# Spektroskopische Messungen
# End report

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**Abstract**

The goals of this experiment were to determine which kind of material was contained in a lamp by looking at the emission spectra and comparing it to a database of known values, and analyzing the solar spectrum (in particular the Fraunhofer absorption lines). We first calibrated the camera using the already known values of the helium spectral lines.

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# 1 Introduction

As light passes through a material, it interacts with the atoms comprising the material. The electrons in the atoms absorb photons and in the process receive energy. This energy causes electrons to transition to an unstable higher energy level. When the electrons return to their respective stable levels, they release energy in the form of a photon of a specific wavelength, depending on the energy difference. Since the energy levels of the electron states are quantized, and not continuous, a plot of distinct lines of different intensities at specific wavelengths can be seen. We are using a spectrometer of the Czerny-Turner configuration in order to study these lines. The reason why we use this spectrometer configuration is that the data depends only on a rotating knob, which controls the angle of the grating, and moreover the pixel position of the spectral lines, which can be seen on a CCD camera.

# 2 Results

## 2.1 Calibration of the CCD camera

By measuring the knob position and attributing every spectral line to its corresponding wavelength[1], we get the following result:

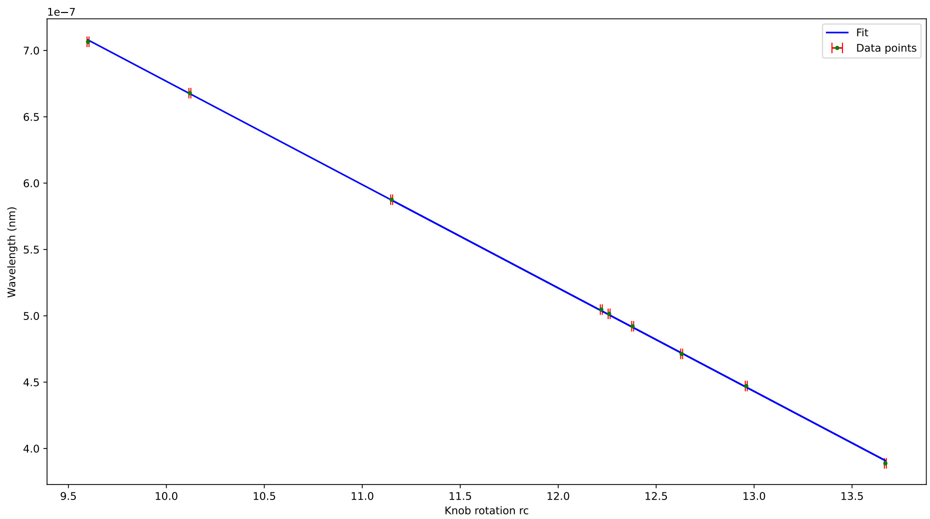


Figure 1: Plot displaying the linear relationship between the wavelength $\lambda_c$ and the knob rotation $r_c$

Whilst measuring the wavelength $\lambda_c$ based off of the rotation of the knob $r_c$ we estimated the instrument's imprecision to be $\sigma_{r_c} = 0.005$ (We could clearly read differences higher than that by looking at the knob, and small changes in the knob rotation resulted in appropriate changes in the part of the spectrum we could see, which wasn't the case in our previous experiment with this apparatus). In order to get a relation between the knob position $r_c$ and horizontal pixel $x_c$ position, we took 7 pictures of the first order maximum at various $r_c$ knob rotations 2, and we plotted the relationship between the change in $r_c$ and the resulting pixel position $x_c$ of the first order maximum 3.

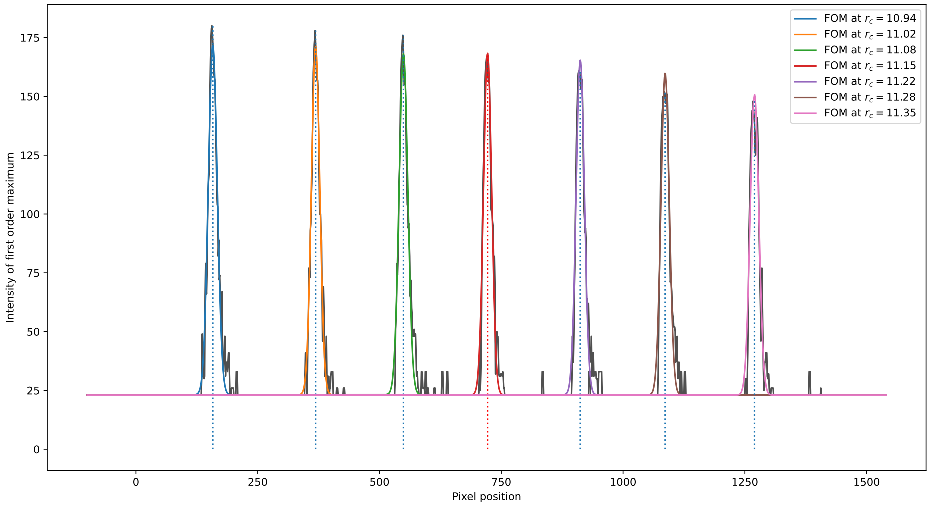


Figure 2: Plot of the FOM (first order maximum) at various $r_c$ knob rotations. The intensity is the sum of the brightnesses in each colour channel.

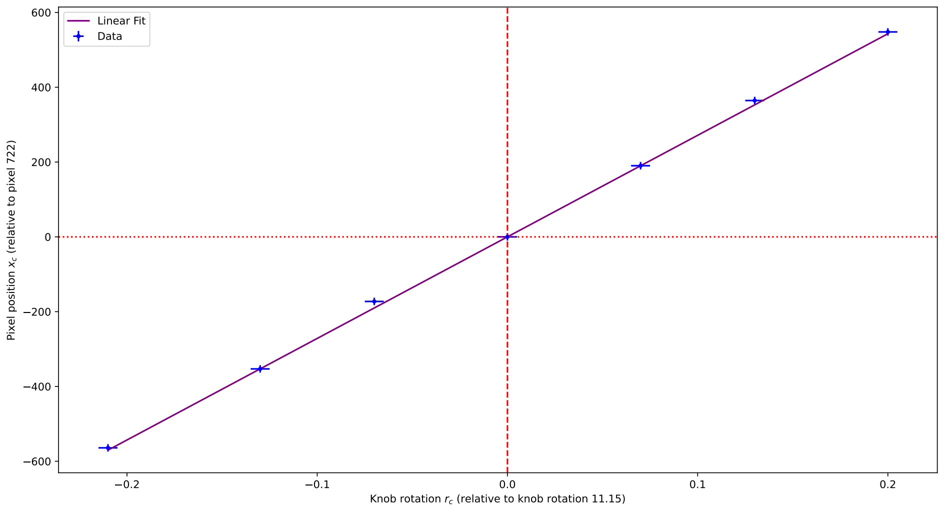


Figure 3: Plot displaying the linear relationship between the knob rotation $r_c$ and the pixel position of the FOM. We estimated a (vertical) error in the pixel position of 10 due to the standard deviation we got from the gaussian fits being at most 10 pixels.

Having collected and processed all the data, we can finally do the last step of the calibration process and calculate the linear relation between horizontal pixel position $x$ and the wavelength: $\lambda$

$$\lambda = \lambda_c + \frac{a_1}{a_2}(x - x_c) \tag{1}$$

where $a_1$ is the gradient from Figure 1 and $a_2$ is the gradient from Figure 3. It is important to note that we utilized RawTherapee for image processing before working with them within Jupyter Notebook.

## 2.2 Determining a source from spectral lines

We were tasked with determining the type of atoms that were contained in a lamp just by the spectral lines that reached the grating. We first took pictures for every spectral line we could see together with the $r_c$ value at which the spectral line was centred. We then stitched all the pictures together to get this:

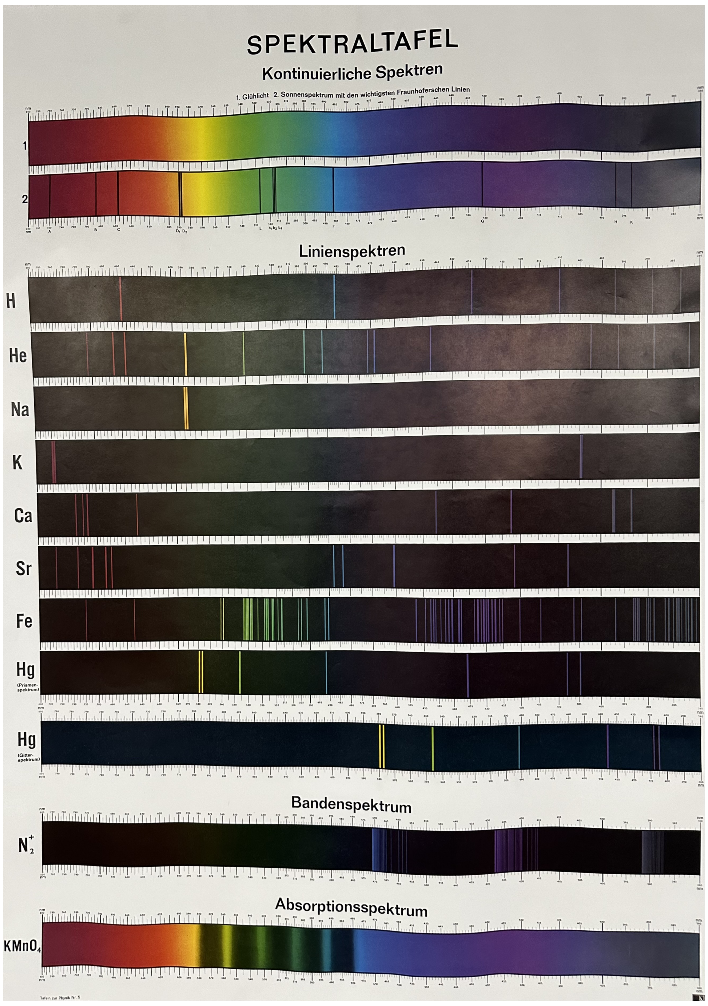


Figure 4: Table of spectras of the possible materials

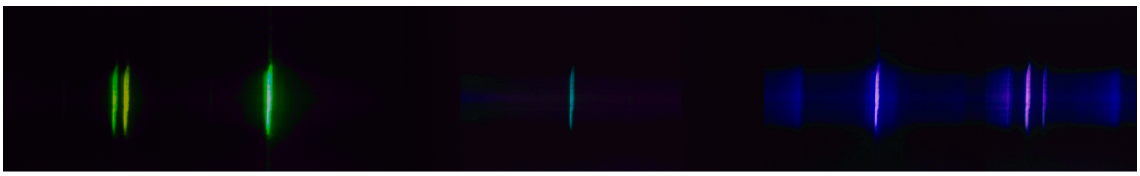

Figure 5: Spectrum of the unknown material

We first compared the spectral lines we could see thanks to the CCD and the table we were provided by eye 4. We found that the element that most closely matched the spectral lines 5 was Mercury (`Hg`).

In order to more accurately determine whether we had found the right element, we compared the wavelengths we'd found with two sources: The NIST database [2], and the table we were provided.

We can thus have a high degree of certainty that the data we have found corresponds to mercury. It is important to notice that the high uncertainties were due to us also taking the standard error

| Measured wavelength (nm) | Literature (table, nm) | Literature (NIST, nm) |
|---|---|---|
| 624 ±5 | ? | 623.436 ±0.010 |
| 613 ±5 | ? | 612.327 ±0.005 |
| 608 ±5 | ? | 607.264 ±0.010 |
| 579 ±5 | 579.5 ±0.5 | 579.06700 ±0.00010 |
| 577 ±5 | 577.0 ±0.5 | 576.96100 ±0.00010 |
| 546 ±5 | 546.5 ±0.5 | 546.07500 ±0.00010 |
| 491 ±5 | 492.0 ±0.5 | 491.6068 ±0.0010 |
| 435 ±6 | 436.0 ±0.5 | 435.83350 ±0.00010 |
| 408 ±6 | 405.0 ±0.5 | 407.78370 ±0.00010 |
| 405 ±6 | 408.0 ±0.5 | 404.65650 ±0.00010 |

Table 1: Comparison of Measured and Literature Wavelengths

of the fit slope and offset into account for the Gauss error propagation. Otherwise the errors would be around 0.5 nm.

We also found three wavelengths that hadn't been mentioned in the table we'd seen in the laboratory, which were mentioned in the NIST table. This further supports our claims of the material being composed of Mercury atoms.

## 2.3 Fraunhofer absorption lines

Lastly, we were tasked to look at the solar spectrum in order to find the so-called 'Fraunhofer absorption lines' that is lines in which part of the intensity doesn't reach us due to it being absorbed by elements in the atmosphere. We took pictures of the solar spectrum at constant $r_c$ changes of $\Delta r_c = 0.2$, and after processing them we tried to merge all the images into one. This took considerably longer than expected due to some human errors, but, after some manual corrections, the end result displayed the Fraunhofer absorption lines quite clearly:

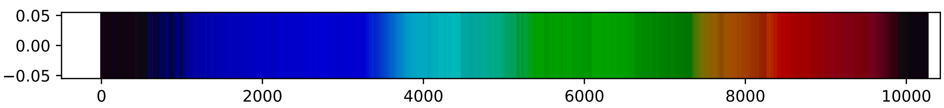


Figure 6: Table of the recorded solar spectrum

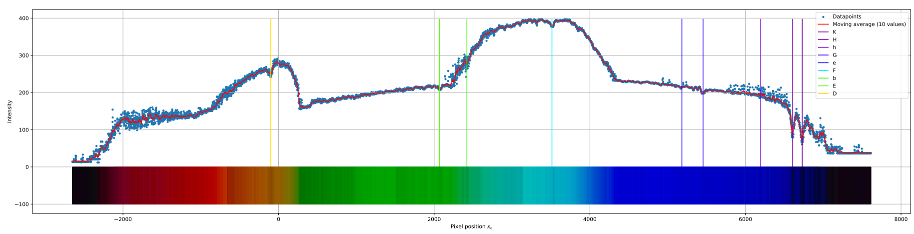

Figure 7: Table of the recorded solar spectrum, with the Fraunhofer absorption lines marked by vertical lines

It is important to notice that the images are flipped: The first image 6 displays the data ordered ascending by wavelength, whereas the second one 7 displays it by pixel. Furthermore, our determination of the Fraunhofer absorption lines was partly biased by the fact that we could compare what we'd found with the literature values [3] to see whether it was noise or a Fraunhofer absorption line. In order to remain as unbiased as possible, we avoided looking at literature values until we'd estimated which wavelengths we thought to be absorption lines. We did this manually by looking where the moving average depicted in the table presented an unusual trough which was big enough with respect to the nearby oscillations to be dismissable as noise.

We were unable to accurately determine whether the `e` line was noise or not, but we decided to plot it anyways.

Beginning from the lowest wavelength (right) to the highest (left) we identified multiple Fraunhofer absorption lines. We are displaying them as a table to make them easy to read.

| Line | Element | Measured (nm) | Literature (nm) |
|---|---|---|---|
| K | Ca+ | $394 \pm 6$ | 393.4 |
| H | Ca+ | $398 \pm 6$ | 396.8 |
| h? | $H_\delta$ | $409 \pm 6$ | 410.1 |
| G | Fe or Ca | $431 \pm 6$ | 430.8 |
| e? | Fe | $438 \pm 6$ | 438.4 |
| F | $H_\beta$ | $486 \pm 5$ | 486.1 |
| b | Mg or Fe | $518 \pm 5$ | 517.3 |
| E | Fe | $528 \pm 5$ | 527.0 |
| D | Na or He | $590 \pm 5$ | 589.6 |

Table 2: Comparison of Measured and Literature Wavelengths

This result is quite satisfying as our imperfect setup was able to determine the Fraunhofer absorption lines quite well! We also tried to find other Fraunhofer absorption lines, however we were unable to correctly determine whether they were truly Fraunhofer absorption lines, or just noise. This uncertainty was most likely caused by the imprecision of the setup.

# 3 Conclusion

Throughout our experiment, we encountered several challenges:

1. A blue LED from another grating apparatus in the lab interfered with our measurements.
2. The room was not completely dark, leading to some unwanted effects in our spectrum. We improved this situation by covering our apparatus with a coat, which made a noticeable difference.
3. Measuring the Fraunhofer absorption lines was particularly tricky. We had to carefully position the fibre cable outside the window. Additionally, the fact that we analyzed the solar spectrum bit by bit over about 30 minutes introduced some complications.

Despite these issues, the experiment was a success.

Our results show that spectroscopic analysis is a powerful tool for identifying elements, as seen in our correct identification of Mercury and the accurate matching of measured wavelengths with known Fraunhofer lines. Even with the limitations we faced, our findings were close to established data, proving the effectiveness of this method.

This experiment was not just about following procedures; it also taught us valuable lessons in dealing with unexpected problems and adapting our approach. These experiences are crucial in any scientific work.

In conclusion, our experiment met its goals by providing accurate data and a deeper understanding of spectroscopy. The hands-on experience and problem-solving skills we gained are assets for future scientific projects.

# References

[1] ETH Zurich Physics Department. Grundlagen zur spektroskopie. https://ap.phys.ethz.ch/24.html. Accessed: November 27, 2023.

[2] NIST. Nist asd output. https://physics.nist.gov/cgi-bin/ASD/lines1.pl?spectra=Hg+I&limits_type=0&low_w=400&upp_w=650&unit=1&submit=Retrieve+Data&de=0&I_scale_type=1&format=0&line_out=0&en_unit=0&output=0&bibrefs=1&page_size=15&show_obs_wl=1&show_calc_wl=1&unc_out=1&order_out=0&max_low_enrg=&show_av=2&max_upp_enrg=&tsb_value=0&min_str=&A_out=0&intens_out=on&max_str=&allowed_out=1&forbid_out=1&min_accur=&min_intens=&conf_out=on&term_out=on&enrg_out=on&J_out=on. Accessed: December 2, 2023.

[3] Wikipedia. Fraunhofer lines. https://ap.phys.ethz.ch/24.html. Accessed: December 2, 2023.