Advanced and Intermediate Physics Lab Experiments

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This paper describes organization of the Advanced and Intermediate Physics Lab course at the Department of Physics and Astronomy of the Johns Hopkins University. It serves both as a guide for students and at the same time as a template and example for them to organize the lab report. This course is intended for physics major students at the junior or senior level, or graduate students if equivalent course has not been taken as part of undergraduate education.

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I. INTRODUCTION

The goal of the course is to teach students how to do scientific research through exposure to a number of prominent experiments that set the stage for our understanding of modern physics. Throughout this course, students

- learn theoretical background and history of experimental discoveries;
- obtain hands-on experience in performing physics experiments;
- improve data-analysis skills and learn analysis techniques;
- work on presentation and communication skills, both written and oral;
- learn software programs for data acquisition, data handling, publication, and presentation.

There is no required textbook for this course. However, each lab experiment has extensive reading material, which students are required to read **before** coming to class. All material can be found in the web link, see Ref. [1]. There are also some software programs that students may need to learn. There is introduction to data analysis given in lectures at the beginning of the course. However, Ref. [2] may be good reference material for understanding the measurement errors.

II. EXPERIMENTS

There are ten experiments available in the lab. At any given time not all ten of them may be available for students due to required setup and repairs. Eight experiments are expected to be available. The course requirements are the following:

- eight (8) experiments are required to be performed by each student;
- lab reports for five (5) experiments are required to be written to be graded;
- first three (3) lab reports will be reviewed for the "W" requirement;
- one (1) lab experiment will be presented orally.

The ten experiments are the following (note that we start with experiments 1–8):

1. Muon lifetime;
2. Photo-electric effect;
3. Pulsed NMR;
4. Franck-Hertz experiment;
5. Nuclear spectroscopy;
6. Rutherford scattering;
7. Brownian motion;
8. Hall effect;
9. Zeeman effect;
10. Millikan oil drop experiment.

Students are expected to work in groups of 2-3 people. The group size is optimized for efficiency of the course, individual student experience, and models collaborative team work in research. Four groups come on Monday morning and four groups on Monday afternoon, with eight groups total. Team work is expected and encouraged in setting up the experiments and collecting the data. However, analysis of the data and further presentation (written and oral) is individual work of each student.

III. SCHEDULE

In the first week of classes students are expected to

- get an overview of the lab course;
- obtain card access to the lab and computer accounts;

- get organized into the teams and understand the schedule;
- read material for the first lab to be performed on the following week;
- make data analysis example and paper templates work (to make sure their computer setup is ready).

The schedule for the following weeks is shown in Table I. Note that it is required that students come prepared after reading required material for each lab assigned on a particular day. Several days will be left for make-up labs for a few experiments that may require extra time. However, it is important that the schedule is followed closely for coordination purpose. Some lab reports may require extra iterations between the student and the instructor and the due dates are given when the report is returned, typically due within a week. This is especially important for the first three reports to satisfy the "W" (writing) requirement.

TABLE I: Schedule of labs, lectures, and due dates in the Spring 2010 semester.

	Date	Events
1	Jan.25	Introduction lecture
2	Feb.1	LAB1, lecture
3	Feb.8	LAB2, lecture
4	Feb.15	extra time for LAB1 and LAB2
5	Feb.22	LAB3, 1st report due
6	Mar.1	LAB4
7	Mar.8	LAB5, 2nd report due
8	Mar.15	Spring break, no labs
9	Mar.22	LAB6, students present
10	Mar.29	LAB7, 3rd report due, students present
11	Apr.5	LAB8, students present
12	Apr.12	followup LAB, 4th report due, students present
13	Apr.19	followup LAB, students present
14	Apr.26	followup LAB, 5th report due, students present

Assignment of individual lab experiments (according to the experiment numbering given above) is shown in Table II. Each team of students should have a number assigned G1, G2, ..., G8 and find its schedule in Table II. Note that groups G1, G2, G3, and G4 are the morning teams and groups G5, G6, G7, and G8 are the afternoon teams. Some of the experiments from the full list exp#1,...,10 may be substituted by the instructor on a case-by-case basis.

IV. GRADE RULES AND PENALTIES

The final grade is based on the following:

- pass on writing requirements in the first three lab reports (more than one iteration may be required);

TABLE II: Assignment of experiments (exp#1,...,8) to groups (G1, G2, ..., G8) according to lab dates.

	exp#	1	2	3	4	5	6	7	8
1	Jan.25								
2	Feb.1	G1	G2	G5	G6	G3	G4	G7	G8
3	Feb.8	G8	G7	G4	G3	G6	G5	G2	G1
4	Feb.15	G1/8	G2/7	G4/5	G3/6	G3/6	G4/5	G2/7	G1/8
5	Feb.22	G5	G6	G1	G2	G7	G8	G3	G4
6	Mar.1	G4	G3	G8	G7	G2	G1	G6	G5
7	Mar.8	G2	G1	G6	G5	G4	G3	G8	G7
8	Mar.15								
9	Mar.22	G7	G8	G3	G4	G5	G6	G1	G2
10	Mar.29	G6	G5	G2	G1	G8	G7	G4	G3
11	Apr.5	G3	G4	G7	G8	G1	G2	G5	G6
12	Apr.12								
13	Apr.19								
14	Apr.26								

- pass on performing all eight experiments;
- 70% – score of the best five lab reports which the student turns in;
- 20% – oral presentation in class (20 minutes);
- 10% – participation and lab notes, judged by the instructor and the TA.

A. Report due time

The due dates of the five lab reports are given in Table I. The students have some choice which experiment is written in the lab report from those labs which have been performed by the due date. The deadline is at 11:59pm on Monday as indicated in the Table. The time is recorded by the time (Eastern Standard Time) email with the report attachment is sent to the TA and the instructor. Late reports will be accepted no later than one week after the due date under the following rules:

- full credit if there is a written confirmation of a medical or similar event;
- only 50% credit otherwise.

No reports accepted more than one week after the due date (e.g. if the first report is turned in more than one week after its due date, it will be considered as the second lab report and zero will be given for the first one), unless serious medical or similar conditions are documented. The same rules apply to the followup iterations on lab reports when requested by the instructor or TA.

In addition to schedule requirements, the deadline rule models situation in research when certain results need to be ready by certain time, especially in a collaboration of scientists or in competition with another team of researchers.

B. Oral presentations

Oral presentation model presentation of research results at a conference. Students are given 20 minutes to motivate their experiment, describe apparatus, discuss results, and give a summary or outlook. There will be time for questions from the audience. Attendance at these presentations is mandatory for all students in a given section.

Presentations should be given via computer with software of the student's choice (Powerpoint, Openoffice, Latex, etc). If a student does not have a laptop, the instructor can arrange to borrow a departmental one. In this case the students would compose the presentation on a PUC or home computer and then transfer the file to the borrowed laptop at least one hour in advance of the section, to be arranged with the instructor.

Oral presentation time will be assigned by the instructor during the section time on one of the weeks after the spring break. This assignment will be given after the first report is turned in by all students. However, students can express preference for the date of their presentation, which may or may not be taken into account (we cannot have all presentations in one day for example).

C. Participation and lab notes

Participation in all eight lab experiments, in lectures, and in student presentations is required.

The students are required to keep accurate lab notes, which in some cases may be substituted by careful documentation of data files on the computer account, with appropriate dates recorded. All notes should be unique and cannot be copied from anybody else. These notes should be kept until final grade is issued and may be checked by the instructor or TA.

V. LAB REPORTS

The typical lab report should include sections on:

- Introduction and motivation for the experiment, including some historical note;
- Theory behind the experiment and what was expected to measure;
- Experimental apparatus;
- Data and conditions under which these data are collected;
- Analysis of the data and results;
- Discussion and conclusion.

The report should be written in latex format starting from template provided by this paper. This is a standard for submitting to APS journals (Phys. Rev. Lett. for example). Some of the samples of prior student reports can be found on the course web pages, to be used as editorial examples. Lab reports have to be submitted by email to the instructor and TA (see below) by the due time (see above). The typical length of a report is three pages in the present format (note Phys. Rev. Lett. page limit of four pages, which is typical for a brief article).

The following brief subsections provide a simplified example modeled with fake numbers, to be used as template for a report.

A. Introduction

In 2010 somebody decided to measure dependence of y on x.

B. Theory

There is deep theory behind this measurement. It was shown that y and x are related as

$$y = a + b \times x, \quad (1)$$

where a and b are fundamental constants of great importance.

C. Experiment

We have repeated the experiment suggested by the original authors.

D. Data

The measured values of y and x, including statistical and systematic errors, are given in Table III. These data are also shown in Fig. 1.

TABLE III: Measured values of x and y in five experiments discussed in text.

x	y
1.00 ± 0.10	1.15 ± 0.20
2.00 ± 0.10	1.81 ± 0.20
3.00 ± 0.10	2.85 ± 0.20
4.00 ± 0.10	4.27 ± 0.20
5.00 ± 0.10	4.80 ± 0.20

E. Results

In order to extract the values of a and b, we perform the least-χ^2 fit to our data with a linear function according to Eq. (1). The fit is shown in Fig. 1 and the results are shown in Table IV.

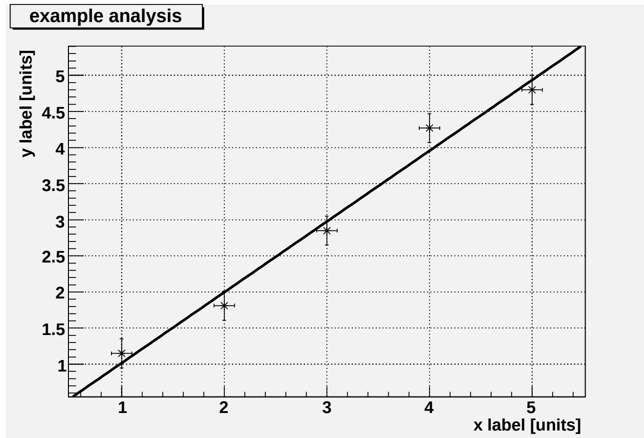

FIG. 1: Measurements of x and y, and the least-χ^2 fit to the data with a linear function.

TABLE IV: Measured and expected values of a and b.

parameter	measured value	expected value
a	0.04 ± 0.23	0.00
b	0.98 ± 0.07	1.00

F. Conclusion

As it is evident from Table IV, our measured values of a and b are in good agreement with theory. This confirms the theory behind this measurement.

VI. SOFTWARE

There are several types of software programs that may be required to learn:

- software in each lab setup (if applicable) is described in the manual for each experiment;
- data analysis software is left to student's choice, the instructor provides examples in Root [3];
- presentation software is Latex [4] for lab reports, and student's choice for oral presentation.

This software has been installed on the PUC lab computers (Mac and Windows). However, if students would like to install those on a home computer, links to free applications are available in Refs. [3–5].

The above data analysis example was performed in Root with the program `fit_example.C` available on the course page. To run it, start root, type `.x fit_example.C` to execute it and `.q` to quit.

All computer files (data, analysis, presentation, reports) need to be saved on the nevill PUC server under individual accounts to avoid loosing them after the lab computer is rebooted at night or the user is logged out.

VII. MEETING AND CONTACT INFORMATION

Location: Bloomberg 478
Time: Mondays, 10am–12:50pm (morning)
and 1:30–4:20pm (afternoon)
Instructor: Prof. Andrei Gritsan,
office 433, phone 410-516-5070
email: gritsan@jhu.edu
TA: Jingsheng Li, email: jsli@pha.jhu.edu
office 467, phone 410-516-7206

VIII. CONCLUSIONS

Overall, students may find this course very challenging and demanding. Setting up the experiments may be frustrating sometimes if something does not work as expected and clear presentation in the lab reports may require significant amount of work. However, the students may find the course rewarding after succeeding in all the experiments and learning how research is performed.

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[1] Course web page for the Spring 2010 class: `http://www.pha.jhu.edu/~gritsan/2010.173.308/`
[2] Philip Bevington and Keith Robinson, "Data Reduction and Error Analysis for the Physical Sciences," ISBN 0-07-247227-8.
[3] "ROOT – Data Analysis Framework," `http://root.cern.ch/`
[4] "LaTeX – A document preparation system," `http://www.latex-project.org/` see also REVTeX 4.1 macros `http://authors.aps.org/revtex4/`
[5] "OpenOffice.org – The Free and Open Productivity Suite," `http://www.openoffice.org/`