DIY Spectrometer

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ETH Zürich

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Outline

Guidelines for the summary

- Each person should write a summary of the experiment (2 summaries per group);
- It should contain a description of the experiment: the goal etc...
- Write it in English;
- 1 page maximum;
- Save it in PDF format;
- Don't copy, write it in your own words;
- It must be sent to me by email before the beginning of the lab at this email masgalli@phys.ethz.ch.

Manual and other links

Before the lab you need to read the manual carefully.

- This is the link to the Praktikum webpage, where you can find all the info about the course;
- Manual for the DIY Spectrometer.

Other useful links that you can also find on the manual:

- Youtube video that you can watch to have an idea on how to build the spectrometer;
- Paper to (maybe) take grating constant values.

  Problems in opening the paper?
  - You need to be connected with ETH network (either in person or use a VPN)
  - If you are redirected to another page, the problem is usually due to cookies that are not enabled in the browser: follow the instructions on the website.

The Material you need to prepare before the lab.

- Cardboard;
- CD-R that you don't need (NOT a DVD);
- scissors or cutter;
- ruler;
- razor blades;
- tape (preferably dark);
- a smartphone or camera;
- optional: laser pointer (useful for task 1).

Suggestion: As you can see from the manual or from the youtube video, you'll need to remove the reflective foil from the CD. I suggest you try to remove it before the lab session, because it may be difficult depending on the CD, and you may need to change it.

Plan for lab session

1. **Introduction**
   - Follow this short presentation;
2. **Summaries**
   - Send the summary to masgalli@phys.ethz.ch;
3. **Build the Spectrometer**
   - 1 breakout room for each group;
   - If member of the same group are not physically in the same room, you must build one spectrometer per person;
   - If in the same room you can build only one spectrometer per group.
   - Build the DIY spectrometer:
     - Use Manual directions;
     - Take pictures;
     - Write down the procedure you follow!
4. **Do the tasks**
   - There are 3 mandatory tasks + an optional one;
   - Write down measurements you get.

Zoom organisation

Zoom rooms

- Main zoom room for general announcements;
- I will assign group members to the same breakout room so that you can work together;
- If you get kicked out due to the change of room, please reconnect.

Communication

- I will come to your room regularly to check how it goes and whether you have questions;
- You can always ask for help (there is a button on Zoom called "Ask for Help") at any time if you have a question or need help.

Build the Spectrometer

Box

- Inside of the box should be non reflective and dark (plain cardboard is fine);
- Make sure that no light enter the box apart from the slit.

Slit

- The slit is made with the two razor blades, and attached to the tube with tape;
- The razor blades have to be parallel;
- The width of the slit should be of the order of 0.1 mm;
- *Suggestion: Build the slit using a piece of paper to separate the razor blades; in this way you can be sure that they are parallel and that the distance is small enough.*

Grating

- The CD without the foil acts as the grating;
- Make sure it's clean enough (you will see also from the quality of the pictures);
- Grooves in the CD should be parallel to the slit. *Hint:* the grooves in the CD are concentric.

You can start taking the first pictures!

The experiment is composed of 3 mandatory tasks and an optional one.

- **Task 1** - Measure the grating constant of the CD;
- **Task 2** - Calibration (measure d);
- **Task 3** - Measure the wavelenght from some other source of light;
- **Task 4** (*Optional*) - Fraunhofer lines.

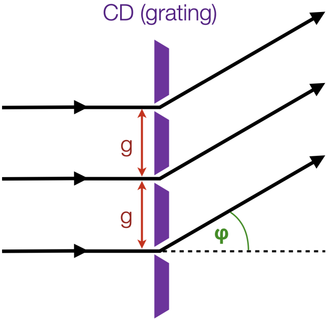
The first two tasks allow you to measure the features of your spectrometer; once that is done, you can point your spectrometer to every light source and measure the wavelengths of the components (Task 3).

Task 1 - Measure the grating constant of the CD

- The goal is to measure the grating constant of the CD;
- The formula useful to know for this task is:

$$p\lambda = gsin\phi \tag{1}$$

where p=1 is the order number, λ is the wavelenght, g is the grating constant and ϕ is the diffraction angle.



Task 1 - Measure the grating constant of the CD

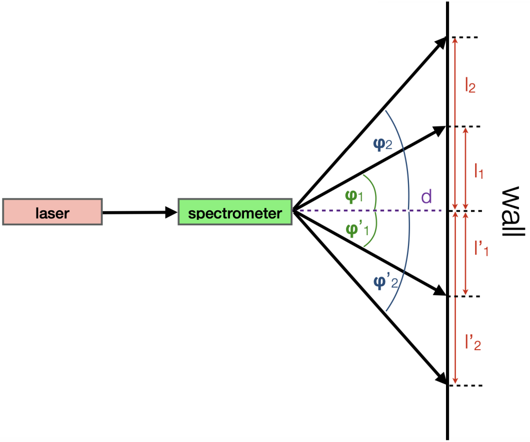
If we know λ, we still have two unknown variables in the equation: g and ϕ.

$$\lambda = gsin\phi$$

How to measure g? There are different ways, here some:

- With a laser pointer: you can measure ϕ as in the figure, then you can calculate g.
- If you don't have a laser pointer: depending on the features of your CD, you can find the grating constant from the table in the paper.

Suggestion: if you use the laser pointer, you might want to put a piece of paper on the wall in order to write down the position of the light and then measure it with the ruler.



Task 2 - Calibration

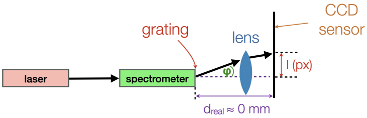
Calibrating the spectrometer means to measure the distance between the grating and the sensor of the camera. It is not a distance you can measure directly, so you need to find a way to calculate it.

Knowing λ we have two unknown variables in the equation: g and ϕ. You measured g from Task 1, so you only miss ϕ.

$$\lambda = g sin\phi$$

How to measure d?

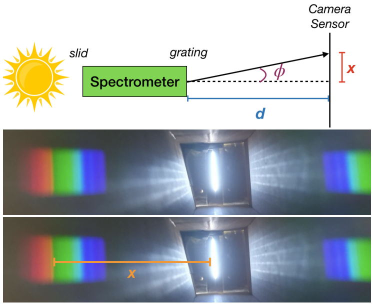
- You can use again the laser pointer (scheme on the right);
- Or you can use the sunlight spectrum (next slide).



Note: since only ratios are involved, you don't necessarily need to convert from pixels to mm.

How do we measure d from the sunlight spectrum?

$$\lambda = gsin\phi$$



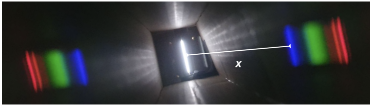
- Take a picture of what you see in the spectrometer if you point it to the sunlight;
- Measure the distance x (in pixels) between the slit and the color line you decided to measure (choose a narrow color band, like cyan or orange);
- To measure you need to analyse the picture on your computer (PowerPoint or any image processor);
- How to estimate the **uncertainty** on x? Go to Section 3 of these slides;
- You can keep all your measurements in pixels, OR you can convert them in mm (but be careful with the uncertainties!);
- Now that you measured x, you can calculate d as a function of λ, x, g! Remember to propagate the uncertainties!

Task 3 - Take Pictures of different light sources

Now your spectrometer is completely calibrated: you know both its grating constant g and the effective distance d.
It's now time to use it for its purpose: **measure some wavelenghts**!

Take pictures of different light sources and see what you find.

- Take pictures of the white light on your laptop, what do you see?
- Let's use again the equation $\lambda = gsin\phi$. Measure the x in pixels for blue (or another color) and calculate λ (with its uncertainty). Now compare it with the actual wavelenght of λ_{blue}.
- Take pictures of other light sources and/or from different colors (see this website).



Task 4 - Fraunhofer Lines

This is an optional task: not everyone can see the Fraunhofer lines, because of the camera or the spectrometer.

- Can you see the Fraunhofer lines?
- Can you measure the corresponding wavelenght of some of them?

Do you have another idea that you want to try?
Do it and document it in the report!

Report

You need to write a report of the experiment.
Only 1 report per group is required.

General content of the report:

- Descriptions of the experimental setup (two if you are NOT in the same room)
- Measurement (two if you are NOT in the same room)
- Analysis of the measurements.

Requirements:

- See minimal requirements here
  - Units
  - Meaningful number of significant digits
  - Measurement uncertainties, error propagation
  - Explain your data analysis and error calculations
- The report must written in English
- The report must NOT be hand-written. You can use a Word Processor or try Latex! (you can use Overleaf) Send the report as a PDF.
- Send me the report by email at masgalli@phys.ethz.ch before next Tuesday noon (12:00 am).

Some guidelines:

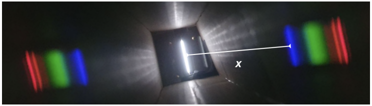
- Introduction with a brief theoretical discussion about the experiment (see also manual of experiment 15) ;
- Write clearly your measurements and their uncertainties: How did you measure it? How did you find the associated uncertainty? Which numbers have you measured?
- When you do calculations, all the formulas you use have to be written in the report, explaining what you are doing. The numbers should be put only at the end!
- When you calculate a variabile, you need to propagate the uncertainty. Use the guidelines in Section 3 of these slides. Write the final formula of your propagation on the report!
- Always remember to write the units.
- Write the bibliography. Where have you taken the g value? Where do the concepts of the introduction come from? etc...

Report - self evaluation

DIY Spectrometer - self-feedback table			
	Levels of performance		
	very good	**good**	**insufficient**
Experiment	I built a working spectrometer; I did the three mandatory tasks plus I also added something that was optional (some more light sources, another way of computing task1 etc...)	I built a working spectrometer and I did the three mandatory tasks	I built a spectrometer and I didn't do all the mandatory tasks
Measurements and calculations	I took required measurements with their uncertainties, and I explained explicitly how I did that in the report; I calculated the required values and propagated their uncertainty correctly, writing in the report explicit formulas and final values.	I took required measurements with their uncertainties; I calculated the required values and propagated their uncertainty correctly. In the report I only wrote final values with the uncertainties, without explaining how I did things and the formulas I used.	I took required measurements and calculated the required values, without taking into account the uncertainties.
Report	The report is divided in useful sections; There is a nice theoretical introduction; All the measurements and their uncertainties are clearly written either in a table or in text in the report; All the used formulas are present and quoted in the text; All the units are written explicitly next to all the numbers I write; There are images of the work done.	The report is divided in useful sections; Measurements and their uncertainties are clearly written; All the used formulas are present and quoted in the text; All the units are written explicitly next to all the numbers I write.	The report is divided in confusing sections; Measurements and their uncertainties are not clearly written, and difficult to find; Some values comes without the units.
Formal issues (spelling errors, references, number of pages, overall impression)	Good general impression; Almost no spelling mistake; Bibliography	Correct general impression; some spelling mistakes; no Bibliography	Sloppy general impression with no bibliography.

Uncertainty on a single measurement

In our experiment, we measure distances in pixels. For example (in figure) you want to measure the distance between the slit and the blue band of the RGB spectrum. The blue band is thicker than 1 pixel, than you want to estimate an uncertainty that takes that into account. For example, if the distance x is between 200px and 220px, the result will be $x = 210px \pm 10px$.



Linear uncertainty propagation

In order to estimate the uncertainty on $y = f(x_1, ..., x_n)$, depending on the independent quantities $x_1, ..., x_n$ having uncertainties $\Delta x_1, ..., \Delta x_n$.
The linear uncertainty propagation formula is:

$$\Delta y = \sqrt{\sum_{i=1}^{n} \left(\frac{\partial f}{\partial x_i}\right)^2 (\Delta x_i)^2} \tag{2}$$

We measure $x = x_0 \pm \Delta x$, and $\Delta x \ll x_0$.

Question. What is the uncertainty on x^2?

a) $\Delta\left(x^2\right) = \Delta x$

b) $\Delta\left(x^2\right) = (\Delta x)^2$

c) $\Delta\left(x^2\right) = 2x_0\Delta x$

d) I don't know

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Standard Error of the Mean

You don't need this for the experiment, just for your knowledge...

We measure $N = 20$ times the same quantity x (e.g. the period of the pendulum) of (unknown!) mean μ and standard deviation σ in the same experimental conditions (e.g. the length of the pendulum does NOT change). We have a series of measurements $x_1, x_2, ..., x_N$ with empirical mean $\bar{x}$ and standard deviation s.

Recall that:

- $\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i$
- $s = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2}$

Question 1. What is the uncertainty on $\bar{x}$?

a) s at 68% CL (confidence level)

b) $2s$ at 95% CL

c) $s/\sqrt{N}$ at 68% CL

d) $2s/\sqrt{N}$ at 95% CL

e) I don't know