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How to write a Laboratory Report

An unofficial guide on writing lab reports

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Abstract

This is an unofficial guide on writing laboratory reports. The most fundamental points are described and motivated. The guide is intended for students and supervisors alike. For students, it explains in a compact fashion how to write a laboratory report. For supervisors, it acts as a common benchmark that lab reports should meet and students can be referenced to.

Tip

The abstract concisely summarizes the laboratory report. It provides i) the context, ii) the aims, iii) the used methods, iv) the results, and v) the conclusion. Even though it appears as the first section of the report, it is usually written last as it is based on all the other sections.

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1. Introduction

Writing a laboratory report is the final part of an experiment. This means you already proved your proficiency in the theoretical aspects of the experiment and measured data. Now, you are left to analyze the data and summarize all previous steps in a clear and concise manner.

This guide provides fundamental knowledge about how to write a laboratory report. It is by no means complete but intends to give a brief overlook of the most important points.

First, the main structure (Sec. 2) is described. Then the fundamental topics citing (Sec. 3), values (Sec. 4), formulas (Sec. 5), plots and graphic representations (Sec. 6), as well as tables (Sec. 7) are introduced. Next the analysis (Sec. 8) in general and handing in your report (Sec. 9) are explained.

The guide uses three kinds of tip boxes. They are shown at the bottom of the page together with their respective explanations.

In addition to this guide, a checklist for the bare minimum requirements can be found here and the official short guide of the practical course B is available in German[1] and in English[2]. In general, the websites of the practical course are good contact points for further information. Different versions exist for the practical course A, practical course B and practical course M.

This version of the guide is neither complete nor perfect. If you have any feedback or would like to see sections added to this guide, please contact the authors under `bonah@ph1.uni-koeln.de`.

Tip

The Tip boxes provide additional tips.

Pro Tip

The Pro Tip boxes provide tips that make the report immaculate, in particular, you are welcome to use them in your bachelor thesis.

Latex Tip

The Latex Tip boxes provide tips concerning LaTeX. Please note, that it is not obligatory to use LaTeX for the report. However, LaTeX is one of the most popular tools for creating scientific documents and therefore certain tips are included to give you a little headstart.

[1] Visit `https://physik.uni-koeln.de/fileadmin/Downloads/praktikum/BP_Merkblatt_DE.pdf`
[2] Visit `https://physik.uni-koeln.de/fileadmin/Downloads/praktikum/BP_Merkblatt_EN.pdf`

2. Structure

The structure of a laboratory report can vary depending on the performed experiment and the main emphasis of the experiment. This said, each laboratory report should consist of i) a title page, ii) an introduction, iii) theoretical considerations, iv) a description of the experimental setup, v) a description of the experimental procedure, vi) the analysis and results, vii) a discussion, and viii) a conclusion. To help the reader navigate your document, it is advisable to clearly lay out the structure in a table of contents and in writing (e.g. in the introduction). Especially the latter allows you to motivate your structure.

In the following, the mentioned sections are explained in greater detail.

The **title page** or cover sheet is the first page and provides the reader with the fundamental information about the report. This information should include i) the type of document (laboratory report), ii) title and identifier of the experiment, iii) names and matriculation numbers of the students, iv) name of the assistant, v) name of university and institute, and vi) date of the report.

> **Pro Tip**
> To make the title page visually interesting, a graphic illustrating the performed experiment or the logo of the university (can be found here as of January 2022) can be added.

The **introduction** should explain the purpose of the experiment and provide some basic physical context. This includes inter alia historic predecessors, prices won by the author for the experiment, and important findings based on the experiment.

The **theoretical considerations** summarize important theory for the experiment. This should be done in such a way, that also readers unfamiliar with the experiment can understand its fundamental principle. In particular, all formulas used in the later sections of the report should be introduced here.

The **experimental setup** section describes the experiment and how the components work together. In addition to text, a sketch or schematic view should be provided.

> **Tip**
> In the optimal case, the sketch or schematic view of the experimental setup is created by the authors of the report themselves. However, it can also be copied from the respective manual or another source. In the latter case it is essential to cite the original source (see Sec. 3).

The **experimental procedure** section describes how the experiment was performed and which data was obtained.

The **analysis and results** section explains how the results were obtained from the raw data and presents the results.

The **discussion and conclusion** section assesses the results and compares them to previous findings (especially unexpected findings should be explained here). Additionally, the success of the experiment is evaluated and possible improvements are presented. If questions were presented in the introduction they should be answered here.

Tip

The goal of a laboratory report is to clearly describe the performed experiment, its results, and its implications. It should be understood as a measure to share science rather than a literary masterpiece. Structures and phrases familiar to the reader should be used instead of reinventing the wheel (consider e.g. the commonly used phrase "The null hypothesis was rejected").

Latex Tip

When you refer to sections, tables, equations, or figures of your report, reference them correctly with the *ref* or *autoref* command, with the latter requiring the *href* package. This allows the reader to find them unambiguously and quickly (e.g. this chapter would be referenced as Sec. 2).

3. Citing

Many statements in your laboratory report are not discovered by you but are already well known and published, e.g. the theory section and the experimental setup. Therefore, your laboratory reports will often contain the work of other authors. This work can appear in a multitude of forms with some of them being knowledge, proofs of your own statements, text, graphics, or programs. The usage has to be credited by citing the original work of the author. The original work once again can have multiple forms, e.g. a published article, a book, or a website. Different citation styles are commonly used. For the laboratory course, no specific citation style is mandatory. However, a consistent citation style should be chosen for the whole report.

Examples can be seen in the two following sentences: Stephen Hawking gives his view on 12 fundamental questions of physics and mankind in "A brief History of Time" [1]. Rotational constants for the molecules were taken from the Cologne Database for Molecular Spectroscopy [2, 3].

Make sure to cite all sources as this can otherwise be seen as a plagiarism attempt. The same applies to copying text from older laboratory reports. Such behavior will not be tolerated and can lead to immediate exclusion from the laboratory course.

Prefer paraphrasing sources over directly quoting whole passages in the theoretical considerations section. Also, provide sources for all other resources that are not your own work (e.g. graphs or images).

Tip

Many publishers of scientific journals allow to easily create different formats of citation on their websites. For websites, many web browsers support add-ons that allow creation of a citation entry for the current website.

Latex Tip

In LaTeX different packages are available to create the bibliography. Here the package *natbib* is used. The citations are copied in BibTeX format to a **.bib* file. Each entry has an identifier that then can be referenced with the *cite* command in the text.

4. Values

This chapter explains how to specify values. It is a condensed version of extracts from Ref. [4]. A value consists of a number, an unit, and sometimes an uncertainty. Quantity symbols are written in italic type while the number and unity are written in roman type. The value and unit are separated by a space. The exemplary quantity A would be written as

$$A = 100\,\mathrm{m} \tag{4.1}$$

Now an uncertainty of 1 m is added to the value. Two prevalent styles exist, however, the choice should be consistent throughout the document. The two styles are

$$A = 100(1)\,\mathrm{m} \tag{4.2}$$
$$= (100 \pm 1)\,\mathrm{m} \tag{4.3}$$

Additionally, make sure to choose a sensible number of significant digits. Different recommendations exist, with the most prevalent ones ranging from 1 to 3 digits. A single significant digit suffers from rounding, as e.g. both $\Delta A = 0.5102\,\mathrm{m}$ and $\Delta A = 1.4987\,\mathrm{m}$ would result in $A = 100(1)\,\mathrm{m}$. On the other hand, each additional significant digit makes the quantity harder to read. So consider, what kind of precision you need, as the maximum possible relative rounding error for one, two, or three significant digits is about 100 %, 5 %, or 0.05 %, respectively.

Constants, chemical elements, and defined functions or operators are written in roman type. Subscript and superscript appear in roman or italic type. Roman type is applied for descriptive sub- and superscripts (e.g. the density of oil ρ_{oil}) but italic type if a quantity is represented (e.g. for running numbers $\sum_i x_i$).

Latex Tip

Use the LaTeX package *siunitx* for values. It was used to produce the here shown examples and makes it easy to correctly display values and ranges.

5. Formulas

Formulas are a fundamental way of concisely formulating physical knowledge. This chapter will provide some tips to create well-looking equations. Also see Sec. 4 for tips on values in your formulas. In the following, first, a bad example and then a good example are shown. The bad example contains some frequently encountered mistakes

$$E_n^{\pm} = 1/2 * hbar(\pm\sqrt{\delta^2 + \Omega_n^2} - \delta) + ((n+1)\hbar\omega_d \tag{5.1}$$

Multiple things can be improved. Going from left to right, the factor $1/2$ is hard to read, especially in combination with the star symbol for multiplication (use $a \cdot b$ instead of $a * b$). Next, a typo causes $\hbar$ to be $hbar$. The first pair of brackets are too small for the content, making it difficult to see which brackets form a pair. The second pair of brackets is actually a triplet, with one opening bracket never being closed. Improving all these points results in the following formula

$$E_n^{\pm} = \frac{1}{2}\hbar\left(\pm\sqrt{\delta^2 + \Omega_n^2} - \delta\right) + (n+1)\hbar\omega_{\mathrm{d}} \tag{5.2}$$

The difference in appearance between the two formulas should be clearly visible. Therefore, always carefully check your formulas for easily avoidable mistakes.

Pro Tip

Bonus points are rewarded for everyone who spotted, that the subscript of ω_{d} changed from italic type in Equ. 5.1 to roman type in Equ. 5.2. The reason being, that d stands for *driving field* and therefore is descriptive (compare Sec. 4).

Latex Tip

The second formula uses *\left(* and *\right)* instead of *(* and *)* to create brackets that match their content. The equal signs are aligned by using the *align* environment and the text in between is added as *intertext*. See the source code of this guide for more information.

6. Plots and graphic Representations

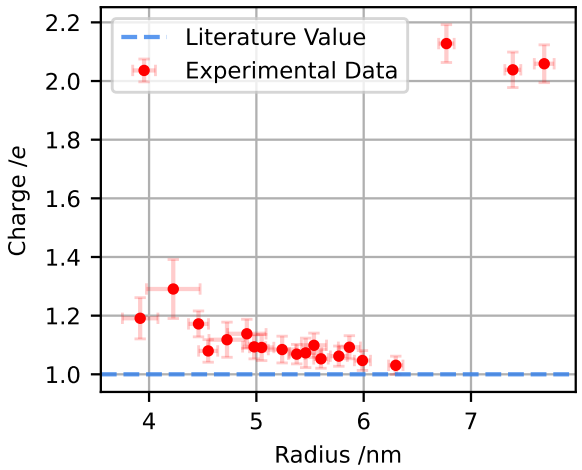
Plots and graphic representations can present data in a more pleasing and digestible manner than text. Therefore, they should be used in addition to text when suited. All figures should have a caption and a label below the figure. The caption describes what is presented in the figure and what its purpose is. The label allows to easily reference the figure. Every figure should be referenced in the text at least once with its content, message, and connection to the text being explained. Make sure to reference the label of the figure, as it is not sufficient to reference a figure as e.g. *the next figure* or *the figure on the left*. Such a reference is less precise and the relative positioning of the text to the figure might change.

Use suitable units (e.g. 12 nm instead of 0.000 000 012 m) for the values and always label your axes. All text should be clearly visible without the need to zoom into the PDF. When using colors, make sure that they are easily distinguishable and are used consistently throughout the report.

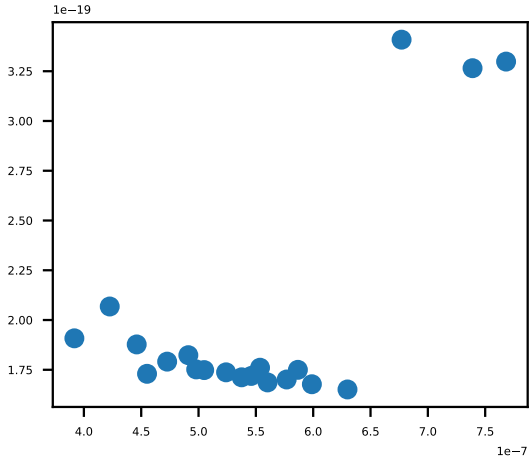
The here mentioned points are highlighted in Fig. 6.1. The good example in Fig. 6.1a and the bad example in Fig. 6.1b show the same data. In the bad example, it is unclear, what the figure shows as the axes are not labeled and the text is too small to read easily. Furthermore, the data points are hard to distinguish and have no error bars. Due to labeled axes and the legend, it is immediately clear what is shown in the good example. Additionally, its caption describes the content of the figure and the implications of the two distinct groups.

To summarize, the improvements of the good plot are:

- The font is easily readable as it is sized sensibly
- The axes are labeled with the quantity and the corresponding unit
- The ticks on the axes are given in sensible units and distances (as in this example the quantization is of interest, the good plot displays the charge in units of the elementary charge e)
- The data is plotted with uncertainties
- The literature value is plotted as a reference and is clearly distinguishable from the data
- The caption describes the figure and highlights key points
- The view area is chosen sensibly, meaning there is a small margin between the borders of the plot and the data. In other instances it is important to include special coordinates outside the data range, e.g., often the intersection between a trend line and the x- or y-axis has physical meaning



(a) The charge in units of e against the radius. Clearly two distinct groups of charges are visible, hinting at quantization.



(b) The charge and radius

Figure 6.1: Comparison of a good (left) and bad (right) plot. The good plots labeled axes, legend, and caption make clear what is shown and what the figure implies.

Latex Tip

Figures are added with the *figure* environment. Different packages are available for including different formats (here the *graphicx* and *pdfpages* packages are used). To create figures consisting of multiple subfigures (e.g. Fig. 6.1) the *subfigure* package is used.

7. Tables

Tables allow presenting data in a concise and clear manner. All tables should have a caption and a label. The caption and label are placed above the table (in contrast to figures where they are placed below). The reasoning behind this is, that tables can span across multiple pages and therefore it is important that the caption and label are at the beginning of the table. Use the label to reference your table at least once from the text. The table itself begins with one or more header rows which describe the columns concisely. The header is followed by the data and sometimes one or more summary rows below the data. No vertical lines should be used and horizontal lines should only be used to separate sections of the table not lines in the same section. Concerning the data in your table, values that are constant across the whole table can usually be neglected from the table and mentioned in the caption. Units should be mentioned in the column header and not in every field. Also, be consistent with the number of significant digits for values and uncertainties. Text is left-aligned while numbers are right-aligned.

Pro Tip

To go the extra step, align numbers at the decimal sign, making it easy to quickly compare their magnitudes.

Tab. 7.1 is a good example and Tab. 7.2 is a bad example. Tab. 7.1 allows the reader to quickly understand the presented data. The alignment of the numbers at the decimal sign allows to get an immediate idea of the different magnitudes. Additionally, the last row summarizes the data by providing the total weight and price of the new hypothetical experiment. The buyer, which is the same for all materials, is given in the caption rather than in its own column. In contrast Tab. 7.2 is difficult to read and it takes more time to understand the presented data. The header is not distinguishable from the data and numbers are not aligned, making it difficult to compare them. Additionally, a concise caption and uncertainties are missing.

Table 7.1: Material usage and cost for a hypothetical new experiment. All materials were bought by the PH1 institute and prices were rounded off.

Material	ρ [kg/m^3]	Price/kg [USD]	m [kg]	Price [USD]
Water	997.12(22)	0.29	109.97(20)	31.89
Iron	7874.45(23)	33.10	234.23(20)	7753.01
Gold	19 317.39(97)	51 371.11	1.43(20)	73 460.68
Total			345.63(60)	81 245.58

Table 7.2: Prices of experiment

Name	ρ	Price	Amount	Price	Buyer
Water	997.121	0.29	109.971	31.891	PH1 Institute
Iron	7874.4	33.1	234.2	7753.0	PH1 Institute
Gold	19317.39112	51371.11232	1.43239911	73460	PH1 Institute

Latex Tip

Use the S column specifier from the *siunitx* package to align numerical values at the decimal sign. The *booktabs* package allows to easily add horizontal lines.

8. Analysis

The analysis is the central part of the report. Here, the already measured data is evaluated and new values and results are determined. Therefore, it is especially important that this section is as clear and understandable as possible. It is important to provide all used values. E.g. it is a good habit to tabulate all constant values and their uncertainties at the beginning of the analysis or in the experimental procedure section. Furthermore, the measurement data should be provided in the analysis chapter or (especially for large data sets) in the appendix and be referenced in the analysis section. Making the used data accessible is fundamental for any scientific report and allows the reader to validate the analysis. Then the steps of the analysis should be described. For this, the theoretical considerations should be used and referenced. Important (intermediate) results should be visualized.

One major part of the analysis will be uncertainties and error propagation. Each measured quantity has an intrinsic uncertainty. When new values are derived from these measured quantities, also the new value will have an uncertainty. If not otherwise specified, the Gaussian error propagation is used in the laboratory courses. There are two prevalent formulas for Gaussian error propagation, one for correlated and one for uncorrelated quantities. If you use the formula for uncorrelated quantities make sure, that your quantities are actually uncorrelated.

> **Tip**
> A plethora of very good guides on error propagation exist online. There is also a short guide for the laboratory course A (under this link) which is unfortunately only available in German.

The formula for uncertainties of a quantity depending on multiple correlated quantities usually results in very cumbersome formulas. Therefore in certain special cases, it might be justifiable to neglect certain correlations, however, this has to be indicated in the text. For cases where the correlations can not be neglected, it is recommended to use software solutions that help to take the correlation into account.

> **Tip**
> Two popular software options for error propagation are the uncertainties library for Python and the measurements library for Julia. When using any such software, note the usage in the text and add the script to the appendix or as a separate file.

9. Handing in your Report

When you have written the last sentence of your report you are not quite there. First, every group member should read it again and make sure that there are no more mistakes and all the here mentioned points are followed. After you have ensured all this, send the final version as a PDF to your assistant.

Your assistant will correct your report and send you an annotated version with shortcomings that have to be improved. If anything is unclear or you feel that there is a misunderstanding, it is recommended to contact your assistant instead of guessing what is wrong.

The progression of each experiment is documented in the laboratory course database[1]. There you can check the dates of the experiment and the corrections to make sure you meet the deadlines. When the report meets all requirements, the database entry shows ET for *Endtestat*. Congratulations, you successfully completed your report!

Tip

Make sure to meet the deadline for handing in your report. The deadline for the report is three weeks. Then your assistant has three weeks to correct the report and send the feedback back to you. Each of the following corrections has a deadline of one week for both sides. Be aware that the deadlines also apply to the lecture-free time. Should you not be able to meet the deadline, notify your assistant ahead of time and ask for an extension. If your assistant does not meet their deadline, you may inform the corresponding coordinator of the laboratory course.

[1] Visit `https://lecture.ph1.uni-koeln.de:8080`

References

[1] S. Hawking, M. Jackson, A Brief history of Time, Scientific American Modern Classics, 2004.

[2] C. P. Endres, S. Schlemmer, P. Schilke, J. Stutzki, H. S. Müller, The Cologne Database for Molecular Spectroscopy, CDMS, in the Virtual Atomic and Molecular Data Centre, VAMDC, J. Mol. Spectrosc. 327 (2016) 95–104. doi:10.1016/j.jms.2016.03.005.

[3] H. S. Müller, F. Schlöder, J. Stutzki, G. Winnewisser, The Cologne Database for Molecular Spectroscopy, CDMS: a useful tool for astronomers and spectroscopists, Journal of Molecular Structure 742 (2005) 215–227. doi:10.1016/j.molstruc.2005.01.027.

[4] A. Thompson, B. Taylor, Guide for the Use of the International System of Units (SI), special publication 811, National Institute of Standards and Technology, US Department of Commerce (2008).