uses a very small distance between detector and light source and the geometrical properties of the wave-front can not be neglected.

2.2 Aperture function

From the diffraction pattern which can be seen on the screen one can calculate the so called aperture function $g(x)$. this aperture function gives the characteristics for the grating, used in the experiment, in dependence of the location. With the Kirchhoff integral-theorem it can be shown, that the Intensity distribution I of the diffraction pattern is equal to the to the squared Fourier transformed aperture function g of the grating.

$$I = |\Psi(\vec{x}, \vec{y})|^2 = \left| \int_{aperture} g(\vec{k}) \cdot e^{i\vec{k}\cdot\vec{x}} dA_{aperture} \right|^2 \tag{2}$$

we will look at two different types of gratings in this experiment on the one hand there will be amplitude gratings, on the other hand one so called phase grating

2.3 Amplitude grating

To make things easy in the beginning we firstly look at one single slit with the width d and length l where $l \gg b$. The aperture function can then be written as:

$$g(x)_{singleslit} = \begin{cases} 1 \text{ if } |x| \leq b/2 \\ 0 \text{ if } |x| > b/2 \end{cases} \tag{3}$$

for the amplitude $\psi(\Theta)$ of the light-wave-function on the screen we obtain the following relation from [1]:

$$\psi(\Theta) \sim \int_{-b/2}^{b/2} e^{ikx\sin(\Theta)} dx \underset{\substack{\uparrow \\ \text{where } \beta(\Theta) = \frac{kb\sin(\Theta)}{2}}}{=} \frac{sin(\beta(\Theta))}{2\beta(\Theta)} \tag{4}$$

with this and Equation 2 it follows, that:

$$\psi^2(\Theta) \sim \left(\frac{sin(\beta(\Theta))}{2\beta(\Theta)}\right)^2 \sim I \tag{5}$$

Now let us look at a greating with many slits in a row. d shall still indicate the width and the grating constant which indicates the distance between the centers of two adjacent slits shall be called K. So the aperture function for a grating with N-slits can be described similar to the one above in Equation 3 as:

$$g_{ampl}(x) = \begin{cases} 1 \text{ if } m \cdot K \leq x \leq j \cdot K + b \text{ where m} \in \{0,1,\ldots, \text{N-1}\} \\ 0 \text{ else} \end{cases} \tag{6}$$

Also $\psi(\Theta)$ can now be written as a sum of integrals, in form of the one shown in Equation 4 , like this:

$$\psi(\Theta) = \sum_{j=0}^{N-1} \int_0^{j \cdot K + b} e^{ikx \sin(\Theta)} dx \tag{7}$$

this gives us for the intensity distribution, the following:

$$I(\Theta) = \psi^2(\Theta) \sim \left(\frac{\sin(\beta(\Theta))}{2\beta(\Theta)}\right)^2 \cdot \left(\frac{\sin(N\gamma(\Theta)}{N\sin(\gamma(\Theta))}\right)^2 \tag{8}$$
$$\text{where} \quad \gamma = \frac{kK\sin(\Theta)}{2}$$

In cases where the distribution of the intensity is not known well, the approximation with a Fourier series is sufficient to calculate the aperture function.

$$g(x) = \sum_{m=0}^{\infty} \sqrt{I_m} \cos\left(\frac{x}{K} 2\pi\, m\right) \tag{9}$$

For example a sin grating. It was theoretically worked out with the Fourier series, that a grating with only one maximum of the first order could only be possible if it follows the following equation:

$$g_{\sin}(x) = \sqrt{I_0} + \sqrt{I_1} \cos\left(\frac{x}{K} 2\pi\right) \tag{10}$$

2.4 Resolution

From [2] we know that the resolution α is

$$\alpha = \frac{\Delta\lambda}{\lambda} \leq N \cdot m \tag{11}$$

where λ is the wavelength, $\Delta\lambda$ is equal to the distance of two distinguishable wavelengths of the same diffraction order, N is the number of illuminated slits and m the number of visible maxima.

2.5 Phase grating

The second type of grating which is being used in the experiment is a phase grating. While the ones discussed were gratings which only differed the amplitude of an electromagnetic wave, the phase gratings are invisible and diffract light by a fluctuations of the refraction indices and also differ, like the name indicates, the phase. This is realised in the experiment by ultrasound waves in isooctane. the waves change the pressure of the liquid and therefore the refraction index periodically. This relation can be written as follows:

$$\frac{\Delta n}{n-1} = \frac{\Delta\rho}{\rho_0} \tag{12}$$

Now we can write the refraction index in terms of the position inside the isooctane with a given sonic-wavelength Λ as:

$$n(x) = n_0 + \Delta n \sin\left(\frac{2\pi x}{\Lambda}\right) \tag{13}$$

because the sonic-intensity is proportional to the voltage applied to the oscillating ultra sound quarz we can change the refraction index by adjusting the voltage applied to the quarz.
In the case of a Phase grating, the Grating constant is given by the wavelength Λ so with Equation 1 it follows, that:

$$\sin(\Theta_m) = m\frac{\lambda}{\Lambda} \tag{14}$$

2.6 Raman Nath theory

For small wavelengths and amplitudes of the sonic waves, the relations above can be explained by the Raman Nath theory which basically states two important things. Firstly the already explained Equations 1 and 14 and secondly that the ratio of the intesities of two maxima of the order m relate to one another, like the ratio of the respective besselfunctions J_m squared of the same order m.

$$\frac{I_m}{I_{m'}} = \frac{J_m^2(\Delta n \cdot D\frac{2\pi}{\lambda})}{J_{m'}^2(\Delta n \cdot D\frac{2\pi}{\lambda})} \tag{15}$$

where D is the thickness of the field in which the sonic waves propagates.

3 Experimental setup and execution

3.1 Setup

The setup of the experiment is shown in Figure 1 .
A helium neon LASER is used in this experiment and produces a wavelength of (λ = 632.8nm). L1 (f = $50mm$) is the first lens after a beamsplitter, it expands the beam so that L2(f = $100mm$) can parallelise again. It will now seem like the gratings are infinitely distant from the beam. It then goes through an aperture (L6) which diminishes the rays. T is the isooctane tank and G the grating mounting. L3 is the third and last lens ($f = 300mm$), it focuses the beam on the measuring diode (D1). D1 has an additional slit in front of the diode to minimise the light intensity of other sources in the room. D is a rotating mirror, it moves with a frequency of 12.5 Hz. The second diode acts as trigger, triggered by the splited beam part which goes over a mirror S towards D, so that the signal produced by the main beam in Diode 1 can be read out on the oscilloscope and can be read out by a computer next by. Depending on the task the third lens will be replaced by a white screen with mm-pattern, to manually measure the distance of the diffraction pattern from the sin-grating.

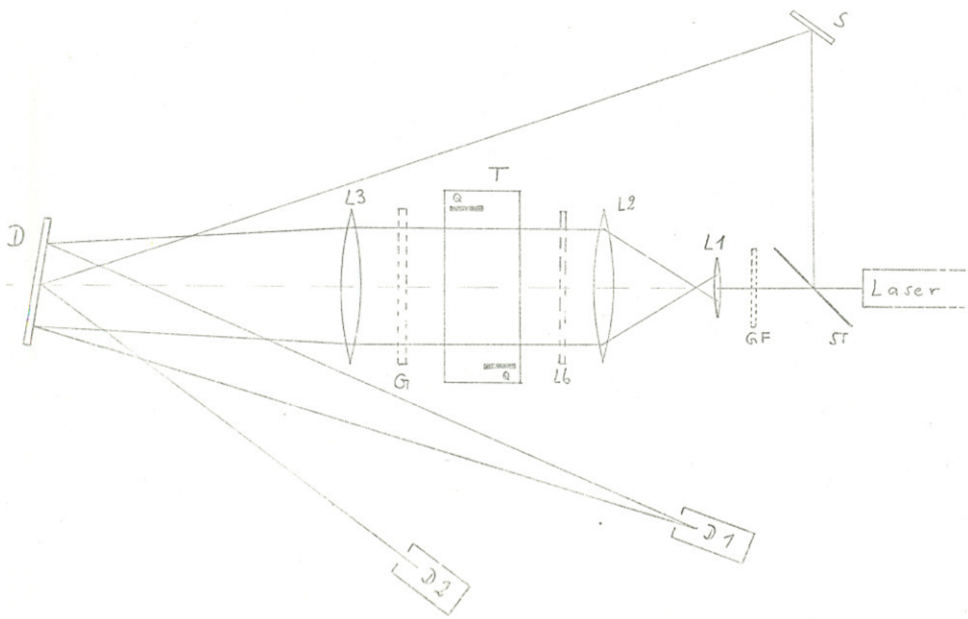


Figure 1: The setup of the experiment. The single parts are explained in the text above. Taken from [3]

3.2 Execution

In the first part of the experiemt, we used the setup above without lens 3 and without the isooctane tank. In the grating holder, a sin-grating is being installed and a screen with a x-y mm-scale is put up instead of the third lens. It is important to place lenses L1 and L2 in a distance of the sum of their focal lengths ($150mm$). Now it is possible to measure the distances on the mm scale between the first and zeroth order maximum. Also the distance between screen and grating is measured with a caliper rule. For the next tasks we implemented lens three for the screen and tried to focus on the diode. This was not possible, due to the trigger ray, which was likely to hit the mounting of lens 3 as soon as we put it closer to the rotating mirror. The sin grating is now replaced by the reference grating 'R' with a known grating constant of $K = \frac{1}{80}$cm. After switching on the rotating mirror, The diffraction pattern is shown on the oscilloscope. We saved the images as well as the .CSV data from the connected computer. This procedure is repeated for gratings 1 to 5. Also, the diameter of the beam with the closed aperture and the open aperture is noted.
For the last part of the experiment we now implement the isooctane tank and place the reference grating behind it. The Voltage applied is 0V and the frequency is adjusted to $\sim$ 2100 kHZ. The image is being recorded.
From 0V to 10V we measure the diffraction patterns on the diode in steps of 0.5 V. We noticed that the frequency changed while increasing the voltage.

4 Data Analysis

In this section we use the time t and the amplitude (intensity) I of the respective peaks. We obtained these quantities graphically by plotting the respective interference pattern and using the zoom function which is implemented in the python 2.7 module matplotlib. The time values t can be found in appendix 6.4 where we called them μ to emphasise their meaning as the mean value of a (roughly) gaussian-shaped peak.
For grating 1 (cf. section 4.3) we also fit a gaussian function to each of the peaks to examine whether the precision of the measurement can be improved significantly by this method.
By varying the orientation of the gratings in the laser beam, we obtained subjectively symmetrical interference patterns, so we constrained the data used for our calculations to the peaks on the right side of the 0th peak for the amplitude gratings (cf. section 4.3) and the peaks on the left side for the phase grating (cf. section 4.4).

4.1 Sine grating

To compute the grating constant of the sine grating, we first need to calculate the distance of the first order interference maximum from the 0th order on the screen. Therefore we use our measured x- and y- distances, compute the hypotenuse c and then take the mean value $\overline{c}$ of the two hypotenuses on the right and left side. The measured values can be found in appendix 6.1. The result is shown in the table below:

left			right			
x [mm]	y [mm]	c [mm]	x [mm]	y [mm]	c [mm]	$\overline{c}$ [mm]
45.0 ± 0.4	5.0 ± 0.4	45.3 ± 0.6	44.0 ± 0.4	5.0 ± 0.4	44.3 ± 0.6	44.8 ± 0.5

Table 1: calculation of the distance between the diffraciton peaks of the sine grating

To calculate the grating constant of the sine grating, we use eq. 1:

$$K = \frac{\lambda m}{\sin\Theta} = \lambda \frac{\sqrt{l^2 + \overline{c}^2}}{\overline{c}} \tag{16}$$

$$s_K = \lambda \cdot \sqrt{\left(\frac{l s_l}{\overline{c}\sqrt{l^2 + \overline{c}^2}}\right)^2 + \left(\frac{l^2 s_{\overline{c}}}{\overline{c}^2\sqrt{l^2 + \overline{c}^2}}\right)^2} \tag{17}$$

where s_K is the uncertainty on K, $l = 56.8 \pm 0.9$mm is the measured distance between the grating and the screen and $m = 1$ since a sine grating only has peaks of 0th and 1st order.
We obtain the following result:

$$K = (1.022 \pm 0.012)\mu\text{m} \tag{18}$$

4.2 Time Conversion Factor

Since we know the grating constant K of the reference grating and the fact that the spinning mirror in the experimental setup has a constant angular velocity, we can use eq. 1 to calculate the time conversion factor from the theoretical $\sin\Theta_m$-values and their linear dependence of Δt, which is the time difference between the respective peak and the 0th maximum:

$$\sin \Theta_m = \frac{m\lambda}{K} = a\Delta t + b \tag{19}$$

The linear fit is shown in figure 2:

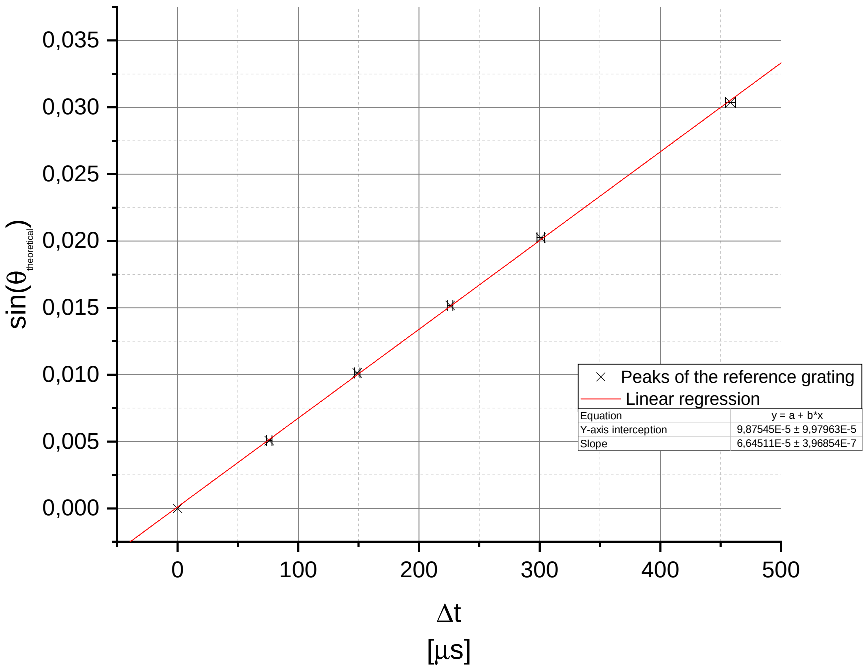


Figure 2: Theoretical $\sin\theta_m$ values in dependence of Δt and linear fit

From the linear fit we obtain the slope a and y-intercept b:

$$a = (6.65 \pm 0.04) \cdot 10^{-5} \frac{1}{\mu\text{s}} \tag{20}$$

$$b = (1 \pm 1) \cdot 10^{-4} \tag{21}$$

4.3 Amplitude Gratings

Plots of the interference patterns we measured can be found in appendix 6.2.
For grating 1, we fitted each peak by a gaussian function of the form:

$$f(t) = a \exp\left\{ -\frac{(t-\mu)^2}{2\sigma^2} \right\} + c \tag{22}$$

Plots of these fits can be found in appendix 6.3 with the results for their respective fit parameters. We calculate the grating constants of the five amplitude gratings, using the time conversion factor $\beta \equiv a \cdot \Delta t + b$ (cf. eq. 19) for each peak:

$$K = \frac{m\lambda}{\beta} \tag{23}$$

$$s_\beta = \sqrt{(\Delta t)^2 s_a^2 + a^2 s_{\Delta t}^2 + s_b^2} \tag{24}$$

$$s_K = \sqrt{\frac{m^2\lambda^2}{\beta^4} s_\beta^2} = \frac{k s_\beta}{\beta} \tag{25}$$

We now have a grating constant for each peak which can be found in the tables in appendix 6.4. It seems appropriate to average over all the visible peaks to get rid of statistical errors from irregularities in the grid etc.
We also compute the resolution α according to eq. 11:

$$\alpha = N \cdot m = m\frac{D_{Laser}}{K} \tag{26}$$

$$s_\alpha = \alpha\sqrt{\left(\frac{s_D}{D}\right)^2 + \left(\frac{s_K}{K}\right)^2} \tag{27}$$

Where for grating 2 we used a laser beam diameter of $D_{Laser} = (1.0 \pm 0.3)$mm and for all the other gratings $D_{Laser} = (4.0 \pm 0.3)$mm.
We obtain the following mean values $\overline{K}$ and resolutions α:

Grating no.	$\overline{K}$ [μm]	α [-]
1 (from gaussian Fit)	144.2 ± 0.5	110 ± 8
1 (from plot)	145.2 ± 0.7	
2	37.96 ± 0.02	52 ± 16
3	114.7 ± 0.3	174 ± 13
4	110.4 ± 0.2	181 ± 13
5	56.5 ± 0.2	283 ± 1

Table 2: Results for $\overline{K}$ and α

We can now approximate the aperture function of grating 1 according to eq. 9, where we use the square root of the normalised Intensities (divided by the intensity of the 0th peak) as coefficients and approximate the infinite sum by the first five sumands which correspond to the maxima up to the 4th order. The Intensities and grating constants we use are obtained by the gaussian fit method in appendix 6.3. The aperture function we obtained is shown in fig. 3

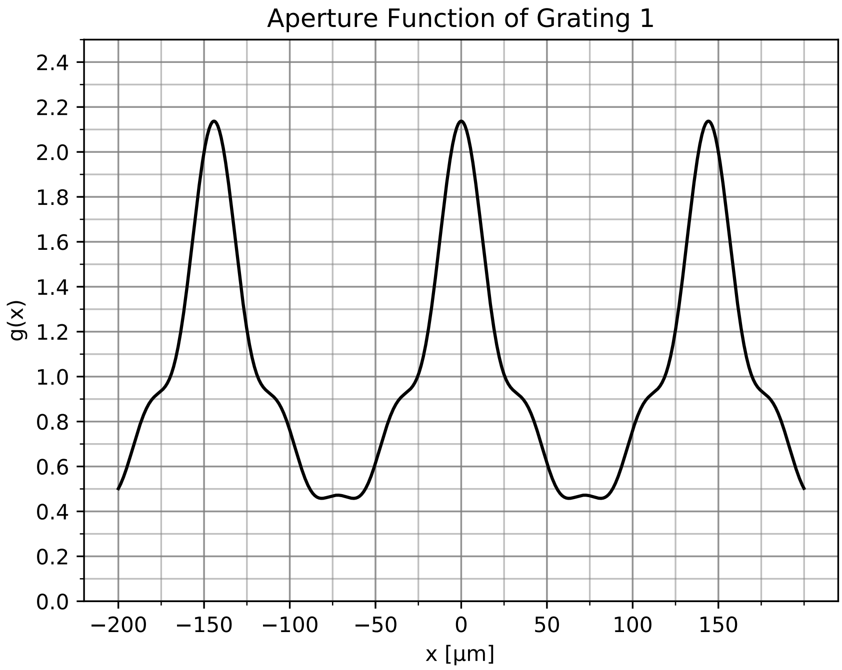


Figure 3: Aperture function of grating 1

We compute the slit-width b of the grating as the FWHM value of the main peaks of the aperture function:

$$b = 35.0\mu\text{m} \tag{28}$$

which is is only a rough estimation due to the approximation up to the 4th summand of $g(x)$. Therefore we leave this value without an uncertainty.
The ratio $\frac{b}{K}$ is:

$$\frac{b}{K} \approx 0.24 \tag{29}$$

which we leave without an uncertainty, too.

4.4 Phase Grating

Figure 4 shows the relative amplitudes of the 3 observed orders (zeroth, first and second) against the applied voltages. The frequency applied changed during the task (caused by the sonic wave generator) and is protocolled in the Appendix (cf. Figure 16) and was also plotted against the Voltage.

Equation	B*(j0(A*x))^2
A	0,1883 ± 0,0071
B	0,93858 ± 0,02671

Equation	B*(J1(A*x))^2
A	0,25883 ± 0,00761
B	1,29162 ± 0,04648

Equation	B*(Jn(A*x,2))^2
A	0,3016 ± 0,01557
B	0,82387 ± 0,06647

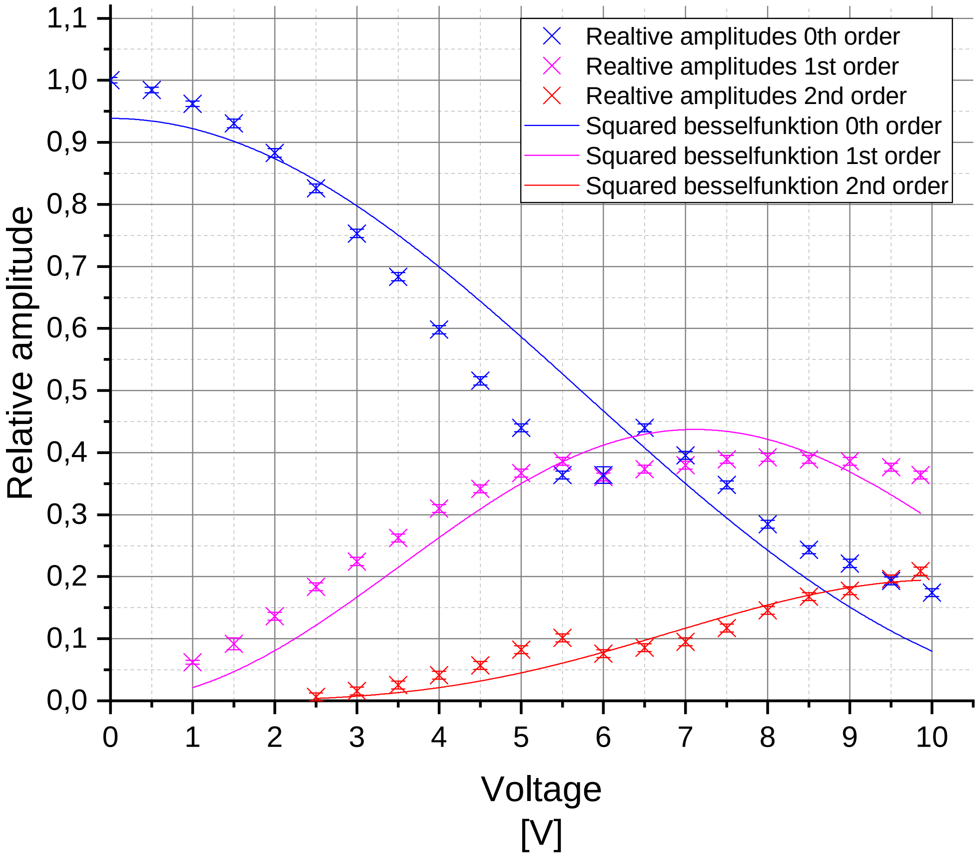


Figure 4: Squared bessel functions fitted to the data of the respective orders.

From the Table in 6.5 we calculated the Δt for each Maximum for every Voltage. Then with Equation 24[1] we can calculate the Wavelength of the ultra sound in isooctane. therefore:

$$\Lambda = \frac{\lambda m}{a\Delta t + b}$$

(for the calculation of a and b cf. fig. 15) with gaussian error propagation analogously to eq. 17 we used for the grating constant we get the final result of:

$$\Lambda = (509 \pm 4)\mu\text{m}$$

The theoretical value is calculated by the set frequency ($\nu = 2133 \pm 0,7$)kHz.
With the known relation and the velocity of sound in isooctane from [3] the theoretical value is:

$$\Lambda_{calc} = \frac{v_0}{\nu} = \frac{1111\,\frac{\text{m}}{\text{s}}}{2133\text{kHz}} = (520,9 \pm 0,2)\mu\text{m} \tag{30}$$

$$s_\Lambda = \Lambda_{calc} \cdot \frac{s_\nu}{\nu} = 0,2\mu\text{m} \tag{31}$$

[1]only in this case we calulate Λ but it is known, that $K \widehat{=} \Lambda$

5 Summary and Discussion of the Results

Grating Constants and Resolution: We obtained the following Results for the different Gratings:

grating	K [μm]	α [-]
sine grating	1.022 ± 0.012	-
1 (from gaussian Fit)	144.2 ± 0.5	110 ± 8
1 (from plot)	145.2 ± 0.7	
2	37.96 ± 0.02	52 ± 16
3	114.7 ± 0.3	174 ± 13
4	110.4 ± 0.2	181 ± 13
5	56.5 ± 0.2	283 ± 1

Table 3: Results for $\overline{K}$ and α

Note that for grating 2 we shut the aperture to a beam diameter of $D_{Laser} = (1.0 \pm 0.3)$mm because it led to a more clear interference pattern. All the other measurements were performed with a widened aperture and a beam diameter of $D_{Laser} = (4.0 \pm 0.3)$mm. This obviously leads to a significantly smaller resolution of grating 2 in this measurement.
The amplitude gratings subjectively showed macroscopic irregularities such as bumps and variations in colour and brightness. We assume to have these averaged out by averaging over all the observed orders of diffraction of each grating.
The grating constant obtained for grating 1 by fitting a gaussian function to each peak coincides within 1σ with the grating constant obtained by graphical determination of the peaks. The uncertainties of the average over the K values from the different orders of diffraction lay within the same order of magnitude for both methods. Moreover, the uncertainty for every constituent K of this average (cf. appendix 6.4) does likewise. Therefore we can conclude that fitting gaussian peaks does not significantly improve the precision of our measurement.

Aperture Function and Slit-Width: From the measured intensities of grating 1 we approximated the aperture function g(x) which we plotted in fig. 3. This allowed us to roughly estimate the slit-width / grating constant ratio to

$$\frac{b}{K} \approx 0.24$$

Comprobation of the Raman Nath theory: In fig. 4 we fitted the squared bessel functions of 0th, 1st and 2nd order to the relative intensities of the respective diffraction orden in correlation to the applied voltage at the ultrasound cell. The plot shows a tendency of the bessel functions to fit our data although the amplitudes show an unexpected "jump" at $V = 6.5$V which we suspect to be due to an irregularity in the sonic frequency generator: The generator is supposed to hold a constant frequency but shows a variation of about 4.5kHz during the measurement. This variation is visualised in fig. 16 in appendix 6.5 where one can observe a collapse of frequencies around the middle of our voltage range.
As to a quantitative inspection of the theory, we find out that our value for the wavelength of sound in isooctane,

$$\lambda = (509 \pm 4)\mu\text{m}$$

which coincides with the reference value, obtained (eq. 30) from the reference value for the speed of sound [3],

$$\lambda_{isooctane} = (520.9 \pm 0.2)\mu\text{m}$$

within 3σ. This confirms our suspicion from the bessel fit, that our data fits the theory to some degree but still shows a significant deviation which we blame the ultrasound generator for.

6 Appendix

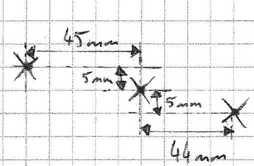
6.1 Lab notes

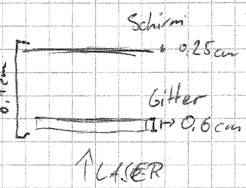
30.8.2018

Ultraschall

1.) Sinusgitter

Die Achse der Beugungsmaxima ist etwas zur Achse der Millimeterskala auf dem Schirm verdreht:





Durchmesser des Strahls bei Gitter

↳ Blende zu 1mm ± 0,3mm

↳ Blende auf 4mm ± 0,3mm

5.) Phasengitter

$\nu = 2131.499 \pm 0{,}50$ kHz

File Nr.	U [V]
U1	0,52
U2	1,00
U3	1,51
4	2,01
5	2,50
6	3,00
7	3,50
8	4,00
9	4,50
10	5,00
11	5,50
12	6,00

Neue Messung mit größerer Blende:

~~ν=2134.5 ± 2~~

ν = 2133,0 ± 0,7 MHz

Simona Orzipulo

File Name	U [V]
u00	0,00
u01	0,50
u02	1,00
u03	1,50
u04	2,00
u05	2,50
u06	3,00
u07	3,50
u08	4,00
u09	4,50
u10	5,00
u11	5,50
u12	6,00
u13	6,50
u14	7,00
u15	7,50
u16	8,00
u17	8,50
u18	9,00
u19	~~9,86~~ 9,50
u20	9,86

6.2 Plots of the Interference Patterns

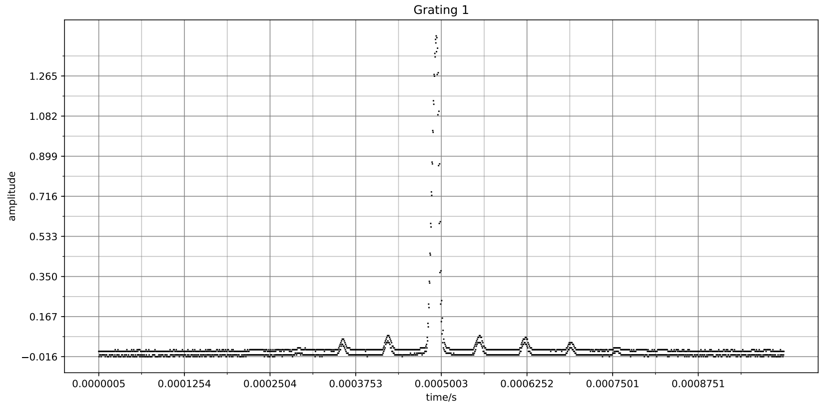


Figure 5: Interference pattern of grating 1

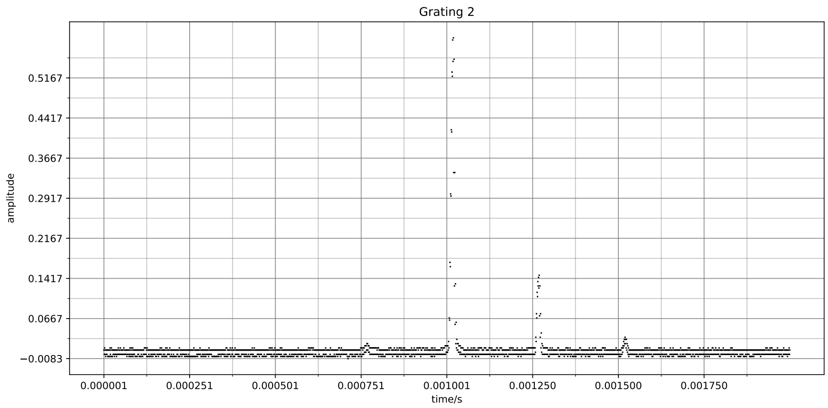


Figure 6: Interference pattern of grating 2

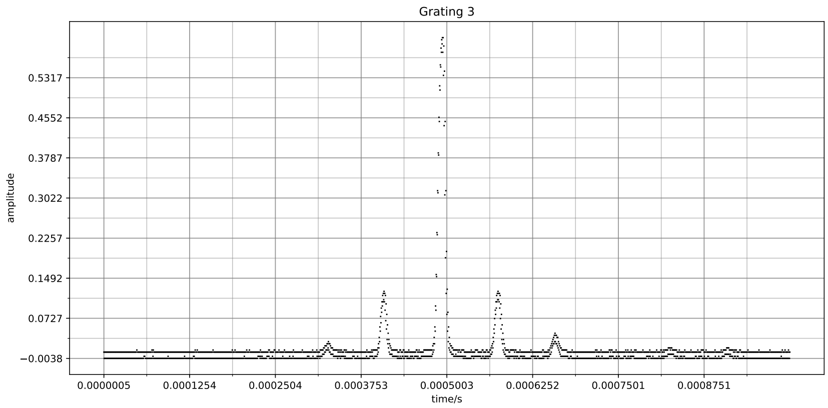


Figure 7: Interference pattern of grating 3

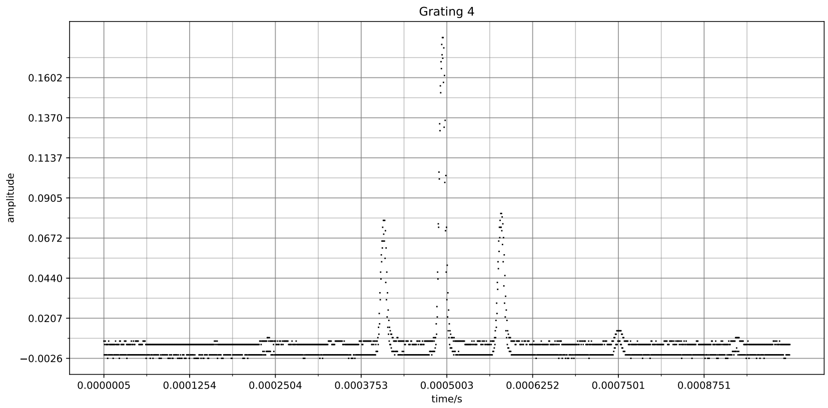


Figure 8: Interference pattern of grating 4

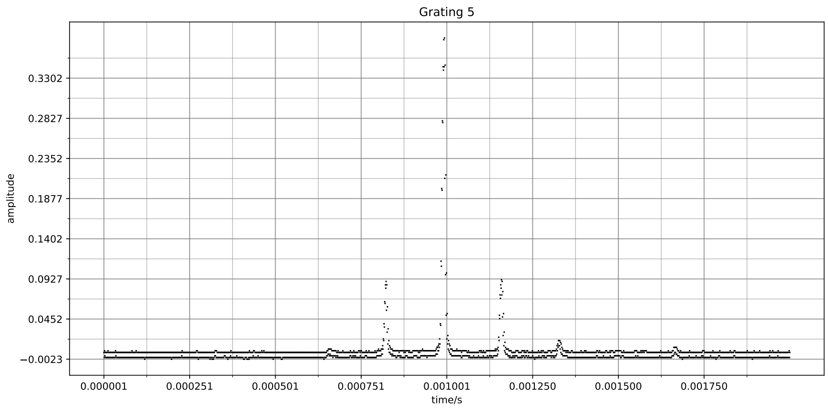


Figure 9: Interference pattern of grating 5

6.3 Gaussian Fit to Grating 1 Peaks

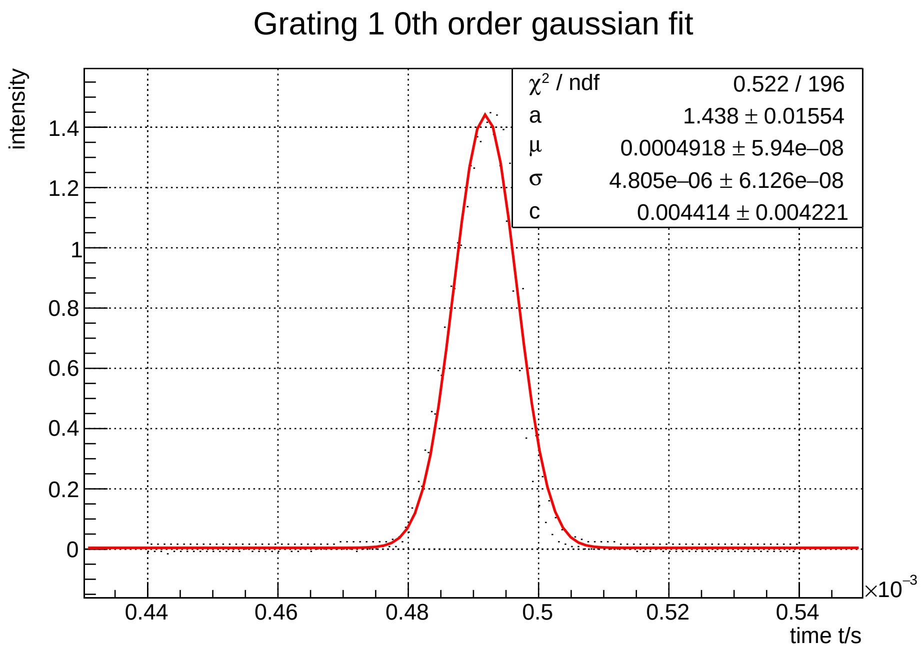


Figure 10: Gaussian fit to peak of 0th order

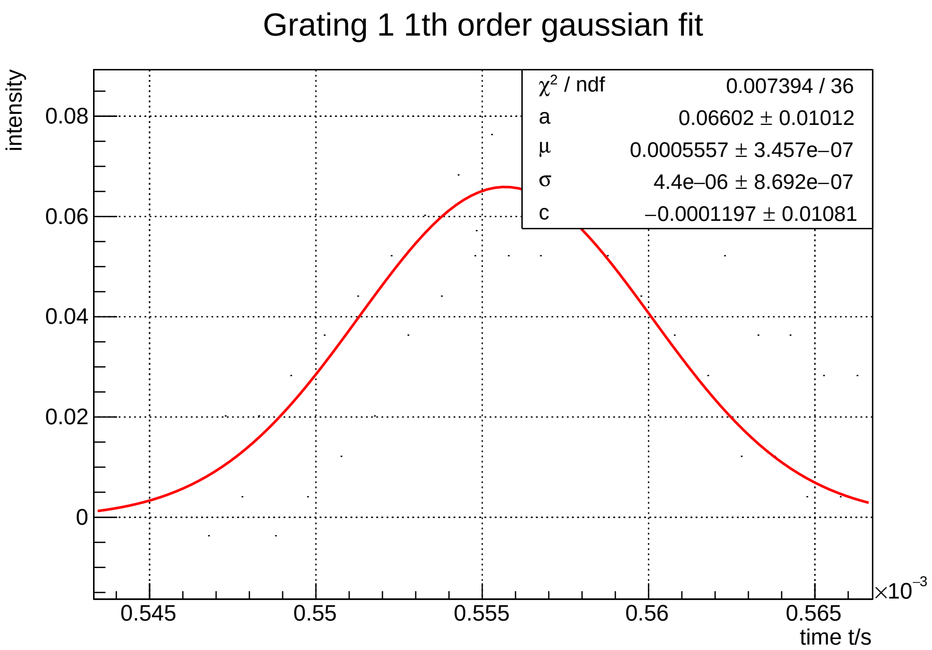


Figure 11: Gaussian fit to peak of 1st order

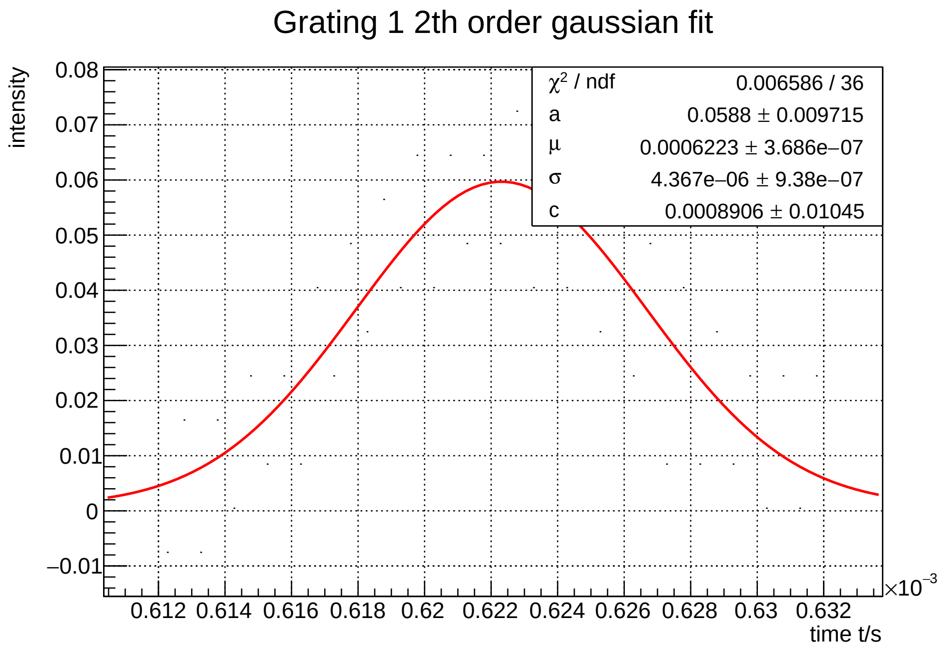


Figure 12: Gaussian fit to peak of 2nd order

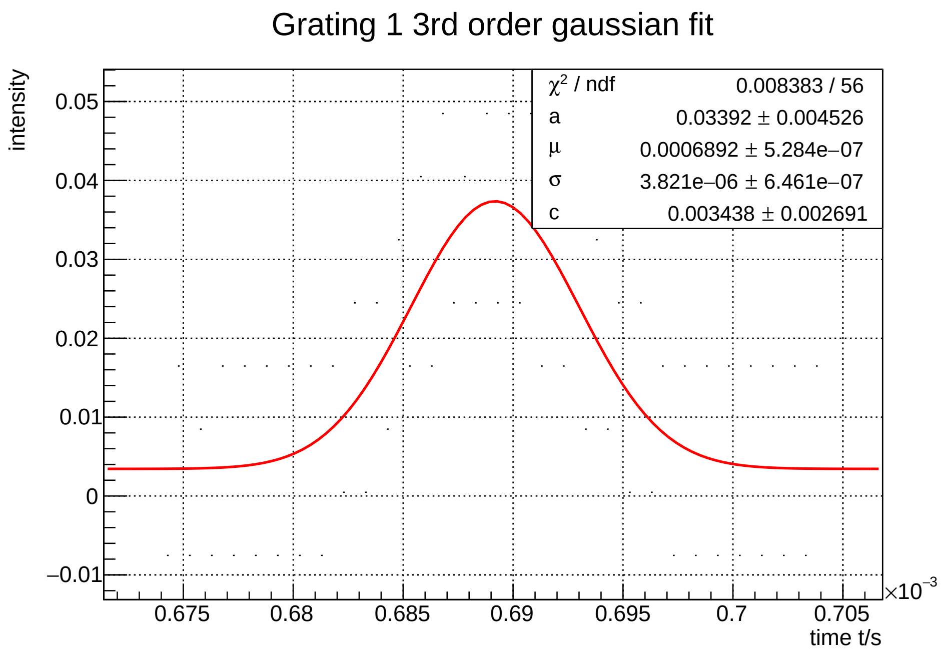


Figure 13: Gaussian fit to peak of 3rd order

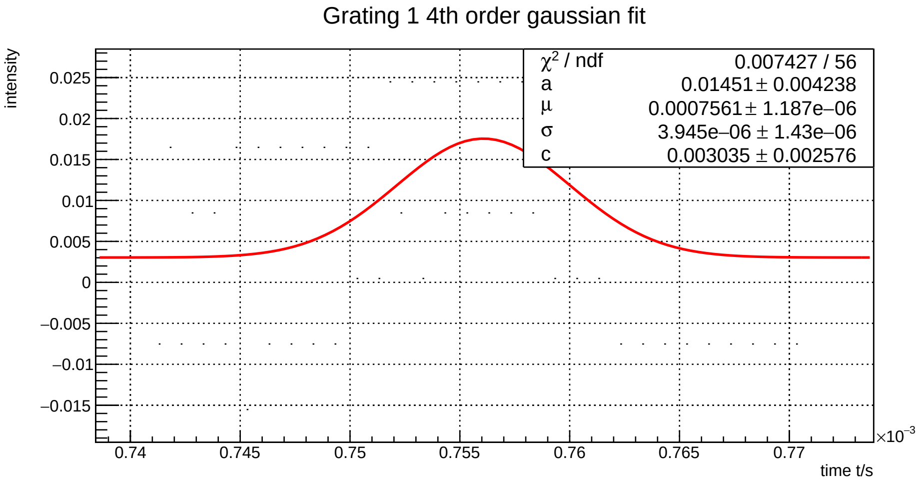


Figure 14: Gaussian fit to peak of 4th order

6.4 Data for Calculation of Grating Constants

Results from Gaussian Fits to grating 1 :												
order	μ [μs]			Δt [μs]			β [-]			K [μm]		
0	491,85	±	0,05	-			-			-		
1	555,7	±	0,3	63,9	±	0,3	0,00434	±	0,00010	146	±	4
2	622,3	±	0,4	130,5	±	0,4	0,00877	±	0,00012	144	±	2
3	689,2	±	0,5	197,4	±	0,5	0,01322	±	0,00013	143,6	±	1,4
4	756,1	±	1,2	264,3	±	1,2	0,01767	±	0,00017	143,2	±	1,3

Table 4: Calculation of grating constants using the data obtained from gaussian fits (cf. data from graphical analysis in tab. 6.4 on next page)

Results from the data obtained graphically												
Grating 1												
order	μ [μs]			Δt [μs]			β [-]			K [μm]		
0	492,8	±	0,1									
1	556	±	2	63	±	2	0,00430	±	0,00017	147	±	6
2	622	±	2	129	±	2	0,00869	±	0,00017	146	±	3
3	689	±	2	196	±	2	0,0131	±	0,0002	144	±	2
4	756	±	2	263	±	2	0,0176	±	0,0002	144	±	2

Grating 2												
order	μ [μs]			Δt [μs]			β [-]			K [μm]		
0	1019	±	1	-			-			-		
1	1268	±	2	249	±	2	0,0167	±	0,0002	38,0	±	0,5
2	1519	±	2	500	±	2	0,0333	±	0,0003	38,0	±	0,3

Grating 3												
order	μ [μs]			Δt [μs]			β [-]			K [μm]		
0	494	±	0,5									
1	575	±	2	81	±	2	0,0055	±	0,0002	115	±	4
2	658	±	4	164	±	4	0,0110	±	0,0003	115	±	3
4	826	±	6	332	±	6	0,0222	±	0,0004	114	±	2
5	909	±	3	415	±	3	0,0277	±	0,0003	114,2	±	1,2

Grating 4												
order	μ [μs]			Δt [μs]			β [-]			K [μm]		
0	494	±	1									
1	579	±	1	85,0	±	1,4	0,0058	±	0,0001	110	±	3
3	750	±	3	256	±	3	0,0171	±	0,0003	110,9	±	1,6
5	923	±	3	429	±	3	0,0286	±	0,0003	110,5	±	1,1

Grating 5												
order	μ [μs]			Δt [μs]			β [-]			K [μm]		
0	992	±	2									
1	1160	±	2	168	±	3	0,0113	±	0,0002	56,1	±	1,1
2	1327	±	3	335	±	4	0,0224	±	0,0003	56,6	±	0,7
4	1660	±	10	668	±	10	0,0445	±	0,0007	56,9	±	0,9

Table 5: Calculation of grating constants using the data obtained graphically

6.5 Calculations of the Phase grating

Voltage [V]	Order	Amplitude [V]	$s_{Amplitude}$ [V]	Time [μs]	s_{zeit} [μs]	rel_{ampli}	$s_{RelAmplitude}$	Λ [m]	s_{Λ} [m]
0	0	3,16	0,01	98,30	0,40	1,00	0,0045		1,06E-04
0,5	0	3,11	0,01	98,20	0,40	0,98	0,0044		1,06E-04
1	0	3,04	0,01	97,70	0,40	0,96	0,0044		1,06E-04
	1	0,20	0,01	77,50	0,50	0,06	0,0032	4,55E-04	1,09E-04
1,5	0	2,94	0,02	97,90	0,60	0,93	0,0070		1,11E-04
	1	0,29	0,03	78,00	2,00	0,09	0,0095	4,66E-04	1,73E-04
2	0	2,79	0,02	98,30	0,30	0,88	0,0069		1,05E-04
	1	0,43	0,02	78,00	0,70	0,14	0,0063	4,66E-04	1,14E-04
2,5	0	2,61	0,02	97,90	0,40	0,83	0,0068		1,06E-04
	1	0,58	0,02	79,30	0,10	0,18	0,0064	4,99E-04	1,04E-04
	2	0,02	0,02	60,00	5,00	0,01	0,0063	4,87E-04	3,62E-04
3	0	2,38	0,02	97,00	1,00	0,75	0,0068		1,24E-04
	1	0,71	0,02	79,00	1,00	0,22	0,0064	4,91E-04	1,25E-04
	2	0,05	0,02	59,00	1,00	0,02	0,0063	4,74E-04	1,27E-04
3,5	0	2,16	0,02	97,70	0,30	0,68	0,0067		1,05E-04
	1	0,83	0,02	80,00	1,00	0,26	0,0064	5,19E-04	1,25E-04
	2	0,08	0,02	60,00	2,00	0,03	0,0063	4,87E-04	1,74E-04
4	0	1,89	0,02	98,40	0,60	0,60	0,0066		1,11E-04
	1	0,98	0,02	80,70	0,40	0,31	0,0064	5,41E-04	1,07E-04
	2	0,13	0,02	61,00	2,00	0,04	0,0063	5,00E-04	1,74E-04
4,5	0	1,63	0,02	97,50	0,05	0,52	0,0065		1,03E-04
	1	1,08	0,02	80,00	0,10	0,34	0,0064	5,19E-04	1,04E-04
	2	0,18	0,02	60,00	1,00	0,06	0,0063	4,87E-04	1,27E-04
5	0	1,39	0,02	97,00	1,00	0,44	0,0065		1,24E-04
	1	1,16	0,02	80,40	0,90	0,37	0,0064	5,31E-04	1,21E-04
	2	0,26	0,02	61,00	2,00	0,08	0,0063	5,00E-04	1,74E-04
5,5	0	1,15	0,02	97,00	1,00	0,36	0,0064		1,24E-04
	1	1,22	0,02	81,00	1,00	0,39	0,0064	5,51E-04	1,24E-04
	2	0,32	0,02	62,00	1,00	0,10	0,0063	5,14E-04	1,27E-04
6	0	1,15	0,02	97,00	1,00	0,36	0,0064		1,24E-04
	1	1,14	0,02	80,00	1,00	0,36	0,0064	5,19E-04	1,25E-04
	2	0,24	0,02	61,00	2,00	0,08	0,0063	5,00E-04	1,74E-04
6,5	0	1,39	0,02	97,00	1,00	0,44	0,0065		1,24E-04
	1	1,18	0,02	80,00	1,00	0,37	0,0064	5,19E-04	1,25E-04
	2	0,27	0,02	61,00	1,00	0,09	0,0063	5,00E-04	1,27E-04
7	0	1,25	0,02	97,00	1,00	0,40	0,0065		1,24E-04
	1	1,20	0,02	80,00	1,00	0,38	0,0064	5,19E-04	1,25E-04
	2	0,30	0,02	62,00	2,00	0,09	0,0063	5,14E-04	1,74E-04
7,5	0	1,10	0,02	97,00	1,00	0,35	0,0064		1,24E-04
	1	1,23	0,02	81,00	1,00	0,39	0,0064	5,51E-04	1,24E-04
	2	0,37	0,02	62,00	1,00	0,12	0,0063	5,14E-04	1,27E-04
8	0	0,90	0,02	96,50	1,00	0,28	0,0064		1,24E-04
	1	1,24	0,02	80,00	1,00	0,39	0,0064	5,19E-04	1,25E-04
	2	0,46	0,02	62,50	1,00	0,15	0,0063	5,21E-04	1,26E-04
8,5	0	0,77	0,02	96,00	1,00	0,24	0,0064		1,24E-04
	1	1,23	0,02	80,00	1,00	0,39	0,0064	5,19E-04	1,25E-04
	2	0,53	0,02	62,00	1,00	0,17	0,0064	5,14E-04	1,27E-04
9	0	0,70	0,02	96,00	1,00	0,22	0,0064		1,24E-04
	1	1,22	0,02	80,00	1,00	0,39	0,0064	5,19E-04	1,25E-04
	2	0,56	0,02	62,50	1,00	0,18	0,0064	5,21E-04	1,26E-04
9,5	0	0,61	0,02	96,00	1,00	0,19	0,0064		1,24E-04
	1	1,19	0,02	80,00	1,00	0,38	0,0064	5,19E-04	1,25E-04
	2	0,62	0,02	63,00	1,00	0,20	0,0064	5,29E-04	1,26E-04
9,86	0	0,55	0,02	96,00	1,00	0,17	0,0064		1,24E-04
	1	1,15	0,02	80,00	1,00	0,36	0,0064	5,19E-04	1,25E-04
	2	0,66	0,02	63,00	1,00	0,21	0,0064	5,29E-04	1,26E-04

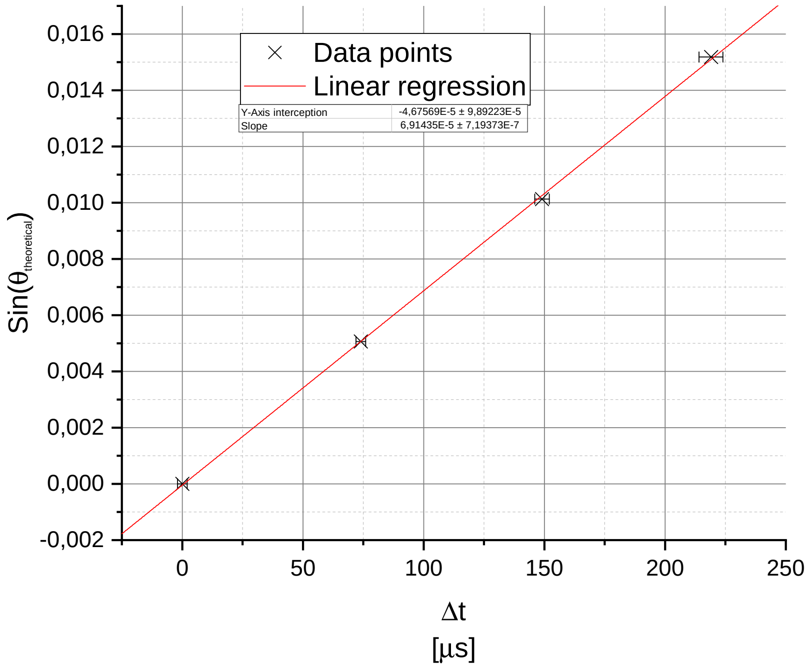


Figure 15: The linear regression for the reference grating with the utrasound cell. Δt is given in μs

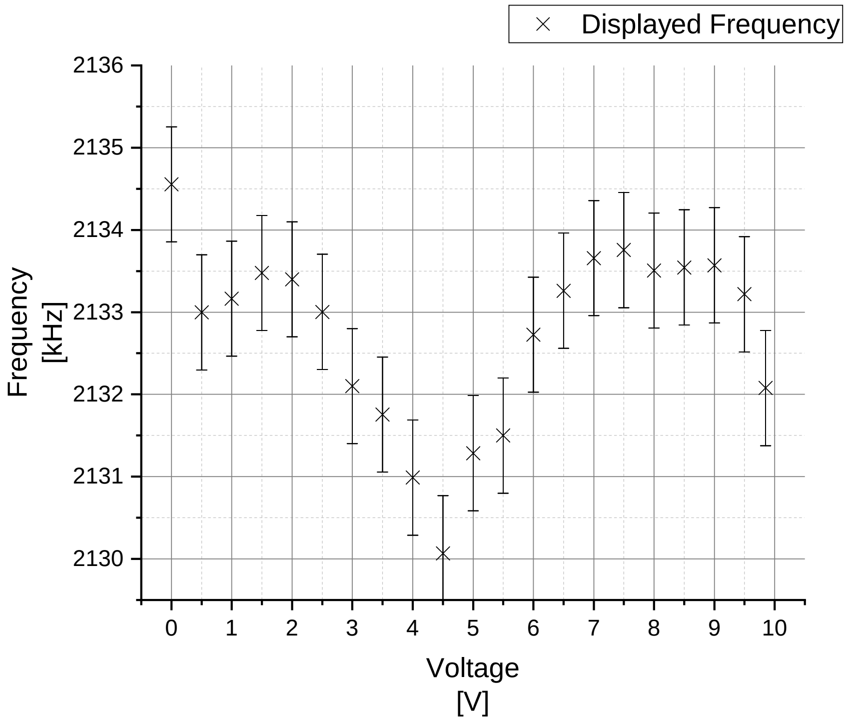


Figure 16: The indicated Frequency against the Voltage

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