
Spectroscopy II

Physics Laboratory 1

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Abstract In this experiment we studied optical spectroscopy using a Czerny-Turner spectrometer equipped with a CCD camera. The spectrometer was first calibrated with the well-known emission spectrum of a helium discharge lamp in two steps: the dependence of the central wavelength on the dial position and the mapping between dial position and pixel coordinate on the CCD. A linear fit to the helium lines yielded a slope of $m = (-0.773 \pm 0.001)$ nm per dial unit and showed that the spectrum shifts by about 27 pixels per dial unit across the CCD. Using this calibration, the source of an unknown lamp was determined to be mercury, as all major peaks, blue $\lambda = 404.42 \pm 0.85$ and 436.49 ± 0.85 , turquoise $\lambda = 492.12 \pm 0.82$, green $\lambda = 546.20 \pm 0.81$ and 577.10 ± 0.80 , were found. Furthermore, the Fraunhofer lines of sunlight (H, G, F, B₄, D₂, a and C) were determined using the Czerny-Turner spectrometer.

ETH Zürich, December 8, 2025

Introduction

Scope of this experiment In this experiment we study optical spectroscopy using a Czerny-Turner spectrometer as described in the student manual [3] and in Ref. [1]. The main goals are to calibrate the relation between wavelength, dial position and pixel position using the well-known emission spectrum of helium, to use this calibration to identify an unknown source, by determine the wavelength of the spectrum, and to measure the Fraunhofer lines from sunlight and compare our results with literature values.

Fraunhofer lines Sunlight contains a rich and highly structured spectrum with several dark absorption lines known as Fraunhofer lines. which are shown in Fig. 1 and were used as a reference when searching for the corresponding lines in our measurements. First systematically catalogued by Joseph von Fraunhofer in the early 19th century, these lines arise when specific wavelengths of light are absorbed by elements in the Sun's and Earth's atmosphere.[4]

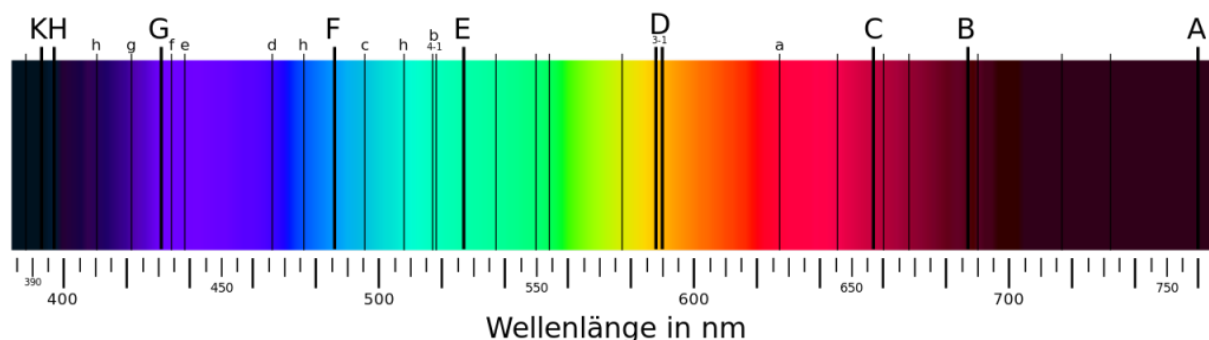


Figure 1: Known Fraunhofer lines of sunlight. [4]

Helium spectrum as a calibration source Helium has a rich but well-tabulated emission spectrum with several isolated and bright lines in the visible range. This makes a helium discharge lamp an ideal calibration source for the spectrometer: the known wavelengths can be assigned to the spectral lines recorded by the CCD, which allows us to determine the linear dependence of the central wavelength on the dial position as well as the mapping between dial position and pixel coordinate on the camera chip. A schematic representation of the helium spectrum in first diffraction order is shown in Fig. 2 and was used as a reference when searching for the corresponding lines in our measurements.

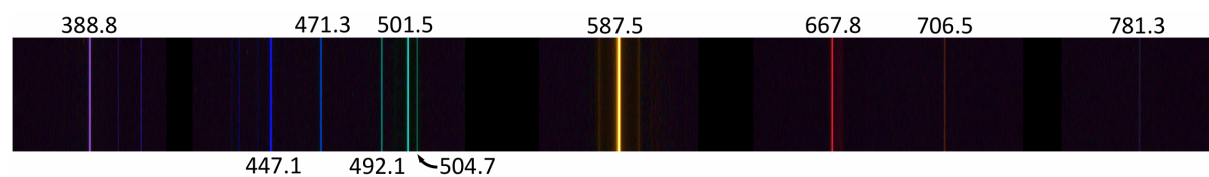


Figure 2: Known He-spectrum of first order. [3]

Experiment

In this experiment a Czerny-Turner spectrometer, with a spectral resolution about 0.1 nm [1], including a CCD camera, and the ThorCam software were used. An overview of the Czerny-Turner spectrometer can be seen in Fig. 3. To generate the helium spectra, a He lamp was used. In this setup, the grating can act either as a simple mirror, producing the so-called *zero diffraction order*, or it can disperse the incoming light according to its wavelength, which produces the *first diffraction order*.

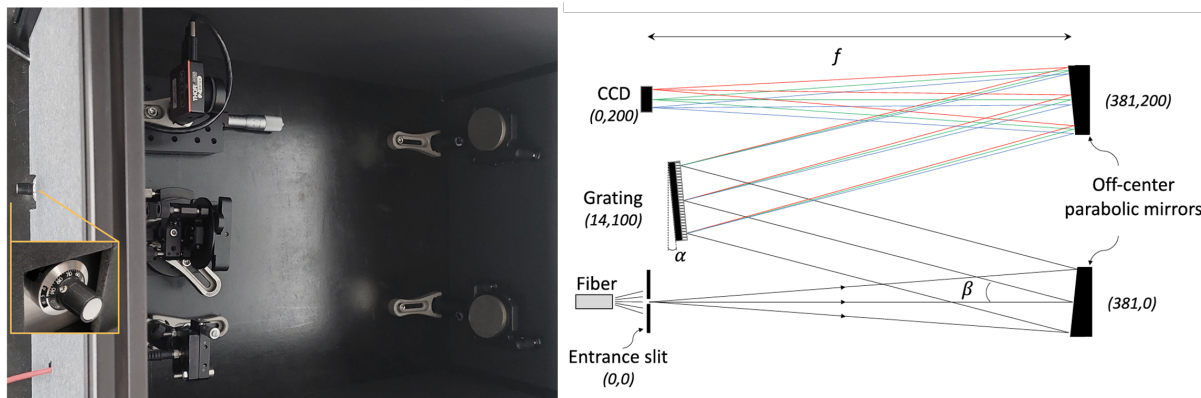


Figure 3: On the left a photograph and on the right a schematic of the spectrometer. [3]

For the calibration of the spectrometer, the He lamp was connected to the spectrometer, using a glass fiber. The grating was oriented so that it was parallel to the parabolic mirrors to find the zero diffraction order spectral line. After orienting the peak of the spectral line at the central pixel, the dial position k was determined and a .bmp file was recorded. By turning the grating-wheel counter clockwise, the first diffraction order spectral lines were found. The measurements were repeated for all visible spectral lines red, orange, green, blue and violet, as seen in Fig. 2. During the first calibration step, each visible helium spectral line was positioned precisely at the central pixel of the CCD. This allowed us to determine the relation between the dial position k and the corresponding central wavelength. For the second calibration step, a bright helium line was moved stepwise across the CCD by adjusting the grating angle. For each position, both the pixel position and the dial position k were recorded in order to establish the linear relation between k and the pixel coordinate. Afterwards, the He lamp was exchanged with the unknown source lamp. By turning the grating anticlockwise, the visible spectral lines green, blue and turquoise of the unknown source were found as in the previous steps. Finally the optic fibre was placed at the window to measure the sun light and each Fraunhofer line was recorded as in the previous steps. All recorded data from both calibration steps were subsequently analysed using Python, where linear regressions were used to determine the calibration parameters needed for the wavelength reconstruction.

Results

The gathered data from the calibration process can be found in Tab.1 and Tab.2.

Table 1: Overview of all measured results from the calibration process, regarding the correspondence between the central wavelength λ_c and the dial position k .

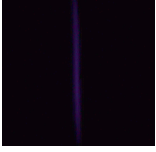
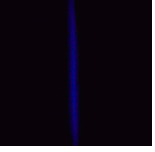
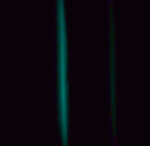
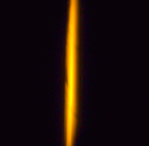
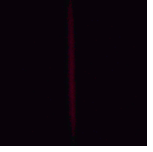
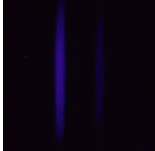
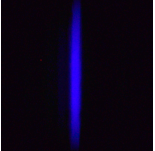
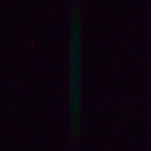
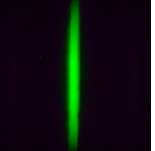
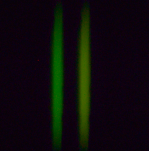
image					
λ_c / nm	388.8	447.1	501.5	587.5	667.8
k	286 ± 1	210 ± 1	140 ± 1	28 ± 1	-75 ± 1

Table 2: Overview of all measured results from the calibration process, regarding the correspondence between the pixels and the dial position k .

pixel	20	420	520	620	820	920	1020	1420
k	4 ± 1	17 ± 1	22 ± 1	25 ± 1	32 ± 1	36 ± 1	40 ± 1	55 ± 1




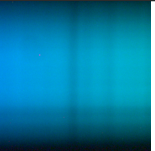
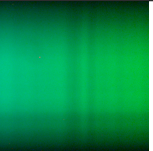
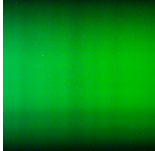

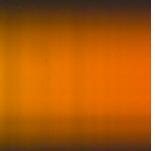
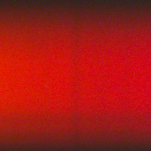
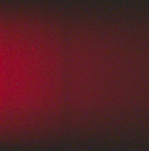
The data collected from the measurement of the unknown source can be found in Tab. 3.

Table 3: Overview of all measured results from the unknown source spectra.

image					
k	265 ± 1	224 ± 1	152 ± 1	82 ± 1	42 ± 1

The data collected from the measurement of the Fraunhofer lines of sunlight can be found in Tab. 4.

Table 4: Overview of all measured results from the measurement of the Fraunhofer lines of sunlight.

image					
k	278 ± 1	274 ± 1	230 ± 1	159 ± 1	120 ± 1
image					
k	108 ± 1	26 ± 1	18 ± 1	-24 ± 1	-61 ± 1

Data Analysis

Calibration

For the helium lamp we first determined how the central wavelength displayed by the spectrometer depends on the dial position. Assuming a linear relation

$$\lambda_c(k) = mk + b,$$

a linear regression of the five measured helium lines (Tab. 1) was performed (Fig. 4) and yielded

$$\begin{aligned} m &= (-0.773 \pm 0.001) \text{ nm per dial unit,} \\ b &= (609.555 \pm 0.212) \text{ nm.} \end{aligned}$$

Thus, turning the dial by one unit shifts the central wavelength by approximately 0.77 nm. The effective zero point of the dial, defined by the condition $\lambda_c(k_0) = 0$, is

$$k_0 = -\frac{b}{m} = 788.940.$$

In a second calibration step, see Fig 5, we determined how the position of a bright helium line on the CCD shifts when the dial is rotated. Fitting

$$p(k) = m_2 k + b_2$$

to the corresponding data gives

$$\begin{aligned} m_2 &= B = (27.285 \pm 0.426) \text{ pixels per dial unit,} \\ b_2 &= (-65.210 \pm 13.585) \times 10^4 \text{ pixels.} \end{aligned}$$

This means that the spectrum moves by about 27 pixels across the CCD per dial unit. The two calibration steps can be combined into the general wavelength relation

$$\lambda(p, k) = m_\lambda (k - k_0) + \frac{p - p_{\text{central}}}{B_\lambda},$$

where $m_\lambda = m$ and $B_\lambda = m_2$ are taken from the regression parameters. Here, p_{central} denotes the pixel position corresponding to the optical axis of the spectrometer, i.e. the pixel where a centred spectral line appears.

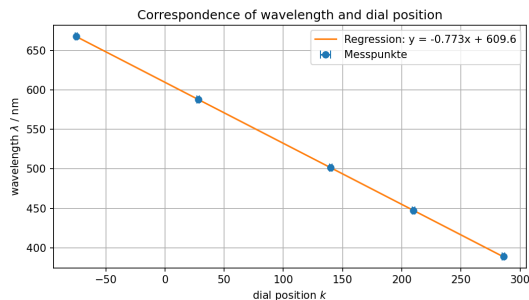


Figure 4: Linear calibration of wavelength vs. dial position.

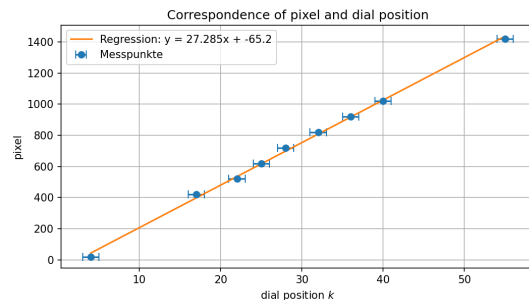


Figure 5: Linear calibration of pixel position vs. dial position.

Unknown source

For the unknown source lamp we recorded several spectra. From the images (see Tab. 3) we could reliably extract five dial positions: $k = 285$ for the light blue line, $k = 224$ for the strong blue line, $k = 152$ for the turquoise line, $k = 82$ for the strong green line and $k = 42$ for the light green line. During the measurements, the spectral lines were centred on the CCD ($p \approx p_{\text{central}}$). Therefore the wavelength can be obtained directly from the simplified relation

$$\lambda(k) = mk + b.$$

The wavelengths were found to correspond with literature values of a mercury lamp. The wavelengths obtained using this simplified relation can be found in Tab. 5 with the corresponding literature values of mercury.

Table 5: Comparison of the literature values of the wavelength of visible mercury emission lines from Ref. [2] with our measured wavelengths.

Line	Literature $\lambda_{\text{lit}} / \text{nm}$	Measured $\lambda_{\text{meas}} / \text{nm}$	$\Delta = \lambda_{\text{lit}} - \lambda_{\text{meas}} / \text{nm}$
1	404.66	404.42 ± 0.85	+0.24
2	435.83	436.49 ± 0.85	-0.66
3	491.60	492.12 ± 0.82	-0.52
4	546.07	546.20 ± 0.81	-0.13
5	576.96	577.10 ± 0.80	-0.14

Fraunhofer lines

For the Fraunhofer lines we recorded several spectra. From the images (see Tab. 4) we could extract ten dial positions: $k = 278$ and 274 for the violet lines, $k = 230$ for the blue line, $k = 159$ for the turquoise line, $k = 120$ and 108 for the green lines, $k = 26$ and 18 for the orange lines and $k = -24$ and -61 for the red lines. During the measurements, the Fraunhofer lines were centred on the CCD ($p \approx p_{\text{central}}$). Therefore, we can use the same simplified relation as in the analysis of the unknown source. Using this relation, the

dial positions of all observed Fraunhofer lines were converted into measured wavelengths. The results, including uncertainties, literature for sun litght [5] and the corresponding deviations $\Delta = \lambda_{\text{lit}} - \lambda_{\text{meas}}$, are summarized in Table 6.

Table 6: Measured Fraunhofer lines compared with their literature values.

Line	k	$\lambda_{\text{meas}} / \text{nm}$	$\lambda_{\text{lit}} / \text{nm}$	Δ / nm
K	278 ± 1	394.36 ± 0.86	393.37	-0.99
H	274 ± 1	397.46 ± 0.86	396.85	-0.61
G	230 ± 1	431.52 ± 0.84	430.79	-0.73
F	159 ± 1	486.49 ± 0.82	486.13	-0.36
B ₄	120 ± 1	516.68 ± 0.81	516.73	0.05
E	108 ± 1	526.11 ± 0.81	527.04	0.93
D ₂	26 ± 1	589.46 ± 0.80	589.00	-0.46
D ₁	18 ± 1	595.65 ± 0.80	589.59	-6.06
a	-24 ± 1	628.17 ± 0.80	627.66	-0.51
C	-61 ± 1	656.68 ± 0.80	656.28	-0.40

The Fraunhofer lines (H, G, F, B₄, D₂, a and C) show very good agreement with the literature, with deviations below 1 nm and well within the experimental uncertainty. For the remaining lines (K, E and D₁), significant deviations occur, which suggests either a measurement error because of the blurred image due to the high exposure time or a misidentification of the dial positions during the measurement or that some lines from higher diffraction orders overlapped in the observed spectrum. Nevertheless, the correctly matched lines confirm that the calibration procedure is reliable over a large portion of the visible spectrum.

Gaussian fitting of the Fraunhofer F line from CCD data

To complement the wavelength determination based on dial positions, we additionally extracted a one-dimensional spectrum directly from the CCD image of the solar spectrum and performed a Gaussian fit to the Fraunhofer F absorption line. This provides an independent consistency check of the calibration and illustrates how individual lines can be analysed directly on the CCD data.

The raw BMP image of the F line exhibits noticeable pixel-to-pixel noise due to the long exposure settings of the spectrometer. To increase the signal-to-noise ratio, a wide horizontal stripe of the CCD image ($150 \leq \text{row} \leq 250$) was averaged, effectively suppressing statistical fluctuations across individual rows.

Even after averaging, the intensity profile still shows high-frequency noise. To reduce this noise without distorting the physical line shape, a Gaussian smoothing filter was applied. Different smoothing widths σ were tested, ranging from nearly unfiltered data ($\sigma = 0.1$)

to strongly smoothed curves ($\sigma \geq 5$). A value of

$$\sigma = 1 \text{ pixel}$$

was found to provide the optimal balance: high-frequency noise is suppressed while the narrow Fraunhofer absorption feature remains undistorted. Larger smoothing widths increasingly broaden the line artificially, while smaller values retain too much noise for a stable fit.

Using the combined wavelength calibration

$$\lambda(p, k) = m k + b + \frac{p - p_{\text{central}}}{B}, \quad (1)$$

the pixel coordinate was converted into wavelength for the dial position $k = 159$, corresponding to the region of the F line. The absorption feature was then modeled by a Gaussian profile of the form

$$I(\lambda) = C - A \exp\left[-\frac{(\lambda - \lambda_0)^2}{2\sigma^2}\right], \quad (2)$$

where A is the absorption depth, λ_0 the line center and σ the Gaussian width.

The fit yielded the following line center for the Fraunhofer F line:

$$\lambda_{\text{F, fit}} = 486.60 \text{ nm}. \quad (3)$$

This value agrees very well with the wavelength obtained from the dial-based analysis, $\lambda_{\text{F, meas}} = 486.49 \pm 0.82 \text{ nm}$ (see Table 6), and is close to the literature value $\lambda_{\text{F}}^{\text{lit}} = 486.13 \text{ nm}$. The small residual discrepancy is compatible with the finite spectral resolution of the spectrometer and mild background structure in the CCD signal.

A plot of the extracted spectrum together with the Gaussian fit of the F absorption line is shown in Fig. 6.

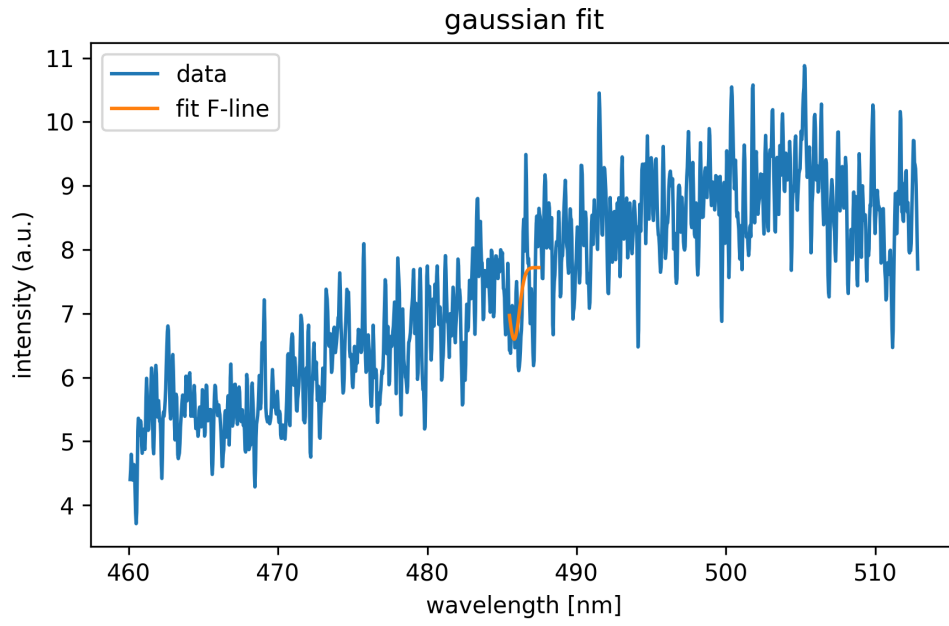


Figure 6: Extracted solar spectrum (Gaussian-smoothed with $\sigma = 1$) and Gaussian fit to the Fraunhofer F absorption line.

Discussion

The two-step calibration of the spectrometer yielded consistent and reliable results. The first calibration, which relates the wavelength to dial position, showed excellent linear behaviour throughout the scanned range, with a slope of $m = (-0.773 \pm 0.001)$ nm per dial unit. The second calibration demonstrated that the spectrum shifts by approximately 27 pixels per dial unit on the CCD. Both regressions show small uncertainties, indicating that the mechanical control of the grating is sufficiently stable for the purpose of this experiment.

Table 5 compares the visible mercury emission lines from the reference spectrum with our experimentally measured wavelengths. All measured values showed very good agreement with their corresponding literature values. In each case, the deviation $\Delta = \lambda_{\text{lit}} - \lambda_{\text{meas}}$ remains smaller than the experimental uncertainty, demonstrating the accuracy of our wavelength calibration. The largest deviation occurs for the second visible line at 435.83 nm, where the difference amounts to 0.66 nm. Even this discrepancy is still well within the measurement uncertainty of ± 0.85 nm. All other lines show deviations below 0.52 nm, confirming excellent consistency across the full spectral range. This strong agreement supports the reliability of our calibration procedure and allows for a clear identification of the unknown source as a mercury lamp.

Table 6 compares the literature values of the Fraunhofer lines of sunlight with our experimentally measured wavelengths of the Fraunhofer lines. Most of the measured values (line H, G, F, B₄, D₂, a and C) show very good agreement with their corresponding literature values, as the deviation $\Delta = \lambda_{\text{lit}} - \lambda_{\text{meas}}$ remains smaller than the experimental uncertainty. The Fraunhofer lines K and E show a small but significant deviation from the literature values, which could result from a measurement error because of the blurred image due to the high exposure time or a misidentification of the dial positions during the measurement. Finally, the Fraunhofer line D₁ show a significant deviation from the literature values. This could be due to some lines from higher diffraction orders being overlapped in the observed spectrum, resulting in misidentification.

Fig. 6 shows the performed Gaussian fit of the extracted spectra, which gave the wavelength $\lambda_{\text{F,fit}} = 486.60$ nm for the Fraunhofer F line which coincides with the calculated and the literature value for this Fraunhofer line, which are $\lambda_{\text{F,meas}} = 486.49 \pm 0.82$ nm and $\lambda_{\text{F}}^{\text{lit}} = 486.13$ nm (see Table 6). This provides an independent consistency check of the calibration and illustrates that the calibration and calculation was successful.

Conclusion

In this experiment, we calibrated a Czerny-Turner spectrometer using helium emission lines and applied this calibration to identify an unknown lamp source, by determining the wavelength of the spectrum, and to measure the Fraunhofer lines from sunlight. The two-step calibration showed a clear linear dependence of both the central wavelength and the CCD pixel position on the dial setting, enabling a consistent description of the spectrometer response.

Moreover, an unknown source lamp was identified to be mercury, using the calibration, as all major spectral lines coincided with the spectral lines of mercury, and in each case the deviation $\Delta = \lambda_{\text{lit}} - \lambda_{\text{meas}}$ remained lower than the experimental uncertainty, with the largest deviation being 0.66 nm.

The Fraunhofer lines of sunlight (H, G, F, B₄, D₂, a and C) were successfully identified, as the deviation from the literature values was smaller than the experimental uncertainty. The Fraunhofer lines K and E showed a small but significant deviation from the literature values, which could result from high exposure times or a misidentification of the dial positions during the measurement. The Fraunhofer line D₁ showed a significant deviation from the literature values. This could result from some lines from higher diffraction orders being overlapped in the observed spectrum. Finally, the Gaussian fit provided an independent consistency check of the calibration.

Appendix

AI Usage Declaration

This report was prepared with assistance from ChatGPT (OpenAI) for language polishing, formatting suggestions, and for helping to develop, debug, and correct the syntax of the Python code. The AI was not used to generate raw data, to select results, or to determine the final conclusions. All scientific content (methods, calculations, results, and interpretation) was critically reviewed and validated by the authors. The authors take full responsibility for the accuracy of the analysis and for any remaining errors. No confidential or personal data were provided to the AI system during the preparation of this report.

References

- [1] Andreas Eggenberger, Tomasz Smolenski, and Martin Kroner. “A simple state-of-the-art spectrometer for student labs: Cost-efficient, instructive, and widely applicable”. In: *American Journal of Physics* 92.2 (Feb. 2024), pp. 146–153. ISSN: 0002-9505. DOI: [10.1119/5.0164044](https://doi.org/10.1119/5.0164044). eprint: https://pubs.aip.org/aapt/ajp/article-pdf/92/2/146/20107891/146_1_5.0164044.pdf. URL: <https://doi.org/10.1119/5.0164044>.
- [2] Rhetos Lexicon of Physics. *Mercury Spectrum*. 2025. URL: <https://www.rhetos.de/html/lex/quecksilberspektrum.htm>. (accessed: 02 December 2025).
- [3] *Physikpraktikum für 3. Semester — Experiment 24 Grundlagen zur Spektroskopie*. Lab manual. Restricted access (ETH login required). ETH Zürich, Departement Physik, Nov. 10, 2025. URL: https://ap.phys.ethz.ch/Anleitungen/Bilingual/24_Manual_PHYS.pdf.
- [4] *Web Site wikipedia.org*. URL: <https://de.wikipedia.org/wiki/Fraunhoferlinie>. (accessed: 01.12.2025).
- [5] Wikipedia contributors. *Fraunhofer lines*. Accessed on 3 December 2025. 2025. URL: https://en.wikipedia.org/wiki/Fraunhofer_lines.

Python Code

```

1 import numpy as np
2 import matplotlib.pyplot as plt
3 from math import atan2, sqrt
4 from dataclasses import dataclass
5
6 # ----- 0) Messdaten aus der Tabelle (nm, k) -----
7 # He: bekannte Wellenlängen und dazugehörige Dial-Positionen
8 hew = np.array([388.8, 447.1, 501.5, 587.5, 667.8], dtype=float)
9 herad = np.array([285, 210, 140, 28, -75], dtype=float)
10
11 # He: Pixelposition einer hellen Linie vs. Dial-Position (Kalibration 2)
12 hepix = np.array([20, 420, 520, 620, 720, 820, 920, 1020, 1420],
13                  dtype=float)
14 hepirad = np.array([4, 17, 22, 25, 28, 32,
15                    36, 40, 55],
16                    dtype=float)
17
18
19 # ----- 1) Lineare Regression für die Kalibration -----
20 # plot 1: lambda vs. k
21 (m, b), cov = np.polyfit(herad, hew, 1, cov=True)
22
23 # Standardfehler der Parameter
24 m_err = np.sqrt(cov[0, 0])
25 b_err = np.sqrt(cov[1, 1])
26
27 print(f"Kalibration 1: lambda(k) = m*k + b")
28 print(f"  m = {m:.6f} pm {m_err:.6f} nm pro Dial-Einheit")
29 print(f"  b = {b:.6f} pm {b_err:.6f} nm")
30
31 # plot 2: pixel vs. k
32 (m2, b2), cov2 = np.polyfit(hepirad, hepix, 1, cov=True)
33 m2_err = np.sqrt(cov2[0, 0])
34 b2_err = np.sqrt(cov2[1, 1])
35
36 print(f"\nKalibration 2: pixel(k) = m2*k + b2")
37 print(f"  m2 = B = {m2:.6f} pm {m2_err:.6f} pixel pro Dial-Einheit")
38 print(f"  b2 = {b2:.6f} pm {b2_err:.6f} pixel")
39
40

```

```

41 # ----- 2) Plots (mit Fehlerbalken) -----
42 # Plot 1: lambda vs. k
43 plt.figure(figsize=(7.2, 4.2))
44 plt.errorbar(herad, hew, xerr=1, fmt='o', capsize=4, label="Messpunkte")
45
46 x_reg = np.linspace(min(herad), max(herad), 200)
47 y_reg = m * x_reg + b
48 plt.plot(x_reg, y_reg, '-', label=f"Regression: y = {m:.3f}x + {b:.1f}")
49
50 plt.xlabel("dial position $k$")
51 plt.ylabel(r"wavelength $\lambda$ / nm")
52 plt.title("Correspondence of wavelength and dial position")
53 plt.grid(True)
54 plt.tight_layout()
55 plt.legend()
56 plt.savefig("cor1.png", dpi=150)
57 plt.close()
58
59 # Plot 2: pixel vs. k
60 plt.figure(figsize=(7.2, 4.2))
61 plt.errorbar(hepirad, hepix, xerr=1, fmt='o', capsize=4, label="Messpunkte")
62
63 x_reg2 = np.linspace(min(hepirad), max(hepirad), 200)
64 y_reg2 = m2 * x_reg2 + b2
65 plt.plot(x_reg2, y_reg2, '-', label=f"Regression: y = {m2:.3f}x + {b2:.1f}")
66
67 plt.xlabel("dial position $k$")
68 plt.ylabel("pixel")
69 plt.title("Correspondence of pixel and dial position")
70 plt.grid(True)
71 plt.tight_layout()
72 plt.legend()
73 plt.savefig("cor2.png", dpi=150)
74 plt.close()
75
76
77 # ----- 3) Kalibrationsparameter ableiten -----
78 # effektiver Nullpunkt des Dials
79 k0 = -b / m
80 print(f"\neffektiver Nullpunkt des Dials: k0 = {k0:.2f}")
81

```

```

82 # mittlerer Pixel der Kamera (angenommen), wurde bei uns fr H zentriert
83 p_central = 720.0
84
85 def lambda_from_k_p(k, p, m, b, k0, B, p_central):
86     """
87     Wellenlge in nm als Funktion von Dialposition k und Pixel p.
88     Allgemeine Formel aus der doppelten Kalibration.
89     """
90     # zentrale Wellenlge bei diesem k
91     lam_center = m * (k - k0)
92     # zustzliche Verschiebung durch Pixelposition
93     delta_lam_pixel = (p - p_central) / B
94     return lam_center + delta_lam_pixel + m * k0 + b # identisch zu m*k + b +
95     (p-pc)/B
96
97 # Fr unsere unknown-Messungen haben wir die Linie jeweils auf den Zentralpixel
98   gesetzt,
99 # daher setzen wir im Folgenden p = p_central und benutzen lambda(k) = m*k + b.
100 def lambda_from_k(k, m, b):
101     """vereinfachte Kalibration fr zentrierte Linien"""
102     return m * k + b
103
104 # ----- 4) Unknown source (nur Dial-Positionen) -----
105 # Aus Tabelle 3: k-Werte der sichtbaren Linien.
106 k_u = np.array([265, 224, 152, 82, 42]) # Dialpositionen
107 names_u = np.array(["U_1", "U_2", "U_3", "U_4", "U_5"])
108
109 # angenommene Unsicherheit in k
110 sigma_k = 1.0
111
112 # Wellenlgen und Unsicherheiten bestimmen
113 lambda_u = lambda_from_k(k_u, m, b) # in nm
114
115 # Fehlerfortpflanzung fr lambda = m*k + b
116 sigma_lambda_u = np.sqrt((k_u * m_err)**2 + b_err**2 + (m * sigma_k)**2)
117
118 print("\n--- Linien (aus Dial-Positionen) ---")
119 for name, k_val, lam, lam_err in zip(names_u, k_u, lambda_u, sigma_lambda_u):
120     print(f"{name:8s}: k = {k_val:.0f} pm {sigma_k:.0f}, "
121           f"lambda = {lam:.2f} pm {lam_err:.2f} nm")
    
```

```

121
122
123 # ----- 5) Fraunhofer-Linien (nur Dial-Positionen) -----
124
125 # Aus Tabelle 4: k-Werte der gemessenen Fraunhofer-Linien
126 # Reihenfolge: von violett nach rot
127 k_f = np.array([278, 274, 230, 159, 120, 108, 26, 18, -24, -61], dtype=float)
128
129 # Symbolische Bezeichnungen der Linien (Standard-Fraunhofer-Linien)
130 names_f = np.array(["K", "H", "G", "F", "B4", "E", "D2", "D1", "a", "C"])
131
132 # Literaturwerte der Fraunhofer-Linien (in nm)
133 lambda_f_lit = np.array([
134     393.37, # K
135     396.85, # H
136     430.79, # G
137     486.13, # F
138     516.73, # B4
139     527.04, # E
140     589.00, # D2
141     589.59, # D1
142     627.66, # a
143     656.28, # C
144 ], dtype=float)
145
146 # Wellenlängen und Unsicherheiten aus der Kalibration bestimmen
147 lambda_f = lambda_from_k(k_f, m, b) # in nm
148
149 # Fehlerfortpflanzung für lambda = m*k + b
150 sigma_lambda_f = np.sqrt((k_f * m_err)**2 + b_err**2 + (m * sigma_k)**2)
151
152 # Abweichungen von den Literaturwerten
153 delta_f = lambda_f_lit - lambda_f
154
155 print("\n--- Fraunhofer-Linien (aus Dial-Positionen) ---")
156 for name, k_val, lam_meas, lam_err, lam_lit, dlam in zip(
157     names_f, k_f, lambda_f, sigma_lambda_f, lambda_f_lit, delta_f):
158     print(
159         f"{name:3s}: k = {k_val:5.0f} +/- {sigma_k:.0f}, "
160         f"lambda_meas = {lam_meas:7.2f} +/- {lam_err:4.2f} nm, "
161         f"lambda_lit = {lam_lit:7.2f} nm, "
    
```

```

162     f"Delta = lambda_lit - lambda_meas = {dlam:6.2f} nm"
163 )
164
165
166
167
168 # ----- Peak plot for Fraunhofer F line from BMP -----
169
170 import os
171 import matplotlib.pyplot as plt
172 from scipy.optimize import curve_fit
173 from scipy.ndimage import gaussian_filter1d
174
175 # Pfad zur Fraunhofer-F-BMP-Datei (ggf. anpassen)
176 bmp_path = r"C:\Users\L-Vis\OneDrive\Desktop\Physik Lab\Spectroscopy
        II\frauhof__F.bmp"
177
178 # Bild einlesen
179 image = plt.imread(bmp_path)
180
181 # ----- 1) 1D-Spektrum aus Bild extrahieren -----
182
183 # Wir verwenden den grnen Kanal (oft bestes SNR im blau/grn-Bereich)
184 channel = 1 # 0 = rot, 1 = grn, 2 = blau
185
186 # Breiter Streifen -> weniger Rauschen
187 row_min, row_max = 150, 250
188 stripe = image[row_min:row_max, :, channel] # Ausschnitt (rows x cols)
189
190 # Mittelwert ber viele Zeilen -> 1D-Spektrum
191 spectrum_raw = stripe.mean(axis=0)
192
193 # Moderate Glttung
194 spectrum = gaussian_filter1d(spectrum_raw, sigma=1)
195
196 pixels = np.arange(spectrum.size)
197
198 # ----- 2) Pixel -> Wellenlnge mit Kalibration -----
199
200 B = m2 # aus Kalibration 2
201 pc = p_central # zentraler Pixel
    
```

```

202
203 # Dial-Wert k, bei dem DIESES Bild aufgenommen wurde (F-Linie)
204 k_image = 159.0
205
206 # allgemeine Kalibration: lambda(k,p) = m*k + b + (p - pc)/B
207 lambda_pixels = m * k_image + b + (pixels - pc) / B
208
209 print("lambda range from BMP: ", lambda_pixels.min(), "to",
        lambda_pixels.max(), "nm")
210
211 # ----- 3) Gaussian-Fit fr die F-Linie -----
212
213 def gauss_abs(x, A, x0, sigma, C):
214     """Gaussian absorption line on constant background: always a dip."""
215     return C - np.abs(A) * np.exp(-(x - x0)**2 / (2.0 * sigma**2))
216
217 def fit_line(x, y, x0_guess, window=1.0):
218     mask = (x > x0_guess - window) & (x < x0_guess + window)
219     x_fit = x[mask]
220     y_fit = y[mask]
221
222     if x_fit.size == 0:
223         raise ValueError(f"No data points found in window around {x0_guess} nm")
224
225     A0 = y_fit.max() - y_fit.min()
226     C0 = y_fit.max()
227     sigma0 = 0.2 # Startwert fr die Breite (in nm)
228     p0 = [A0, x0_guess, sigma0, C0]
229
230     popt, pcov = curve_fit(gauss_abs, x_fit, y_fit, p0=p0)
231     y_model = gauss_abs(x_fit, *popt)
232     return x_fit, y_model, popt
233
234 # Startwert aus deiner Tabelle (gemessene F-Wellenlnge)
235 lam_F_guess = 486.49 # nm
236
237 x_F, y_F, p_F = fit_line(lambda_pixels, spectrum, lam_F_guess, window=1.0)
238
239 print(f"F line fit center: {p_F[1]:.2f} nm")
240
241 # ----- 4) Plot erstellen und speichern -----

```

```
242
243 plt.figure(figsize=(6, 4))
244 plt.plot(lambda_pixels, spectrum, label="data")
245 plt.plot(x_F, y_F, label="fit F-line")
246
247 plt.xlabel("wavelength [nm]")
248 plt.ylabel("intensity (a.u.)")
249 plt.title("gaussian fit")
250 plt.legend()
251 plt.tight_layout()
252 plt.savefig("fraunhofer_F_gaussian_fit.png", dpi=300)
253 plt.show()
```