Experiment 16, Geometrische Optik

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Abstract

In this experiment the main goal is to measure optical instruments: the focal length of three different lenses and two wired nets. With those results, we're able to examine the correctness of Abbe's imaging theory.

Contents

1 Introduction

In general this section should tell the reader why he or she should be interested in your paper. Give some background to the experiment, and describe the underlying principles. This is typically where you provide references to previous publications [1, 2].

2 Experiment

2.1 Measuring converging lenses

2.1.1 Lens equation

To calculate the focal length f using the lens equation, we need to place an object, in our case a wired net, in front of a monochromatic LED light. The light then passes through the lens we want to measure and the image is projected on to a white screen. Now the goal is to adjust the position of the lens, so that the image is as sharp as possible. That gives us two distances: first a between object and lens, and then b between lens and image. We are then able to calculate the focal length using

$$f = \frac{ab}{a+b} \tag{1}$$

2.1.2 Bessel's Method

Now we want to use Bessel's method. Here we have to measure slightly different things. With the same setup, we take a fixed distance d between the object and the image. By varying the location of the lense in between, we are able to find two spots, where there is a sharp image, once magnified, once demagnified. We measure the distance e between those two positions. Then we calculate f using

$$f = \frac{d^2 - e^2}{4d} \tag{2}$$

2.2 Measuring diverging lenses

To measure the focal length of a diverging lens f_{div}, we have to set a converging one with focal length f_{conv} behind it (or in front). Then we measured the focal length f of the resulting lens system like before using the lens equation (1). We can now use the following equation to determine f_{div}:

$$\frac{1}{f} = \frac{1}{f_{div}} + \frac{1}{f_{conv}} \implies f_{div} = \frac{f_{conv} f}{f_{conv} - f} \tag{3}$$

2.3 Measuring wired nets

Here we want to measure the grating constant g of a wired net. To do that, we image the wired net to the screen using a lens with a known focal length. As in the beginning, we try to get the sharpest image possible by adjusting the position of the lens and get a and b like before. From that, we get the magnification scale $v = b/a$ We can then measure the grid width g' of the image, and calculate g by using this equation:

$$g = \frac{g'}{v} \tag{4}$$

Figure 1: In the figure caption you describe what is plotted in the figure. In this case: The measured data is depicted by the blue dots with error bars indicating the statistical error. The red line is a linear fit to the data.

2.4 Critical slit width

Abbe's image theory gives us a formula for the critical slit with $\tilde{d}$. We want to check the accuracy of said theory by measuring d ourself. To do this, we use the same setup as before, but now we put a vertical slit with variable width in the focal plane of the lens. We then close the slit, until the vertical bars in the image just disappear. In order to measure the width d of the slit, we do exactly the same thing as when we were measuring the wired nets.

3 Results

This paragraph is where you present the results from your experiment. This could be in the form of a table (if only very few parameters where measured) or as a figure. In the text you should essentially describe what can be seen in the figures, i.e. explain your axis and how the dependent variable changes as a function of the independent variable. Discuss trends of the data as well as the magnitude, origin and nature of the experimental uncertainties. Keep in mind that the measurement results are always correct! They might just not be the answer to the question you had in mind.

Depending on the experiment the discussion of the results can also be a part of the data analysis section.

4 Data analysis

In the data analysis section you describe the post processing of the data. How did you obtain the data that you plot in the figures? The raw data does not necessarily need to be presented in the report. An important part of this paragraph are the measurement uncertainties. You should provide the uncertainties of all experimental results, i.e. in the form of error bars. Further, you should explain the origin of these uncertainties.

There are many way how you can include equations and mathematical terms in your report. The easiest is to write them inside the text like this: $\Gamma = 1.5\,\mu\mathrm{m}\,\mathrm{s}^{-2}$. If you need to write a long equation, it is recommended to use e.g. the align environment.

$$\Gamma = \frac{a}{4\kappa} \times ... \tag{5}$$

All figures or tables that are part of your report have to be referenced somewhere in the text, ideally in order of their appearance ("as shown in Fig. 1"). Figures have to have axis labels with units and a sensible scale. If more than on data set is plotted you need to provide a legend. This may be a sentence in the caption ("red dots denote data measured with 1 mV, blue crosses were measured with 10 mV").

After you have presented the data you need to interpret it. To this end you want to discuss the theoretical model that describes your data and you will derive model parameters from your measurement data (i.e. by fitting it to the data). Here, you will again elaborate on the confidence interval of the derived values (error propagation). This is an important part of the report and it will be the basis for the next paragraph.

5 Discussion

So far you have discussed how you have obtained your data and the quantities you derived from it. In this section you should discuss the results in the context of physical laws. Depending on the experiment you want to compare your result and its uncertainty with the literature value. If you want to confirm a physical model that explains a certain phenomenon you want to assess if this model describes the data well within the confidence intervals, or whether a simpler model describes the data just as well.

6 Conclusion

In the concluding paragraph you summarize the result, with the emphasis on what you have discovered in this work. You can end this with an outlook on future research, i.e. how could the results be improved or what would be a logical follow up experiment.

7 Dos and Don'ts

- Be honest with yourself and with the reader. Try to find possible loopholes in your conclusion and explicitly mention them.
- Be aware that **scientific fraud** is an important topic that we (and the entire ETH) take very seriously. There are many forms of fraud, from copying text without referencing it to forging data. If unsure, ask your assistants about specific issues.
- Good writing is largely a question of practice and of experience. Why not read some scientific papers to study how professionals write? We are happy to recommend some literature.
- A good practice is to begin each paragraph with a 'topic sentence' that conveys the main message of the paragraph. As an example, the experimental section might start with "We performed experiments with a mechanical resonator inside a vacuum chamber." From this short sentence, the reader gathers immediately that the paragraph is about the experimental setup.
- Avoid using passive voice for extended paragraphs. The use of active language can make the text more interesting to read and is by default preferred by many English writers. For instance, instead of writing "The data points were measured over the course of 405 seconds", you can write "We measured data points over the course of 405 seconds" or simply "The data acquisition lasted 405 seconds". Of course, sometimes it may be better to use passive voice in order to describe basic processes, e.g. "Samples were cleaned for 3 minutes in acetone". The choice is yours - try out what fits better in specific cases.
- Write in short sentences. Always put clarity before artistic form. Whenever possible, avoid interrupting your sentences with brackets, formulas, or complex mathematical signs. Your text is much easier to read when you group such additional information at the end of a sentence, in a table, or in the caption of a figure. Remember that your readers might need their full attention for the physics involved (and do not want to decipher complex sentences).
- Avoid slang and terms that might not be known to the reader. One of the most difficult tasks is to explain something very complicated in simple terms that newspaper readers might understand. If you have to use specialized terms, try to explain them when they first appear.
- When you use abbreviations like 'AFM', make sure you use the full term once. "Nanoscale surfaces can be characterized with an atomic force microscope (AFM)."
- As a rule, use "cannot" instead of "can't", "will not" instead of "won't", "do not" instead of "don't" and so on (the title of this section is an exception).
- Graphs should not be overloaded with information. Make the essential features stand

out. Presenting scientific data is an art!

- Graphs should be drawn with the help of a software. In any case, graphs have to fulfill all relevant criteria of good scientific practice, such as well-scaled and labeled axes (including units), and the data points must be clearly visible and contain error bars where applicable.
- Fitting parameters only need to be provided for actual physical models, not for a "guide to the eye". Measured and derived values should be given with error bars (confidence intervals) and an appropriate number of significant digits.
- Figure captions are an important part of a figure. Ideally, a reader that is familiar with the field should understand your results by merely looking at your figures and reading the captions. Figure captions are an ideal place to give specific numbers that are not absolutely required in the main text (such as 'applied voltage' or 'laser power').
- The reports should be written with a text processing software (e.g. Latex).

References

[1] M. Sato, B. E. Hubbard, A. J. Sievers, B. Ilic, D. A. Czaplewski, and H.G. Craighead, Phys. Rev. Lett. **90**, 044102 (2003).

[2] M. C. Cross, A. Zumdieck, R. Lifshitz, and J. L. Rogers, Phys. Rev. Lett. **93**, 224101 (2004).