General Remarks on the Module Introductory Laboratory Course Physics and on the Preparation of Reports

1 Meaning, Planning, and Performance of Physical Experiments

On March 23, 1989, news from the USA caused a sensation among the scientific community[1]: two internationally renowned scientists working in the field of Physical Chemistry at the University of Utah announced to the world press that they had successfully performed "cold fusion" in a test tube. No other laboratory worldwide had been able to achieve this although billions had been invested for that purpose. Controlled nuclear fusion, with the aim to produce energy, was now said to be possible with means that were available in every small laboratory.

Immediately, feverish activities started all over the world aiming to repeat the described experiment. The involved scientists used international computer networks to exchange their measuring results, to discuss related theories, speculate, to pursue the sources of rumours, and - unfortunately also - to start new rumours.

In the weeks following their discovery, the international experts came to the conclusion that the results of the test tube experiment were not reproducible. The experiment, as well as the theories, which the two Americans had developed to analyse their results were of no use.

The above-mentioned example emphasizes the fundamental conditions of physical experiments:

The results of an experiment are only scientifically significant, if the experiment can be repeated under equal conditions and yield the same results anywhere in the world.

In order to meet these requirements, the *object* of an experiment must be described and defined clearly. Some experiments are performed to clarify whether a theory (e.g. that of ”cold fusion“ or the existence of gravitational waves) is correct or incorrect. Other experiments serve the purpose of quantitatively determining the algebraic relationship between physical dimensions (e.g. Galileo's experiments on the relationship between distance and time in the free fall) or numerical values for physical dimensions (e.g. determining the mass of a molecule using a mass spectrometer).

A description of the object in the experiment is followed by a careful *planning* of the performance of experiments which means the concept of a systematic experimental procedure, choosing suitable measuring instruments, and getting to know the behaviour of those instruments under the scheduled experimental conditions.[2] This is followed by the *set-up* of the experiment, the precise *description* of the experimental set-up, the *performance* of the measurements, and the *recording* of the measured data as well as ambient parameters which may influence the measured data. It is important to eliminate sources of systematic errors to the best of one's knowledge and to quantitatively determine accidental fluctuations of the measured data (cf. instructions for the experiment "*Error theory and regression analysis*“).

The quantitative *analysis* of an experiment performed under such conditions should yield a definite and reproducible solution to the initial questions. However, if there are no clear and reproducible results, all steps from the formulation of questions to the analysis have to be checked again. This means an error has occurred somewhere which has to be eliminated. For example, an unsuitable measuring instrument is used whose measuring accuracy or measuring range is insufficient for the expected effect. Despite meticulous care a systematic error may have crept in during the recording of measured data, or it was attempted to establish a quantitative correlation between two uncorrelated physical quantities. An experiment of this kind will always yield a random distribution of measured values. Or...

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1 https://www.spiegel.de/spiegel/print/d-13495799.html (06.09.2019)

2 The negligence of the two American scientists resulted in the fact that the measured effects, which actually had been caused by heating of the investigated object, being falsely attributed to the influence of neutrons.

2 Educational Objectives of the Introductory Laboratory Course

In order to plan, perform and analyse experiments in the described manner, some experience is required which will be gained during the different successive lab courses during years of study. The introductory lab course serves to convey and allow for the practice of the fundamentals of experimental work. Following successful participation in introductory lab courses the students should know the basic principles for conducting laboratory experiments, thus:

- know how to determine the quantitative relationship between physical parameters and how the value of a physical parameter can be achieved by an experiment
- be able to describe, plan, and perform an experiment
- know the difference between direct and indirect measuring methods
- be familiar with modern measuring methods as well as the function, handling, behaviour and precision of important measuring instruments
- be able to test, adjust and calibrate measuring instruments
- know the basic principles of computerized measuring data acquisition
- be able to appropriately present, analyse, interpret and critically evaluate measured data
- be able to quantify uncertainties of measurements and know the basics of error theory
- know procedures for adjusting fit curves to measured data
- be able to write a report on the performance of an experiment
- be able to give a presentation on the results of an experiment.

Furthermore, the students will be acquainted with other physical phenomena, laws, and methods during the lab course, which cannot be dealt with in lectures due to lack of time. Students may also encounter subjects within the frame of the lab course which were not and will not be covered in the lectures. Therefore, the experimental instructions are given in a way that students with a general knowledge of math and physics in their first two semesters can understand them. However, the instructions may at times be too abstract and the diagrams of the experimental set-ups may prove helpful when preparing for the laboratory course. The diagrams can be found on the webpage of the introductory laboratory course[3]. If there is a common topic between lecture and lab, they will be synchronised as far as possible.

3 Performance of Laboratory Courses

3.1 Group Work

In the beginning of the semester the students form pairs (*teams*) and remain in these groups throughout the semester. These teams *prepare* their lab course *together*, *perform* the experiments *together*, *analyse* their measuring results *together*, and *keep* the records *together*. *Both* students are responsible for *every* part of the report. As a rule, the preparation, the execution and the report are given a common mark.

3.2 Preparing the Experiment

Prior to the laboratory course, the experiments are prepared according to the instruction and by participation in the accompanying seminar. The instructions are distributed to the students normally within the first two weeks of the course. They are additionally available as a PDF file on the internet pages of the laboratory course. It may not always be sufficient to simply read the chapters, especially in case of serious difficulties it is necessary to read the cited literature as well as the lecture notes. It is also advisable and helpful to meet your team partner before and after each experiment for common preparations and discussions.

It is neither useful nor possible to perform the experiments without thorough preparation.

A *selection of books* is available to the students in the lab rooms. The books are not issued on principle. However, they may be used in the lab rooms whenever the room is available. The selection of books also contains other textbooks, selections of equations, and tabular works, which are helpful in evaluating the experiments.
A thorough preparation also includes the *preparation of tables*, in which measured data are entered during the lab course, is done with a pen accepted for use on official documents.

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[3] https://uol.de/en/physics/laboratory-courses/basic-laboratory-course

The prepared tables are stamped by the supervisors at the beginning of the laboratory course and are to be included in the report later on.[4]

By preparing tables for the values to be measured students get a clear survey of the measurements to be performed and of the quantities additionally required for the analysis of the experiments. Furthermore, the preparation of tables helps avoid the measured data being noted down on slips of paper, to be transferred to a “good” copy later on. This procedure is uneconomical, and risks the transformation of errors, and possibly tempts students to subsequently “adjust” measured data. Besides these, it is also advisable to mark relevant information for performing the experiment and important physical formulas in the script or add them to the sheet of paper where your tables are.

Economical work during the preparation, performance, and analysis of experiments requires the students to be provided with the following *auxiliary material*:

Experimental instruction, textbooks, collection of mathematical equations, pocket calculator with scientific and engineering functions, and access to computers (which is ensured for every student during the introductory laboratory course and in the CIP cluster room of the Institute of Physics).

3.3 Performing the Experiment

During the experiment the measuring results are to be entered directly into the prepared data tables. The measuring accuracy of each instrument must be noted for the subsequent error analysis. Finally, all of the specifications of an instrument and other parameters (e.g. ambient temperature) which are required for a complete documentation and analysis of the experiments must be noted.

The extent of the experiments has been chosen so that students who may already have some experimental experience have not finished their experiments after half of the scheduled period of time. This would lead to other students without any experimental experience not always being able to perform all parts of the experiments, particularly in the beginning of the course. What matters in such cases is

Perform some parts of the experiments thoroughly rather than all parts superficially in the case of lack of time! Benefit from the Open Lab to extend your experimental skills independently!

4 Reports

4.1 Importance of Reports

The experimental report has the purpose of documenting the entire experiment, from the formulation of questions and performance until the analysis. It must be *uniform*. Any person who is familiar with the subject must be able to read and understand the report and it should enable that person to repeat the experiment with the same instruments at any time without requiring any additional information.

Reports are not only written as an “annoying duty” during laboratory courses. Writing and filing a report book rather is an indispensable part of the daily routine in scientific work. In case of doubt a report book serves as a supporting document to prove measuring results. The forgery scandals in science, e.g. the case of the physicist JAN HENDRIK SCHÖN in 2002 [5] have led scientific organizations, like the German Science Foundation (DFG), to emphatically remind scientists of their duty to write report books and of the importance of report books [6].

[4] No data tables are required for the experiments in the chapters “Oscilloscope”, “Data Acquisition and Processing with the PC”, and “Fourier Analysis”. This also applies for any measurements where the resulting data are to be entered directly into `Origin`-tables.

[5] See e.g. S. Jorda, PHYSIK JOURNAL 1.11 (2002) 7-8.

[6] DFG: “Vorschläge zur Sicherung guter wissenschaftlicher Praxis“ (“How to secure good scientific practice”), Bonn, 2013 (supplemented edition) (http://www.dfg.de/download/pdf/dfg_im_profil/reden_stellungnahmen/download/empfehlung_wiss_praxis_1310.pdf) .

4.2 Contents and Structure of a Report

A report must contain

- in *clear structure*
- with *numbered chapter headings*
- on *numbered pages*

the following details:

1. *Names*, *working group*, and *date* of the laboratory course.
2. *Title* of the laboratory course.
3. A *table of contents* is not required.
4. An *Introduction*, describing briefly the *aim* of the *experiment* and the quantities to be measured. This part of the report should not exceed ¼ page.

The introduction is followed by logging each (sub-)experiment according to points 5 - 10:

5. A brief description of the *experimental procedure,* and the *set-up* in the form of a sketch including a short explanation. Sketches can also be taken from the reader, or from other sources. In this case, the sources have to be cited correctly, cf. chapter 4.3. All sketches must be numbered and labelled (see 8.). Example:
   "Fig. xx: Set-up for measuring the surface tension with the bubble pressure method."
6. Documentation of *exterior experimental conditions* which may affect the results (e.g. room-temperature during the experiments on surface tension and viscosity) as well as documentation of potential *sources of errors* (e.g. accuracy of measuring instruments).
7. *Tabular presentation* of results from a series of measurements. The columns or lines must contain the "physical quantity / unit", e.g. "U / V" for a voltage, "I / A" for a current, or "t / s" for a time period. This notation is explained in chapter 4.3, item 1. Tables have to be *numbered* consecutively within a report and need to be accompanied by a short explanatory *caption* indicating what is presented in the table. In contrast to a figure caption the caption for a table appears first before the table is presented. Following example is given :

   Table xx: Voltage U and current I as a function of the insertion depth d of copper electrodes into an electrolyte.

***d* / m** ± 10^{-3} m	***U* / V** ± 10^{-2} V	***I* / mA** ± 10^{-1} mA
0,050	1,74	14,8
0,045	1,77	14,2
0,040	1,81	13,4
0,035	1,85	12,6
0,030	1,89	11,8
0,025	1,94	10,8
0,020	2,01	9,8

   Each table must be referenced in the main text, e.g. "The measured values are presented in table xx".

8. *Graphical representation* of the results obtained from a series of measurements. Each diagram must be *numbered* consecutively and include a short explanatory *caption* indicating what is presented in the diagram. The independent variable, i.e. the predetermined quantity (d in the above example), is represented on the abscissa (x – axis), the dependent quantity on the ordinate (y – axis). The scale marks and the position of the axial zero have to be chosen such that the curve of interest is easily recognisable. The coordinate axes must be marked completely. The inscription of columns and lines in tables is also true for the inscription of the axes: It has to be done in the form of "physical value / unit of value". If required, *regressions curves* and/or *error bars* must be inserted. An example is given in the following:

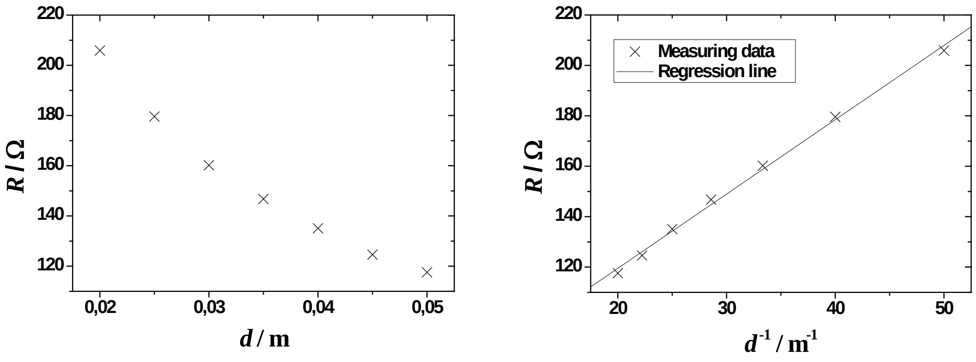

Fig. xx: Ohmic resistance R of an electrolyte as a function of the insertion depth d of the electrode. Left R over d, right linearized representation of R over $1/d$.

The distances between the single values of the independent variable have to be chosen such that the behaviour of the measuring results of the dependent variables is easily discernible. They should be dense when something “happens“ in the diagram. The following example of an amplitude resonance curve of a damped harmonic oscillator illustrates this. In the environment of the angular eigen frequency $\omega_0 \approx 4.5$ Hz the distances of the independent variable ω_1 have been chosen distinctly smaller than outside that area so that the behaviour of the amplitude x_0 is easily discernible in the environment of ω_0:

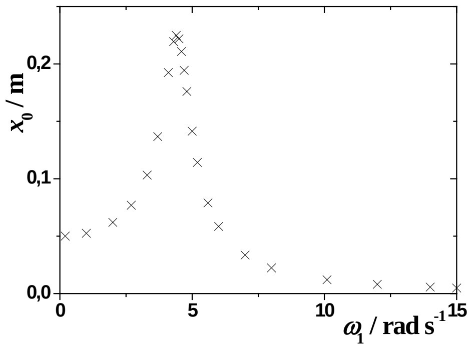

Fig. xx: Amplitude resonance curve of a damped harmonic oscillator

In general, the data points should *not* be connected by a line. A linear connection would suggest e.g. a linear relation between the represented quantities in the region limited by two measurements. If it is necessary to connect the individual points by a line to improve the visualisation of the data, the line must be broken for each data point:

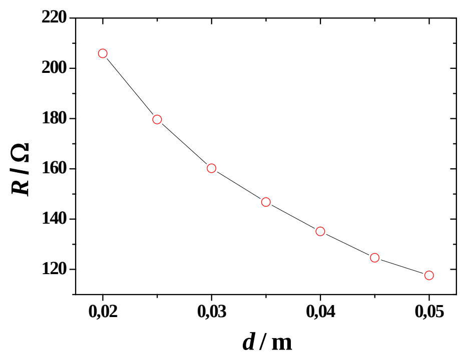

Fig. xx: Ohmic resistance R of an electrolyte as a function of the insertion depth d of the electrode.

Each figure must be referenced in the main text, e.g. “Fig. xx shows the graphical presentation of the data“.

9. *Calculation* of numerical values for the quantities to be measured. For each numerical value, the *error* (*measuring uncertainty*) has to be stated, which is either *calculated* or sensibly *estimated*. Details on this and on proper rounding of calculated numerical values are stated in the instructions of "*Error theory and regression analysis*".
10. *Interpretation and evaluation of experimental results by comparing* them with the theoretically expected results and the results stated in the literature, respectively. To realistically and critically evaluate the obtained results is more important than to come as near as possible to a target value or to quantitatively reproduce results as stated in the literature.

An enumeration of the instruments used is not necessary, since they are listed in the instructions (under "accessories") of the respective experiments. It is thus sufficient to state an appropriate reference.

4.3 Rules to be Kept when Writing Reports

When writing the report certain standards and customs must be observed from the beginning (cf. for example /10/), as they are common practice for students preparing their theses or other scientific papers:

1. A physical value G is stated as a product of the numerical value $\{G\}$ times unit $[G]$ of that quantity, therefore,

   (1) $G = \{G\} \times [G]$

   Example: an electric voltage has a value of 5 V, it means U = 5 V, with $\{U\}$ = 5 and $[U]$ = V.

   According to Eq. (1), tabular columns and lines as well as axes in graphs are marked in the form "$G/[G]$", e.g. "U/V", "d/m" etc. The quotient $G/[G]$ yields exactly the value $\{G\}$, which is written into the table or at the scale marks of the axis, such as 5 10 15 20 etc. Markings in the form "U [V]" or "d [m]" are formally wrong![7]
2. The unit prescribed by the International Unit System (SI: Système Internationale d'Unités) has to be used as the unit $[G]$ of a physical value G /10/. In addition to theseven basic SI-units for the length (meter, m), the mass (kilogram, kg), the time (second, s), the electrical current (ampere, A), the temperature (Kelvin, K), the amount of substance (mole, mol), and the luminous intensity (candela, cd) there are derived SI-units which are *always* expressible as a product of the basic units, thus

   $$[G] = \mathrm{m}^a\ \mathrm{kg}^b\ \mathrm{s}^c\ \mathrm{A}^d\ \mathrm{K}^e\ \mathrm{mol}^f\ \mathrm{cd}^g$$

   with the exponents a,b,c,d,e,f and g. Individual names have been established for many derived units, such as the Pascal (Pa) for pressure (Pa = kg $\mathrm{m}^{-1}\ \mathrm{s}^{-2}$), volt (V) for the voltage (V = kg $\mathrm{m}^2\ \mathrm{s}^{-3}\ \mathrm{A}^{-1}$) or hertz (Hz) for the frequency (Hz = s^{-1}). A list of the legally accepted names for derived units in Germany are found in /11/.
3. There are established symbols for most physical values (e.g. F for force, ω for the angular frequency, U for the voltage, etc.) which should not be deviated from without a grave reason. A list of the symbols and characters are included in /7/.
4. The symbols of physical quantities, e.g. F, ω and U are written in *Italics*, whereas the units belonging to them, in this case N, Hz and V, are written in straight letters. For example, we write F/N, ω/Hz and U/V. The numerical value of a physical quantity and its unit are separated by a whitespace, e.g. F = 1.5 N or U = 5 V.
5. All symbols representing physical values within the text need to be properly defined. E.g. write "..the electrical field E is determined by the voltage U and the distance d as $E = U/d$."
6. When preparing circuit sketches, one should adhere to the regulations of the German Institute for Norms (DIN), which are also applied in the experimental readers. Copies of the corresponding DIN norms [8] are available in the bookcase.

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[7] Partly other types of notations are required in scientific journals. Unfortunately, the rules are not uniform. E.g. NATURE, PHYSICAL REVIEW LETTERS, and PHYSIK JOURNAL each have a different rule set.

[8] E.g. DIN EN 60617: "Graphic symbols for circuit sketches" ; see also the text "*About the set-up of electric circuits* …".in this reader.

7. The numerical values of physical constants are required for a number of calculations. Current optimums of those constants are found in /9/, a selection of them on the back cover page.
8. *All* tables and *all* figures in the report *must* be referenced within the text of the report (see notes under item 7 and 8 in chapter 4.2). Examples: “The principle set-up is shown in fig. 2”, or “Table 3 shows the measured values and fig. 6 their graphical representation.”
9. If graphs, tables or text passages from outside sources (including internet sources) are incorporated into the report, the source *must* be cited correctly. For example, if a diagram is adopted from the Notes for the Module Introductory Laboratory Course Physics, Part I, the caption must be concluded with the hint “(from /1/, p. xx)”. At the end of the report a reference is added:

   References

   /1/ Script of the Introductory Laboratory Course Physics, Part I, CvO University of Oldenburg, Institute of Physics, October 2019

   In case sources from the internet are used, the internet address in the form of URL (Uniform Resource Locator) and the date of search must be quoted [9], for example:

   /2/ Physikalisch Technische Bundesanstalt (PTB): “Research on the new neuen SI”. URL: https://www.ptb.de/cms/en/research-development/research-on-the-new-si.html, Date: 06.09.2014

Reports containing graphs, tables or text passages from outside sources without citing those sources are forgeries and are rated as insufficient. In this context, attention must be paid to the publication “Good scientific practice” by Carl von Ossietzky University of Oldenburg[10] *as well as to an article published in the ZEIT*[11].

If *text processing software* is used to prepare a report, the most important principle is: The foundation of a good report is its contents and structure and not its outward form. Handwritten reports or equations inserted by hand are in principle sufficient as long as they are legible but it makes sense to get used to prepare reports electronically with a computer and to get familiar with current software. Especially for working together on a report as a whole team, there are possibilities online available via internet[12], which can be used for teamwork.

There is one additional iron rule concerning reports:

Each experiment can only be performed when the report of the preceding one has been completed and has been submitted.

5 References

Every experimental reader includes a list of literature stating those books which are especially useful for for preparing the respective experiments. The following books are recommended for general use during the lab course (see also https://uol.de/en/physics/laboratory-courses/literature) [13]

/1/ EICHLER, H.J., KRONFELDT, H.-D., SAHM, J.: Das Neue Physikalische Grundpraktikum, Springer-Verlag, Berlin among others

/2/ GESCHKE, D. [Hrsg.]: Physikalisches Praktikum, Teubner-Verlag, Stuttgart among others

/3/ WALCHER, W.: Praktikum der Physik, Teubner-Verlag, Stuttgart

/4/ GERTHSEN, C. et al: Physik, Springer-Verlag, Berlin among others

/5/ STÖCKER, H.: Taschenbuch der Physik, Harri Deutsch, Frankfurt (is also available as HTML version on the computers in the introductory laboratory)

/6/ BRONSTEIN, I. N., SEMENDJAJEW, K. A., MUSIOL, G., MÜHLING, H.: Taschenbuch der Mathematik, Verlag Harri Deutsch, Frankfurt (is also available as HTML version on the computers in the introductory laboratory)

9 For all URL statements in this text the date is 23.09.2019 if not mentioned otherwise.

10 https://uol.de/fileadmin/user_upload/physik/ag/physikpraktika/download/Faltblatt_GWP.pdf

11 ”Suchmaschine gegen den Gedankenklau – Universitäten rüsten sich gegen Plagiatoren – und verhängen schwere Strafen.” ZEIT 08.02.07; https://www.zeit.de/2007/07/B-Plagiatskontrolle

12 Examples are the use of “cloud computing” or working on a report together using platforms such as “Google Docs” (see: https://www.google.de/intl/de/docs/about/).

13 The years of publication are not given here because of frequent re-editions. You can find the year of publication of the current editions at the internet site of the laboratory course.

The most appropriate tabular works that can be consulted for numerical values of physical quantities:

/7/ LIDE, D. R. [Ed.]: CRC Handbook of Chemistry and Physics, CRC Press, Boca Raton (is also available as PDF file on the computers in the introductory laboratory)
/8/ MADELUNG, O. [Hrsg.]: Landolt-Börnstein: Zahlenwerte und Funktionen aus Naturwissenschaften und Technik, Springer-Verlag, Berlin, among others

Current optimums of physical constants (for a selection see back cover page of this script) are found in:

- https://physics.nist.gov/cuu/pdf/wall_2018.pdf: "CODATA Recommended Values of the Fundamental Physical Constants: 2018", Mai 2019.

Hints for writing scientific manuscripts, and a collection of the basic SI-units including derived units are found in the following booklet of the “Bureau International des Poids et Mesures (BIPM)”[14]:

/9/ Bureau International des Poids et Mesures: The International System of Units (SI), 8th Edition, Paris, 2006. (http://www.bipm.org/utils/common/pdf/si_brochure_8_en.pdf)

A collection of the legally approved units in Germany is found in:

/10/ Physikalisch Technische Bundesanstalt (PTB) [Hrg.]: Die gesetzlichen Einheiten in Deutschland, Faltblatt 2012, Braunschweig, 2012.
(https://www.ptb.de/cms/fileadmin/internet/presse_aktuelles/broschueren/intern_einheitensystem/Einheiten_deutsch.pdf), updated 06.09.2019.

[14] The BIPM was originally founded by 17 countries on 20.05.1875. Since then, 51 countries have signed up as members. The aim of this bureau is the “global unification of measurements”. The main office is located in Paris, the official language of the BIPM is French.