Contents

1 Introduction

The aim of the experiment is to find out the grating constant of a sinus and five other amplitude grids. In addition to that, we will also determine the resolution power of the last five grids. After that, an aperture function of one grid will be determined. With knowledge about the aperture function, the relation between the gap width and the grating constant will be determined. In the end, we will measure the intensity distribution of the different orders of maxima after sending the light through a piezoelectric crystal for different applied potential. These results will be compared with the Raman-Nath theory. We will also determine the length of the ultrasonic wave in isooctane by measuring the diffraction order and compare them with a calculated value.

2 Theoretical background

2.1 Diffraction

Diffraction is a consequence of the behavior of light after an interaction with an obstacle which is not explainable with reflection and refraction. In this experiment, the obstacles are amplitude- and phase grids. It can be explained with the Huygens' principle, which says that every point of a wave becomes a source of a spherical wave. The typical diffraction pattern is a result of the superposition of these new elementary waves.
The waves interfere constructively or destructively. The condition for constructive interference is

$$g = m \cdot \lambda \quad \text{with } m \in \mathrm{N}, \tag{1}$$

where g is the path difference. In case of using a grid you can find the maxima of intensity at

$$\sin(\theta_m) = \frac{m \cdot \lambda}{K}, \tag{2}$$

where K is the lattice constant and θ the diffraction angle.

2.1.1 Aperture-function

We will work with Frauenhofer-Diffraction, that means that the light strikes parallel to the obstacle. The influence of obstacles, in our case the grids, on the light can be described with an aperture-function g. Now you can show that the intensity distribution I is connected to the aperture-function g by using the Kirchhoff-integral theorem and the Fresnel-Kirchhoff integral form.
We obtain

$$I = \left| \int_{\text{Slit}} g(\vec{k}) \cdot e^{i\vec{k}\vec{x}} d\vec{k} \right|^2 \tag{3}$$

As you can see, they are connected via a Fourier transformation. Therefore it is also possible to calculate the aperture-function, if you know the intensity distribution.
If you want to calculate the aperture-function with the Fourier-transformation you can approximate the result as a Fourier series. The coefficients are the square-roots of the amplitudes of the diffraction pattern

$$g(x) = \sum_{j=0}^{\infty} \pm\sqrt{I_j} \cdot \cos\left(\frac{x}{k} 2\pi j\right). \tag{4}$$

For a sinus grid it is good enough to take the first two terms. You obtain

$$g(x) = \sqrt{I_0} + \sqrt{I_1} \cdot \cos\left(\frac{x}{K} \cdot 2\pi\right). \tag{5}$$

2.2 Resolution power

The resolution power a of a grid is defined by

$$a = \frac{\lambda}{\Delta\lambda} \tag{6}$$

while $\Delta\lambda$ is the smallest difference between the wavelength and another wavelength, where a maximum can be optical differentiated. It can be shown that

$$a = N \cdot m \tag{7}$$

holds too. In this case m is the number of maxima and N the number of irradiated gridlines.

2.3 Phase grid

Normally one uses amplitude grids, which change on different postion of the grid the waveamplitude different strong. In this experiment we also use a phase grid, which changes the phase. Here it is realised with a ultra sound wave in isooctane. These consist of areas with high and low density, which changes periodically. The refraction index in high density zones is higher than in lower ones, so it is a sinusoidal phase grid with lattice constant Λ, which is also the wavelength of sound.
The refrection index of the excited isooctane in dependence of the position x can be computed with

$$n(x) = n_0 + \Delta n \cdot \sin\left(\frac{2\pi x}{\Lambda}\right). \tag{8}$$

In this equation n_0 is the refrection index of the not excited isooctane and Δn the variation of the refrection index.

2.4 Raman-Nath theory[3]

The theory is about the diffraction of light by acoustic waves. The result of the theory is

$$\sin\Theta = \pm m \cdot \frac{\lambda}{\Lambda}, \tag{9}$$

while Θ is the angle between the incident and the reflection light waves. Furthermore m is the order of the maximum and so a natural number. This is very similar to the interference behind amplitude grids. The intensity in the m^{th} order is given by

$$I_{\text{m}} = J_{\text{m}}^2\left(\frac{2\pi \cdot \Delta n \cdot W}{\lambda}\right), \tag{10}$$

here is Δn the maximal refraction index and W is the width of the sound wave.
Because $\Delta n \propto U$, the intensity is also given by

$$I_{\text{m}} = J_{\text{m}}^2\left(B \cdot U\right), \tag{11}$$

while B is a constant with the unit $\frac{1}{\text{V}}$.

3 Setup and Implementation

3.1 Sinus grid

For measuring the lattice grid of the sinus grid we use the following setup. We need the Laser ($\lambda = 632{,}8\,\mathrm{nm}$), the grid and a screen with a millimeter paper on it. With the Laser we illuminate the grid. Behind the sinus grid you can see the interference of light on the screen. Because of a big diffraction angle we can relinquish any lenses. Now we can measure the distance g between the grid and the screen and the distance between both maxima of first order.
We repeat this measurement for another distance g between grid and screen for improving the uncertainty.

3.2 Amplitude grids

The second step of this experiment is to determine the lattice constant and the resolution power of five other amplitude grids. To be able to measure the needed values, we first have to adjust our experimental setup. You need a lens (lens 1: $f_1 = 50\,\mathrm{mm}$) to widen the laser beam. For the experiment we need a parallel beam, so its important to set a second lens (lens 2: $f_2 = 100\,\mathrm{mm}$) after the first lens. The distance is the sum of both focuses ($f_1 + f_2 = 150\,\mathrm{mm}$). Behind this disposition we set a split which is responsible for a better diffraction pattern. After this you set the grid, which is still unsurveyed, behind the split. Behind the lattice is a third lens (lense 3: $f_3 = 300\,\mathrm{mm}$). Its function is to focus the beam on one of the photo diodes (see below), which was because of our setup unfortunately impossible. At the end of the optical axis is a rotatable mirror. A photo diode is placed in a way, that the reflection of the mirror hits the diode two times per rotation. The photo diode gives information about the measured intensity of light to an oscilloscope. For triggering it, we use a beam splitter which is placed before the first lens on the optical axis. The beam is redirected to another mirror and from this point to the rotating mirror. There is a second photo diode which receives the reflection of the second beam. The information of this photo diode serve as triggering signal.
You can see the setup in 1.

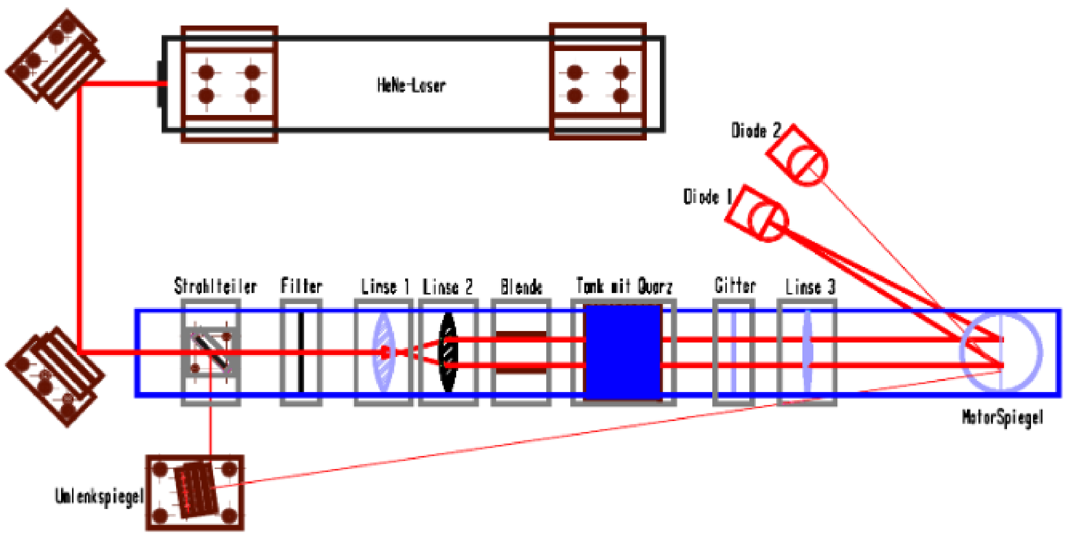


Figure 1: Setup (here: the quartz crystal is already in, however we do not need it in measurement 2) [2]

The setup is ready for measuring. At first, we measure with a grid whose grid lattice is already known. You can determine the time t between any given and the zeroth maximum by using the oscilloscope. With the measured values it is possible to oak the setup, because with a constant α holds

$$\sin(\theta_m) = \alpha t \propto t. \tag{12}$$

After this we change the reference grid successive with the five unknown grids.
For calculating the unknown grid lattice we repeat the measurement in the same way we had done it by the reference grid. The second step is to measure the beam diameter. We read it out by putting a screen (graph paper) into the laser beam.
In addition to that, there is another measuring for grid 1. We need to know the amplitude of each order. You can read them out with help of the oscilloscope again.

3.3 Ultrasonic cell

For the last part it is necessary to change the setup again. We set the ultrasonic cell on the optical axis instead of the grids from measuring 2. First step is again to calibrate the setup. Therefore we repeat the oak measuring from above. The only difference is that there is the ultrasonic cell in front of the reference grid. After finishing we remove the reference grid and measure the intensity and time difference between the chosen maximum and the zeroth order for any maximum and ten different voltages applied at the ultrasonic cell. For reading out the values we use again the oscilloscope.

4 Analysis

4.1 Sinus grid

We want to know the lattice constant K of the given sinus grid. At first we calculate the diffraction angle θ with help of the measured values a and g

$$\theta = \arctan\frac{a}{g}$$

The error is

$$\sigma_\theta = \sqrt{\left(\frac{1}{g}\cdot\frac{1}{1+(\frac{a}{g})^2}\cdot\sigma_a\right)^2+\left(\frac{a}{g^2}\cdot\frac{1}{1+(\frac{a}{g})^2}\cdot\sigma_g\right)^2}.$$

Now we can calculate K by using formula 2

$$K = \frac{m\cdot\lambda}{\sin(\theta)}.$$

The uncertainty is given by

$$\sigma_{\mathrm{K}} = \frac{m\cdot\lambda}{\cos\theta}.$$

The results from above are shown in following table

$2a$ [cm]	$s_{2\mathrm{a}}$ [cm]	a [cm]	s_{a} [cm]	g [cm]	s_{g} [cm]	θ [°]	s_θ [°]	K [µm]	s_{K} [µm]
8,9	0,05	4,45	0,025	5,65	0,03	38,2	1,2	1,022	0,017
11,3	0,05	5,65	0,025	7,15	0,03	38,3	0,8	1,021	0,011

Table 1: Measured and calculated values of the sinus grid

See that we has measured two different length g to the benefit of the uncertainty we have to calculate the weighted mean and its error with

$$\begin{aligned}\bar{x} &= \frac{\sum_{i=1}^{n}\left(x_i/s_i^2\right)}{\sum_{i=1}^{n}\left(1/s_i^2\right)},\\ s_{\bar{x}} &= \frac{1}{\sqrt{\sum_{i=1}^{n}\left(1/s_i^2\right)}}.\end{aligned} \tag{13}$$

With this we obtain

$$K = (1{,}021\pm0{,}009)\cdot10^{-6}.$$

With this lattice constant K you can calculate the gaps per millimeter by using following formula

$$\text{gaps per mm} = \frac{1}{K\cdot 1000\mathrm{mm}}.$$

With the uncertainty

$$s_{\mathrm{gpmm}} = \frac{s_K}{K^2\cdot 1000\,\mathrm{mm}}.$$

So the result is

$$\text{gaps per mm} = (979\pm9)\,\frac{1}{\mathrm{mm}}.$$

4.2 Computation of the grid constants

4.2.1 Reference grid

To calculate the grid constants of the five unknown grid, we measured the time difference between the maxima and the maximum zeroth order of a grid with an already known lattice constant. From the oscilloscope we read out the size of a box d and the distance in box-size a. With this values it is possible to calculate the time difference

$$\begin{aligned} t &= a\,[\mathrm{div}] \cdot d \left[\frac{\mathrm{\mu s}}{\mathrm{div}}\right], \\ s_{\mathrm{t}} &= s_{\mathrm{a}}\,[\mathrm{div}] \cdot d \left[\frac{\mathrm{\mu s}}{\mathrm{div}}\right]. \end{aligned} \tag{14}$$

Before we will plot the values in a diagram, we sum up two values of the same order (arithmetic mean). Furthermore we compute for each order

$$\sin(\Theta) = m \cdot \frac{\lambda}{K}. \tag{15}$$

This values are summed up in Table 2 and in Figure 2 is the time difference t over $\sin(\Theta)$ plotted and an additional linear regression is appended.

Order m	a [div]	s_{a} [div]	d $\left[\frac{\mathrm{\mu s}}{\mathrm{div}}\right]$	t [µs]	s_{t} [µs]	$\sin(\Theta)$
-1 1	3,0 3,0	0,1 0,1	20 20	60	2	0,00506
-2 2	2,45 2,35	0,05 0,05	50 50	120	3	0,01012
-3 3	3,6 3,6	0,1 0,1	50 50	180	5	0,01519

Table 2: Values of the reference grid

The linear regression of this diagram gives us the values

$$\begin{aligned} \text{Intercept: } b &= (0{,}007 \pm 0{,}006)\,\mathrm{\mu s}, \\ \text{Slope: } \alpha' &= (11\,851{,}4 \pm 0{,}7)\,\mathrm{\mu s}. \end{aligned} \tag{16}$$

The value of the Intercept with the time axis b is negligible. So with the reciprocal of α'

$$\begin{aligned} \alpha &= \frac{1}{\alpha'} = 84{,}378\,\frac{1}{\mathrm{s}}, \\ s_\alpha &= \frac{s_{\alpha'}}{\alpha'^2} = 0{,}005\,\frac{1}{\mathrm{s}}, \end{aligned} \tag{17}$$

we can calculate the lattice constant K of the other grids with the formulas 2 and 12

$$\begin{aligned} K &= |m| \cdot \frac{\lambda}{\alpha \cdot t}, \\ s_{\mathrm{K}} &= K \cdot \sqrt{\left(\frac{s_{\mathrm{t}}}{t}\right)^2 + \left(\frac{s_{\mathrm{a}}}{a}\right)^2} \end{aligned} \tag{18}$$

Here is t the time difference between the main maximum and the m^{th} maximum of the new grid. The outcome of this are the values of grid 1,2,3,4 and 5, which are summed up in Table 3, Table 4, Table 5, Table 6 and Table 7.

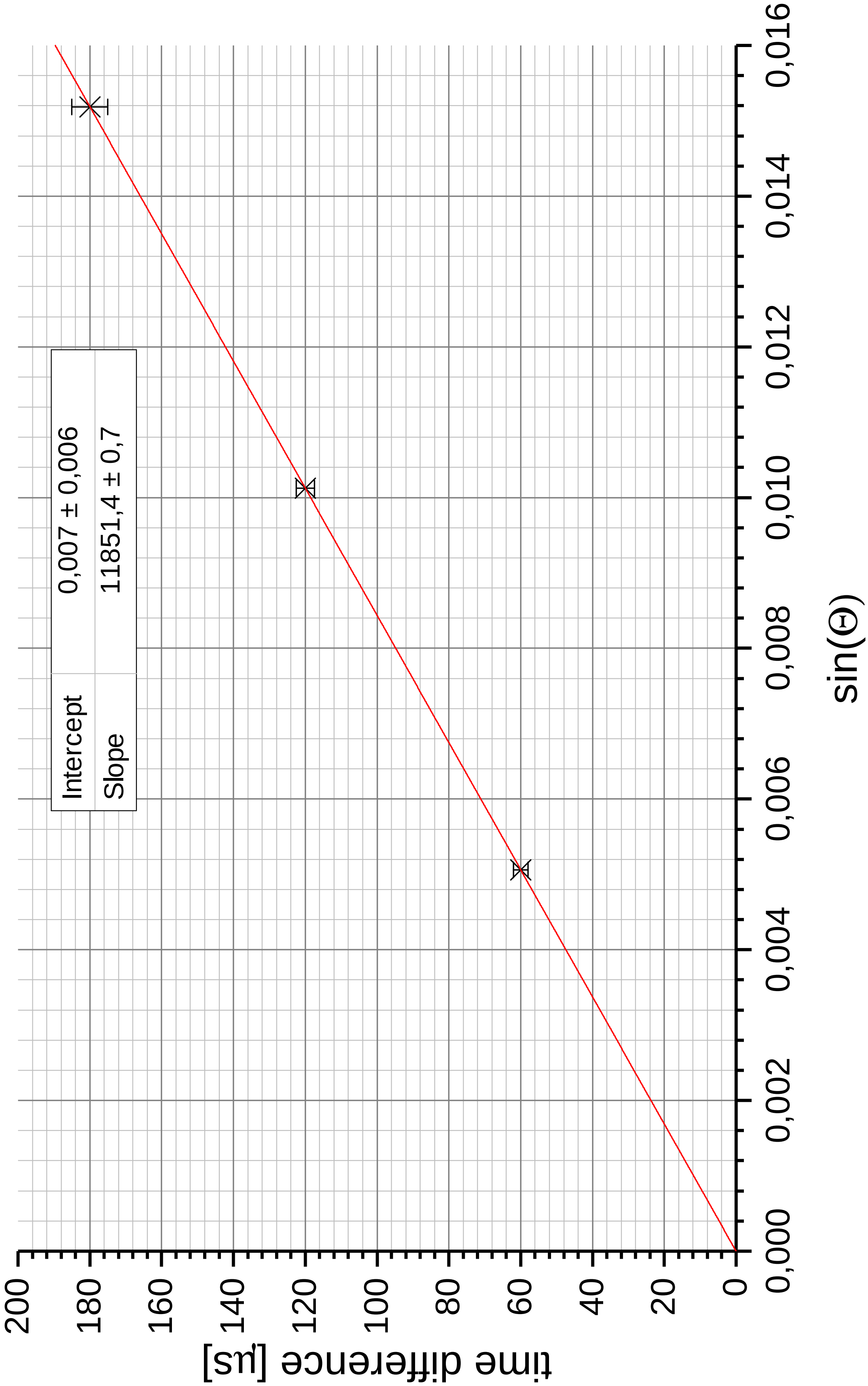


Figure 2: Linear regression of the reference grid [1]

Order m	a [div]	s_a [div]	d $[\frac{\mu s}{div}]$	t [µs]	s_t [µs]	K [µm]	s_K [µm]
-1	2,9	0,1	20	58	2	129	4
1	2,8	0,1	20	56	2	134	5
-2	2,25	0,05	50	113	3	133	3
2	2,2	0,1	50	110	5	136	6
-3	3,35	0,05	50	168	3	134	2
-4	4,5	0,1	50	225	5	133	3

Table 3: Values of grid 1

Order m	a [div]	s_a [div]	d $[\frac{\mu s}{div}]$	t [µs]	s_t [µs]	K [µm]	s_K [µm]
-1	4,20	0,05	50	210	3	35,7	0,4
1	4,10	0,05	50	205	3	36,6	0,4
-2	4,2	0,1	100	420	10	35,7	0,9

Table 4: Values of grid 2

Order m	a [div]	s_a [div]	d $[\frac{\mu s}{div}]$	t [µs]	s_t [µs]	K [µm]	s_K [µm]
-1	3,5	0,1	20	70	2	107	3
1	3,5	0,1	20	70	2	107	3
-2	2,80	0,05	50	140	3	107,1	1,9
2	2,8	0,1	50	140	5	107	4

Table 5: Values of grid 3

Order m	a [div]	s_a [div]	d $[\frac{\mu s}{div}]$	t [µs]	s_t [µs]	K [µm]	s_K [µm]
-1	3,5	0,1	20	70	2	107	3
1	3,5	0,1	20	70	2	107	3

Table 6: Values of grid 4

Order m	a [div]	s_a [div]	d $[\frac{\mu s}{div}]$	t [µs]	s_t [µs]	K [µm]	s_K [µm]
-1	2,80	0,05	50	140	3	53,6	1,0
1	2,75	0,05	50	138	3	54,5	1,0
-2	2,80	0,05	100	280	5	53,6	1,0

Table 7: Values of grid 5

Now we compute the the lattice constants of the five grids with the weighted mean (s. formula 13). The results are precised in Table 8.

grid	K [µm]
1	$133{,}6 \pm 1{,}3$
2	$36{,}1 \pm 0{,}3$
3	$107{,}1 \pm 1{,}3$
4	107 ± 2
5	$53{,}9 \pm 0{,}6$

Table 8: Lattice constants of the unknown grids

4.2.2 Aperture function

We measured the intensity of the left and the right order and calculated the average and its error. To get from the intensity I' [div] and the div-size d $\left[\frac{\text{mV}}{\text{div}}\right]$ to the main intensity I [mV] one calculate

$$\begin{aligned} I &= I' \text{ [div]} \cdot d \left[\frac{\text{µs}}{\text{div}}\right], \\ s_{\text{I}} &= s_{\text{I}'} \text{ [div]} \cdot d \left[\frac{\text{µs}}{\text{div}}\right]. \end{aligned} \tag{19}$$

We obtain the values in Table 9.

order	intensity I' [div]		σ_{I^*} [div]		d $[\frac{\text{mV}}{\text{div}}]$	main intensity I [mV]	σ_{I} [mV]
	left	right	left	right			
0	6,4		0,1		20	128	2
1	6,6	4,4	0,2	0,2	2	11,0	0,3
2	4,6	2,3	0,2	0,2	2	6,9	0,3
3	3,3	—	0,2	—	2	6,6	0,4
4	2,3	—	0,2	—	2	4,6	0,4

Table 9: Measured intensity of the first grid

With formula 4 which is discussed in the physical background we can determine the aperture function of grid 1 (cf. Figure 3).

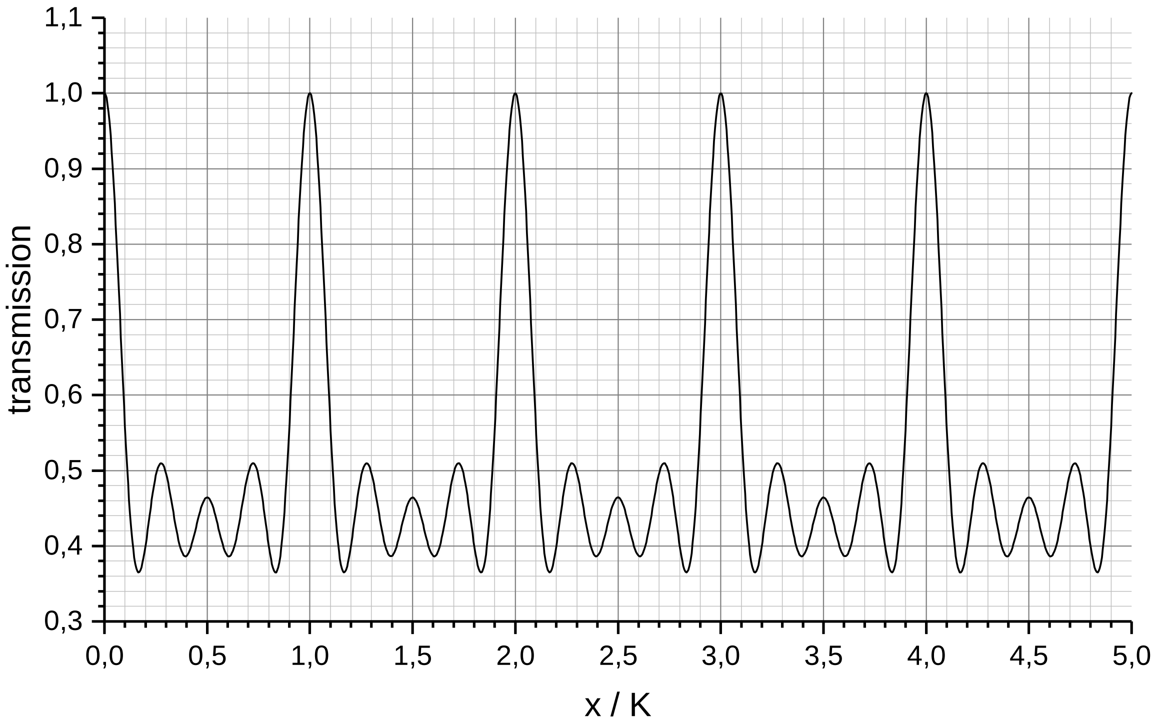


Figure 3: Aperture function of the first grid

For calculating the ratio ν of width of the gap and the lattice constant we read out the full width of the half maximum. With the help of origin we obtain

$$b = 0,222 \cdot K$$

and so

$$\nu = \frac{b}{K}$$
$$\nu = 0,222$$

Since the graph 3 is without errors also the relation $\frac{b}{K}$ is without an error.

4.2.3 Resolution power

We measured the beam diameter s and estimated its error σ_{s}

$$s = (3 \pm 1)\,\mathrm{mm}$$

With s and the calculated lattice constants K_i is it possible to calculate the resolution power a. We need the number of illuminated gaps

$$N_i = \frac{s}{K_i},$$
$$s_{\mathrm{N_i}} = \sqrt{\left(\frac{s \cdot \sigma_{\mathrm{K_i}}}{K_{\mathrm{i}}^2}\right)^2 + \left(\frac{\sigma_s}{K_{\mathrm{i}}}\right)^2},$$

and can use following formula 7

$$a_i = N_i \cdot m_i,$$
$$\sigma_{\mathrm{a_i}} = s_{\mathrm{N}} \cdot m,$$

where m is the number of visible orders.

grid	K [µm]	σ_{K} [µm]	N	σ_N	m	a	σ_{a}
1	133,6	1,3	22	7	4	90	30
2	36,1	0,3	83	28	2	170	60
3	107,1	0,13	28	9	2	56	19
4	107,1	2	28	9	1	28	9
5	53,9	0,6	56	19	2	110	40

Table 10: Resolution power of the unknown grids

4.3 Ultrasonic cell

4.3.1 Comparison with the Raman-Nath theory

In this part we measured the amplitude A_m of the maxima after the diffraction on the ultrasonic waves for different voltages. The conversion from $\left[\frac{\mathrm{mV}}{\mathrm{div}}\right]$ and [div] to [mV] is equivalent to equation 19. We also measured the noise $A_\mathrm{noise} = (4{,}5 \pm 0{,}2)\,\mathrm{mV}$ to get only the values of the interfering light, which is calculable by

$$\begin{aligned} A &= A_\mathrm{m} - A_\mathrm{noise}, \\ s_\mathrm{A} &= \sqrt{s_{\mathrm{A_m}}^2 + s_{\mathrm{A_{noise}}}^2}. \end{aligned} \tag{20}$$

To normalize the amplitude we divided the values by the intensity at 0 V, which is $A_{0\,\mathrm{V}} = (345 \pm 5)\,\mathrm{mV}$, so we get

$$\begin{aligned} A_\mathrm{n} &= \frac{A}{A_{0\,\mathrm{V}}}, \\ s_{\mathrm{A_n}} &= \sqrt{\left(\frac{s_\mathrm{A}}{A}\right)^2 + \left(\frac{s_{\mathrm{A_{0\,V}}}}{A_{0\,\mathrm{V}}}\right)^2}. \end{aligned} \tag{21}$$

This we compute for the maxima zeroth, first and second order (more were not visible or usable). The values of the maxima of order zero, one and two are summed in the Tables 11, 12 and 13 and plotted in the Figures 4, 5 and 6. According to the Raman-Nath theory the intensity should be equal to the squared Bessel function with the order m, which is also the order of the maxima (s. formula 11). Therefore the different squared Bessel functions are fitted in the related figures.

The parameters B_i of the different squared Bessel-fits are

$$\begin{aligned} B_0 &= (0{,}1477 \pm 0{,}0012)\,\frac{1}{\mathrm{V}}, \\ B_1 &= (0{,}181 \pm 0{,}005)\,\frac{1}{\mathrm{V}}, \\ B_2 &= (0{,}182 \pm 0{,}004)\,\frac{1}{\mathrm{V}}. \end{aligned} \tag{22}$$

The Raman-Nath theory says, that these B's should be equal. The quality of our measurements will be discussed in the discussion.

U [V]	A'_{m} [div]	$s_{\mathrm{A'_m}}$ [div]	d $\left[\frac{\mathrm{mV}}{\mathrm{div}}\right]$	A_{m} [mV]	$s_{\mathrm{A_m}}$ [mV]	A [mV]	s_{A} [mV]	A_{n}	$s_{\mathrm{A_n}}$
0,00	7,0	0,1	50	350	5	346	5	1,00	0,02
1,00	6,7	0,1	50	335	5	331	5	0,96	0,02
2,00	6,4	0,1	50	320	5	316	5	0,91	0,02
3,00	6,1	0,1	50	305	5	301	5	0,870	0,019
4,00	5,7	0,1	50	285	5	281	5	0,812	0,019
5,00	5,2	0,1	50	260	5	256	5	0,740	0,018
6,00	4,6	0,1	50	230	5	226	5	0,653	0,017
7,00	4,0	0,1	50	200	5	196	5	0,566	0,017
8,00	3,4	0,1	50	170	5	166	5	0,479	0,016
9,00	6,9	0,1	20	138	2	134	2	0,386	0,008
10,00	5,2	0,1	20	104	2	100	2	0,288	0,007
8,50	2,9	0,1	50	145	5	141	5	0,407	0,016
9,50	5,3	0,1	20	106	2	102	2	0,294	0,007

Table 11: Values of the zeroth order

Table 12: Values of the first order

U [V]	A'_{m} [div]		$s_{\mathrm{A'_m}}$ [div]		d $\left[\frac{\mathrm{mV}}{\mathrm{div}}\right]$	A_{m} [mV]	$s_{\mathrm{A_m}}$ [mV]	A [mV]	s_{A} [mV]	A_{n}	$s_{\mathrm{A_n}}$
	left	right	left	right							
3	3,6	3,1	0,1	0,1	10	33,5	0,7	29,0	0,7	0,084	0,002
4	5,0	4,4	0,1	0,1	10	47,0	0,7	42,5	0,7	0,123	0,003
5	6,3	5,7	0,1	0,1	10	60,0	0,7	55,5	0,7	0,161	0,003
6	3,8	3,4	0,1	0,1	20	72,0	1,4	67,5	1,4	0,195	0,005
7	4,5	4,1	0,1	0,1	20	86,0	1,4	81,5	1,4	0,236	0,005
8	5,4	4,8	0,1	0,1	20	102,0	1,4	97,5	1,4	0,282	0,006
9	6,1	5,5	0,1	0,1	20	116,0	1,4	111,5	1,4	0,323	0,006
10	6,5	6,0	0,1	0,1	20	125,0	1,4	120,5	1,4	0,349	0,007
8,5	6,4	5,9	0,1	0,1	20	123,0	1,4	118,5	1,4	0,343	0,006
9,5	6,6	6,3	0,1	0,1	20	129,0	1,4	124,5	1,4	0,360	0,007

Table 13: Values of the second order

U [V]	A'_{m} [div]		$s_{\mathrm{A'_m}}$ [div]		d $\left[\frac{\mathrm{mV}}{\mathrm{div}}\right]$	A_{m} [mV]	$s_{\mathrm{A_m}}$ [mV]	A [mV]	s_{A} [mV]	A_{n}	$s_{\mathrm{A_n}}$
	left	right	left	right							
3	3,6	3,1	0,1	0,1	10	33,5	0,7	29,0	0,7	0,084	0,002
4	5,0	4,4	0,1	0,1	10	47,0	0,7	42,5	0,7	0,123	0,003
5	6,3	5,7	0,1	0,1	10	60,0	0,7	55,5	0,7	0,161	0,003
6	3,8	3,4	0,1	0,1	20	72,0	1,4	67,5	1,4	0,195	0,005
7	4,5	4,1	0,1	0,1	20	86,0	1,4	81,5	1,4	0,236	0,005
8	5,4	4,8	0,1	0,1	20	102,0	1,4	97,5	1,4	0,282	0,006

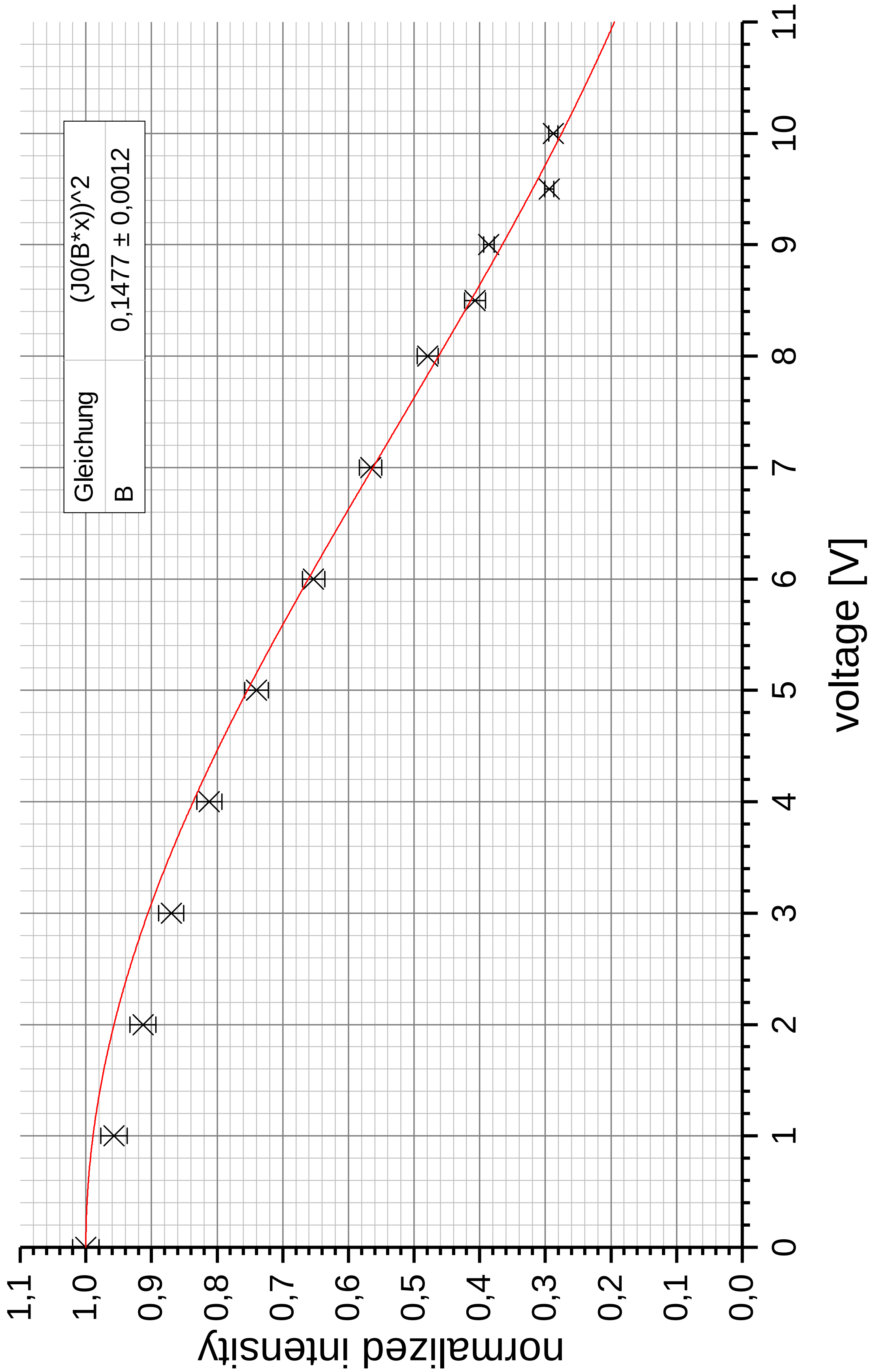


Figure 4: Amplitudes of the zeroth maxima and a fitted Bessel function of order 0[1]

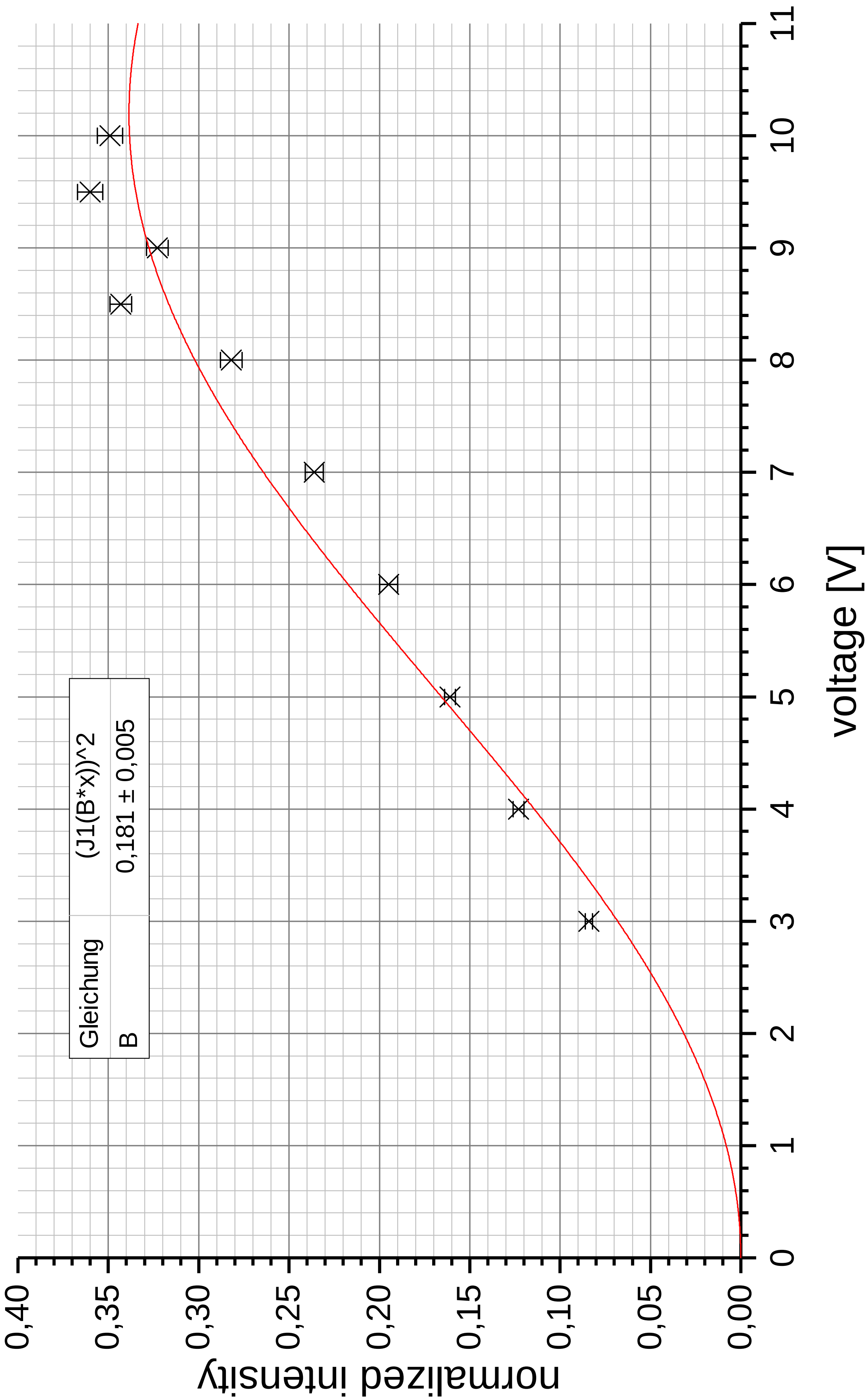


Figure 5: Amplitudes of the first maxima and a fitted Bessel function of order 1[1]

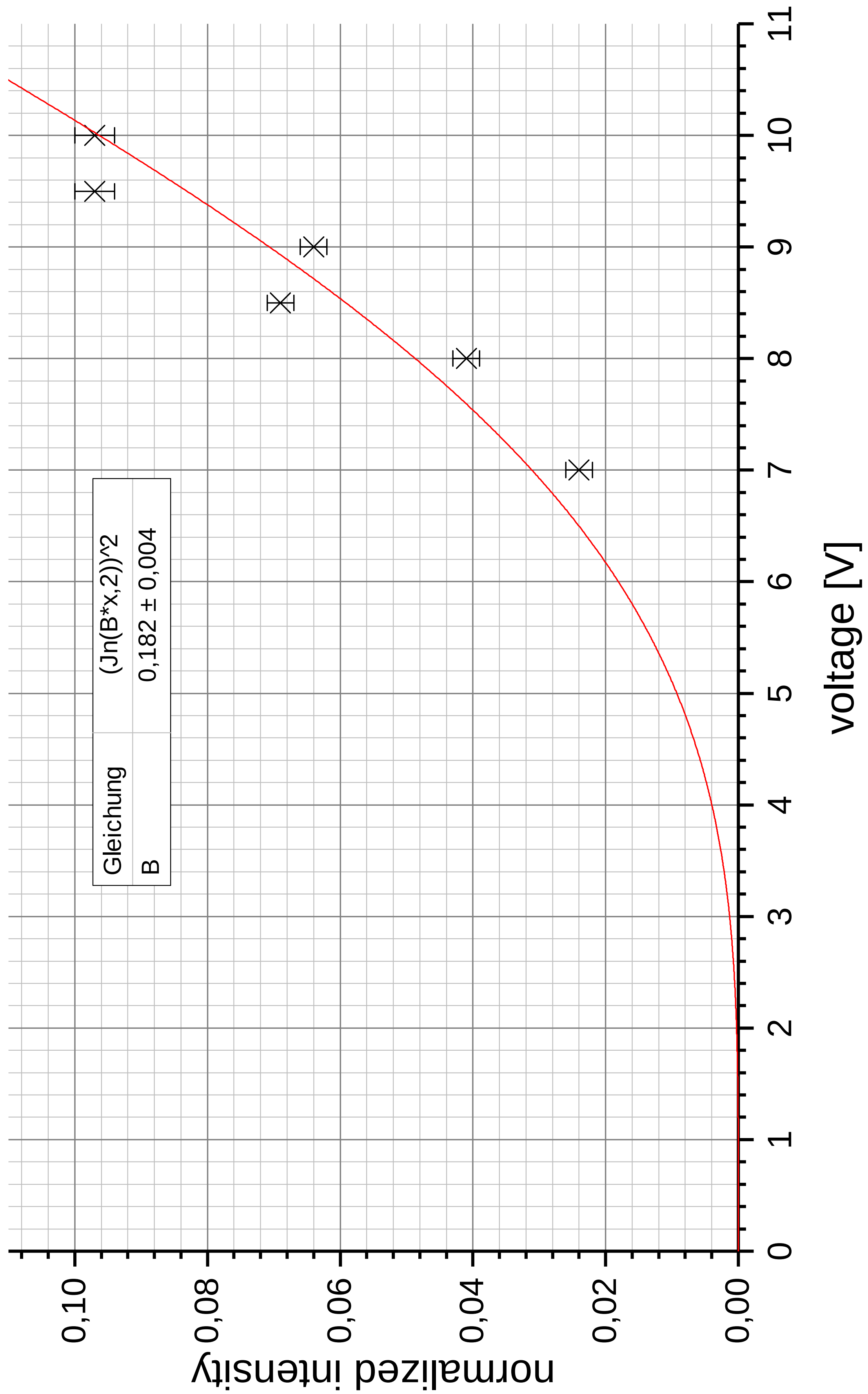


Figure 6: Amplitudes of the second maxima and a fitted Bessel function of order 2[1]

4.3.2 Wavelength of sound

At first we have to oak the setup. We obtained the values of Table 14

order m	divs peak to peak	s_{ptp}	$\frac{t}{div}$ [µs]	t [s]	s_t [s]	$\sin\theta$
1	6,30	0,05	20	63,0	0,5	0,00506
2	5,00	0,05	50	125.0	1,3	0,01012
3	7,5	0,1	50	188	3	0,01519

Table 14: Values of the reference grid

By plotting the values in a diagram and doing a linear regression we obtain the following parameters of the general form of the equation of a straight line.

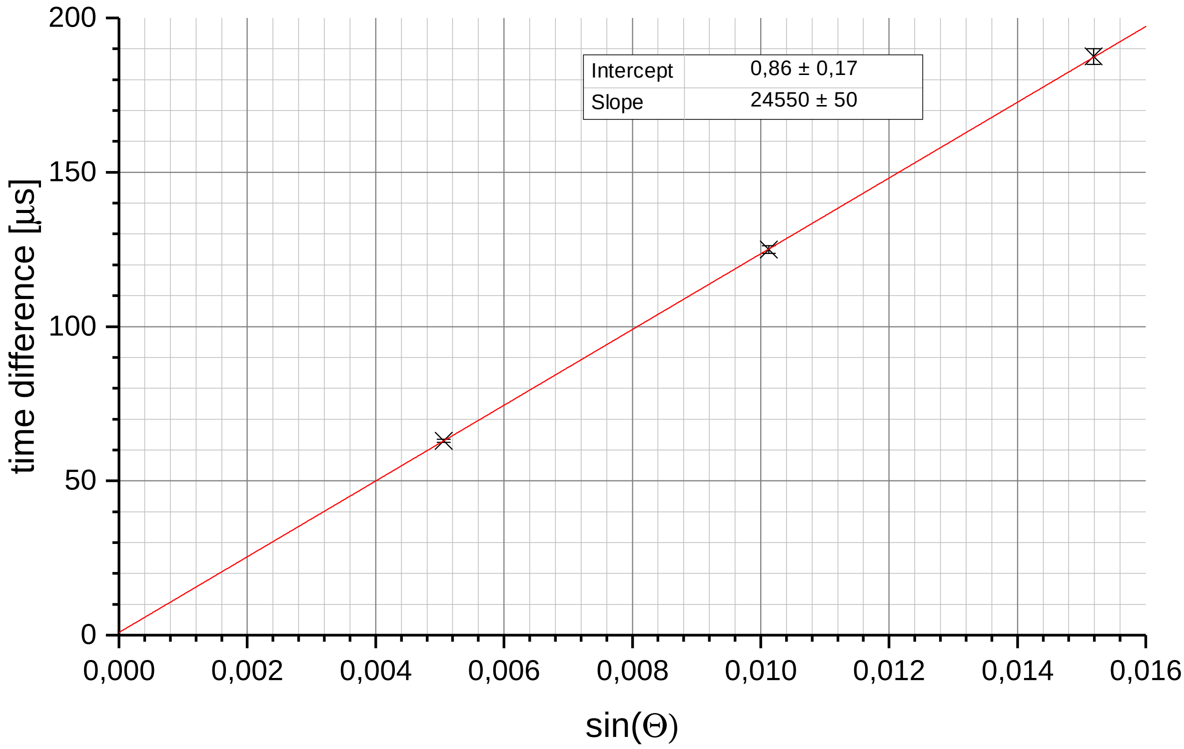


Figure 7: Linear regression of the reference grid

$$\text{Intercept } b = 0{,}86 \pm 0{,}17$$
$$\text{Slope } \alpha = 12\,273 \pm 27$$

Now we can calculate the wavelength Λ in isooctane with formula 9. It holds

$$\Lambda = \frac{\lambda \cdot \alpha \cdot m}{t_{\text{m}}}.$$

We measured the times distance for different voltages. For our calculations we compute the average time distance $\bar{t}$ for the first and second order and their uncertainties $\sigma_{\bar{t}}$. We obtain the values shown in Table 15.

order	$\bar{t}$ [µs]	$\sigma_{\bar{t}}$ [µs]
1	12,83	0,15
2	25,58	0,27

Table 15: Average time distance for order 1 and 2

So we can calculate the wavelength Λ for both time distances and then the arithmetic main.

$$\Lambda = \frac{\lambda \cdot \alpha \cdot m}{\bar{t}}$$
$$\sigma_\Lambda = \sqrt{\left(\frac{m \cdot \lambda \cdot \sigma_\alpha}{\bar{t}}\right)^2 + \left(\frac{m \cdot \alpha \cdot \sigma_{\bar{t}}}{\bar{t}^2}\right)^2}$$

order	Λ [µm]	s_Λ [µm]	$\overline{\Lambda}$ [µm]
1	605,6	1,3	$606{,}4 \pm 0{,}9$
2	607,1	1,3	

Table 16

To be able to compare the value we also computed wavelength on another way. We know the speed of sound in isooctan $\nu = 1111\,\frac{\mathrm{m}}{\mathrm{s}}$ and the chosen frequency $f = (2000{,}05 \pm 0{,}05)\,\mathrm{kHz}$. Up next

$$\Lambda_0 = \frac{\nu}{f} = (555{,}500 \pm 0{,}014)\,\mu\mathrm{m}. \tag{23}$$

5 Discussion

5.1 Sinus grid

We measured the lattice constant K and in addition to that the gaps per millimeter of a given sinus grid. We obtain the following values.

$$K = (1{,}021 \pm 0{,}009) \cdot 10^{-6}\,\mathrm{m}$$
$$\text{gaps per mm} = (979 \pm 9)\,\frac{1}{\mathrm{mm}}$$

On the sinus grid was given a value for the gaps per millimeter. The literature value is

$$\text{gaps per mm} = 1016.$$

So our value is in a 5 times standard error surrounding. We think the error comes to existence because the grid was a bit crooked. As a consequence the way to the left maximum was a bit longer. We tried to fix it but the setup did not allowed us to twist the grid.

5.2 Grid constants

The calculation of the grid constants resulted the values in Table 17.

grid	K [µm]
1	$133{,}6 \pm 1{,}3$
2	$36{,}1 \pm 0{,}3$
3	$107{,}1 \pm 1{,}3$
4	107 ± 2
5	$53{,}9 \pm 0{,}6$

Table 17: Lattice constants of the unknown grids

Cause we do not know the real lattice constants it is not possible to compare the values and check whether they are correct. We might say that the order of magnitude conforms to them of other grid constants we had calculating before also the uncertainties seems to be realistic in regard to the setup. There is also an error source. We noted that the maxima on the left side were more clearly and intensive than on the right one. However it is noticeable that the third and fourth constants are equal. See that we measured the resolution power too it would be interesting to compare them later on.

5.3 Aperture function

Figure 3 shows the calculated aperture function. It confirms to our expectations. We plot the transmission over the ratio $\frac{x}{K}$ because then it is easier to calculate the ratio

$$\nu = \frac{b}{K} = 0{,}222.$$

The value does not have an error because we read out b exactly with help of origin.

5.4 Resolution power

For the resolution power we obtained the following values shown in Table ??.

grid	A
1	90 ± 30
2	170 ± 60
3	60 ± 20
4	30 ± 10
5	110 ± 40

Table 18: Calculated resolution powers

We do not have comparables here too. As noticed in 5.2 it is interesting to compare the third and fourth grid. One can say that the resolution power is different. So it would be better to use the third grid for a spectral analysis because more orders of maxima are visible. Noteworthy is that sometimes it was quite tricky to decide which maxima is even visible. The number of visible maxima m is very important for calculating the resolution power. This is a possible error source.

5.5 Ultrasonic cell

We measured the amplitudes of the interference maxima after the diffraction on ultra sound waves. We also plotted the amplitudes of the different orders and fitted on each a Bessel function with the related order. So we get our Parameter B, which should be, according to the Raman-Nath theory, for all Bessel functions equal. Our values for B are

$$B_0 = (0{,}1477 \pm 0{,}0012)\,\frac{1}{\mathrm{V}},$$
$$B_1 = (0{,}181 \pm 0{,}005)\,\frac{1}{\mathrm{V}},$$
$$B_2 = (0{,}182 \pm 0{,}004)\,\frac{1}{\mathrm{V}}.$$

First it should be mentioned that the Bessel fits do not fit very well on the measuring points. The values and errors have a distance from the fit which is above the expected ordinary. The values of B_1 and B_2 are very similar and overlap in the 1σ-area. But B_0 is far away from the others and also the error is too small to explain this. Like in the upper part the maxima on the left side were much higher than on the right side. For the maxima of the first and second order we averaged the values of the left and the right side. Maybe one of them was defective, wherefore we got such different values for B_0 and the other B's.

5.6 Wavelength of sound in isooctan

We obtained the wavelength

$$\Lambda = (605{,}4 \pm 0{,}9)\,\mu\mathrm{m}.$$

To be able to compare the value we also computed a comparable value with help of the frequency

$$\Lambda_0 = (555{,}500 \pm 0{,}014)\,\mu\mathrm{m}.$$

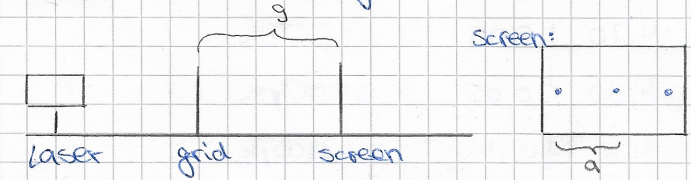
As one can see the error of the value Λ is very small. This small error results because of the small error of the time and the slope α. The error of the second value Λ_0 is small because we were able to set the frequency very exactly. Possibly there was a systematical error of the oscilloscope, they weren't specified and calculated. This could explain the difference.

6 Measurements

Experiment Ultrasonics 24.08.17

Simona Gorgulo

Measure 1: sinus grid lattice constant



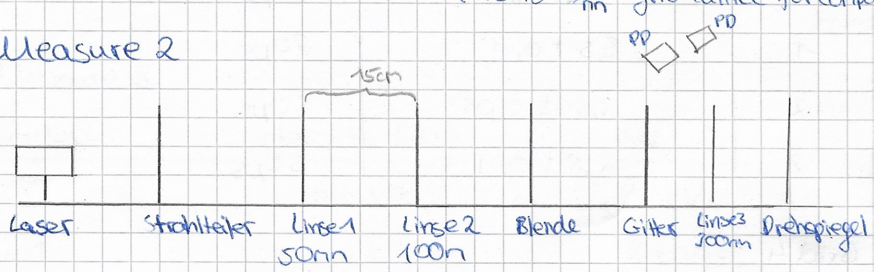
g [cm]	2a [cm]
5,65	8,90
7,15	11,30

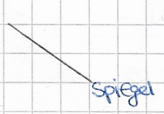
$s_g = 0,03\,cm$ (Messschieber)

$s_{2a} = 0,05\,cm$ (Millimeterpapier)

(1016 L/mm grid lattice for comparing)

Measure 2



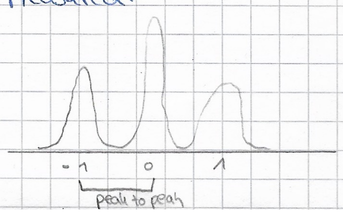


diod-amplifier: x10
x100

Referencegrid

order	distance peak to peak [div]	[div]
-1	3,0 ± 0,1	20 µs
1	3,0 ± 0,1	20 µs
-2	2,45 ± 0,05	50 µs
2	2,35 ± 0,05	50 µs
-3	3,6 ± 0,1	50 µs
3	3,6 ± 0,1	50 µs

We measured:



Grid 2

Order	Peak to Peak [div]	div
-1	4,20 ± 0,05	50 µs
1	4,10 ± 0,05	50 µs
-2	4,2 ± 0,1	100 µs
2	/	/

Grid 3

Order	Peak to Peak [div]	div
-1	3,5 ± 0,1	20 µs
1	3,5 ± 0,1	20 µs
-2	2,80 ± 0,05	50 µs
2	2,8 ± 0,1	50 µs

Grid 4

Order	Peak to Peak [div]	div
-1	3,5 ± 0,1	20 µs
1	3,5 ± 0,1	20 µs

Grid 5

Order	Peak to Peak [div]	div
-1	2,80 ± 0,05	50 µs
1	2,75 ± 0,05	50 µs
-2	2,80 ± 0,05	100 µs

grid 1

order	Peak to Peak [div]	div
-1	2,9 ± 0,1	20 µs
1	2,8 ± 0,1	20 µs
-2	2,25 ± 0,05	50 µs
2	2,2 ± 0,1	50 µs
-3	~~2,30~~ 3,35 ± 0,05	50 µs
3	/	/
-4	4,5 ± 0,1	50 µs

Measure 3

order	intensity [div]	div
0	6,4 ± 0,1	20 mV
-1	6,6 ± 0,2	2 mV
1	4,4 ± 0,2	2 mV
-2	4,6 ± 0,2	2 mV
2	2,3 ± 0,2	2 mV
-3	3,3 ± 0,2	2 mV
3	/	/
-4	2,3 ± 0,2	2 mV
noise	1,8 ± 0,2	1 mV

beam diameter on screen: (3 ± 1) mm

through split (1,2 ± 0,2) mm

25.08.17 Measure 4 - Ultrasonics

frequence [kHz]	Voltage [V]	order	distance [div] left	distance [div] right	μs/div	amplitude [div] left	amplitude [div] right	mV/div
2000,00	0,00	0				7,0±0,1		50mV
2000,07	1,00	0				6,7±0,1		50mV
2000,04	2,00	0				6,4±0,1		50mV
2000,01	3,00	0				6,1±0,1		50mV
		1	1,3±0,1	1,2±0,2	10	3,6±0,1	3,1±0,1	10mV
2000,08	4,00	0				5,7±0,1		50mV
		1	2,6±0,1	2,4±0,1	5	5,0±0,1	4,4±0,1	10mV
2000,04	5,00	0				5,2±0,1		50mV
		1	2,6±0,1	2,5±0,1	5	6,3±0,1	5,7±0,1	10mV
2000,03	6,00	0				4,6±0,1		50mV
		1	2,6±0,1	2,5±0,1	5	3,8±0,1	3,4±0,1	20mV
2000,05	7,00	0				4,0±0,1		50mV
		1	2,6±0,1	2,5±0,1	5	4,5±0,1	4,1±0,1	20mV
		2	5,0±0,3	5,0±0,4	5	2,8±0,2	2,3±0,2	5mV
2000,02	8,00	0				3,4±0,1		50mV
		1	2,6±0,1	2,6±0,1	5	5,4±0,1	4,8±0,1	20mV

Spannung [V] Ordnung Links rechts Links rechts

Abstand ptop [μs] Amplitude [V]

		2	5,1±0,1	5,1±0,1	5	4,0±0,2	3,4±0,2	5nV
2000,08	9,00	0				6,9±0,1		20nV
		1	6,5±0,2	6,5±0,2	2	6,1±0,1	5,5±0,1	20nV
		2	5,1±0,1	5,1±0,1	5	5,8±0,2	4,8±0,2	5nV
2000,00	10,00	0				5,2±0,1		20nV
		1	6,5±0,1	6,5±0,1	2	6,5±0,1	6,0±0,1	20nV
		2	5,2±0,1	5,1±0,1	5	4,2±0,1	3,4±0,1	10mV
		The third order is visible but not sharp enough to be measured						
2000,08	8,50	0				2,9±0,1		50nV
		1	2,6±0,1	2,6±0,1	5	6,4±0,1	5,9±0,1	20nV
		2	5,2±0,1	5,1±0,1	5	6,4±0,2	5,0±0,2	5mV
2000,09	9,50	0				5,3±0,1		20mV
		1	6,5±0,1	6,5±0,1	2	6,6±0,1	6,3±0,1	20nV
		2	5,3±0,1	5,1±0,1	5	4,2±0,1	3,4±0,1	10nV

$S_{frequence}$ = 0,05 kHz

noise : (4,5 ± 0,2) div

1nV/div

$S_{voltage}$ = 0,01 V

Laser : 632,8nm

f_{mirror} : 12,5 Hz

Reference grid

order	P to P [div]	t/div
1	6,30 ± 0,05	20 µs
2	5,00 ± 0,05	50 µs
3	7,5 ± 0,1	50 µs

References

[1] The diagram was generated with OriginPro 2017G.

[2] Versuchsanleitung Fortgeschrittenen Praktikum Teil 1- Ultraschall [http://hacol13.physik.uni-freiburg.de/fp/Versuche/FP1/FP1-2-Ultraschall/Anleitung.pdf] (called on 30.08.2017)

[3] C. V. Raman, N. S. Nagendra Nath (1935): The diffraction of light by high frequency sound waves; From the Department of Physics, Indian Institute of Science, Bangalore.

[4] Lutz Lefèvre (1977): Beugung am Amplitudengitter und Phasengitter. Versuchsaufbau für das Fortgeschrittenen-Praktikum; Physikalisches Institut, Freiburg im Breisgau.