Department of Physics

Advanced Physics Laboratory Course Outline

January 2021

University of Toronto

Welcome to the Advanced Physics Lab!

Physics is an experimental science that tries to describe, understand, and predict the behaviour of physical systems. This requires careful observations and accurate measurement of those systems. The goal of the Advanced Physics Laboratory is to help students better understand the methods and myriad challenges of making such measurements and judging whether relevant physical theories are consistent with the data.

The Advanced Physics Laboratory gives students an opportunity to work on interesting challenging experiments, deepen their understanding of the underlying Physics, and to further develop laboratory, analysis, and communication skills. Students learn how to study physical systems by being responsible for all aspects of several small experimental projects. Every experiment explores important physics and comes with basic objectives, specified equipment, and much support, but students must decide exactly what to study, the details of how to study it, and how to budget their time.

Learning in the Advanced Lab is fundamentally different from regular lecture courses, and is much closer to what happens in research and in other typical careers you may aspire to. Advanced Lab students must choose what to learn and how to learn it; experiments never have a single, correct, final answer, so students must decide when they are finished. Students cannot expect to have already learned about the physics of an experiment in their lecture courses, nor to be formally trained in an experimental technique.

You are left much more to your own initiative in carrying out the experiments than in earlier lab courses. At the same time you are given many more resources to work with - both more sophisticated equipment and a much higher staff-to-student ratio to help you. You are strongly encouraged to make good use of staff and demonstrators. As you become more accustomed to the format and structure of the course, we encourage you to use your imagination when solving problems. If you discover some aspect of the experiment that really interests you, or come up with some innovative way of doing the analysis, you may, with guidance from your professor, modify the exercises to suit you. We want you to have fun and we'd like to help you make the most of the opportunities in this course.

This is a challenging year since we are all interacting much less in-person and much more electronically. Clear and continuous documentation and communication of your work is even more important than usual. Procedures may change as we continue to learn what works best, but by working together we will figure things out.

The course web-site and Quercus pages have the most up-to-date manuals and information.

Please contact the Advanced Physics Lab Coordinator David Bailey if you find any mistakes in this draft course outline or elsewhere on the course website or Quercus pages.

Changes due to COVID-19

The semester lab schedule has been arranged so there are 7 lab periods per experiment instead of 6 as in the past, to give us all a bit more time to work through issues.

Most help and communication will be done remotely

- Check APL Contacts page on Quercus to find out how to contact us.
- Exchange emails with Profs and TAs before start of experiment to arrange contact times and methods. e.g. They may
  - have open Zoom/bbCollaborate sessions during lab periods or other times.
  - ask for your phone number so they can call to see how you are doing.
  - set a time to call or meeting virtually.
  - do an in-person walk through at a set time during regular lab periods
  - …
- Technologists will be in MP234 to provide small items and give advice, but for most repairs you will need to tell them the problem or email them with detailed information. They will check out the problem when you are not present.

When things go wrong or you otherwise need help.

- Live phone/Zoom/… may help debugging some issues, but often Profs/TAs/Techs will want emails or uploads with:
  - detailed description of problem
  - lab notebook pages, photos, plots, ….
- Some help may be given in-person with 2m physical distancing.
- We will see what safely works best.

Students with diverse learning styles and needs are welcome in this course. If you have an acute or ongoing disability issue or accommodation need, you should register with Accessibility Services (AS) at the beginning of the academic year by visiting http://www.studentlife.utoronto.ca/as/new-registration. Without registration, you will not be able to verify your situation with your instructors, and instructors will not be advised about your accommodation needs. AS will assess your situation, develop an accommodation plan with you, and support you in requesting accommodation for your course work. Remember that the process of accommodation is private: AS will not share details of your needs or condition with any instructor, and your instructors will not reveal that you are registered with AS.

STAFF

The professors are available to help you, to discuss your experiment and the associated physics, to evaluate your progress, and to mark your notebooks. The demonstrators are available to help you in the laboratory and do *not* evaluate your experiments. The technical staff is available to help you, maintain the lab equipment, and guard the technical manuals and radioactive sources. The Coordinator has overall responsibility for the course; feel free to contact the Coordinator about any Advanced Lab issue.

Professors will endeavour to respond to email inquiries from students within 1 business day. If you do not receive a reply within this period, please resubmit your question(s) and/or phone (leave a message if necessary). Schedules for TAs and profs may be posted on Quercus or outside MP251.

Detailed contact information for all current Advanced Lab Instructors, TAs, and Staff is available on Quercus. For general inquiries or more information, please contact the APL Coordinator David Bailey, preferably via email to dbailey@physics.utoronto.ca, or Tel. 416-978-7105, Rm. MP251A,

EXPERIMENTS AVAILABLE

Code	Experiment Name	Students	Room
AFM	Atomic Force Microscope (under development)	1	248
BRI	Brillouin scattering	1	247
C3D	Conductivity in less than three dimensions	2	226
CC	Cloud Chamber	1	255
COMP	Measurement of the Compton total cross section	2	245
ESR	Electron spin resonance	1	226
FAR	Faraday Waves	1	239
FE	Ferroelectrics	1	239
FTS	Fourier transform spectroscopy	1	242
FVF	Fractal Viscous Fingering	1	239
GAUS	Gaussian Beams	1	227
GE	Gamma ray spectroscopy with a germanium detector	2	245
GRAN	Granular Patterns	1	239
HALL	Semiconductor resistance, band gap, and Hall effect	1	239
HENE	The helium-neon laser	2	242
HEP	High energy physics	3	at home
HTCM	High temperature superconductors (Make)	1	239
KNOT	Knots and topological transformations in vibrating chains	3	239
LAUE	Laue back reflection of X-Rays	1	226
LENS	Lenses	3	250
LPP	Linear Pulse Propagation and Dispersion	1	246
MOS	Mossbauer effect	1	239
MUON	Muon lifetime (under development)	1	245
NEEL	Phase change in chromium at the Neel temperature	1	239
NMR	Nuclear magnetic resonance	1	239
OPT	Optical Tweezers	1	248
PXR	Powder method of X-ray analysis	1	226
QIE	Quantum Interference and Entanglement	1	244
RAM	Raman effect	0	248
RB	Optical pumping of rubidium	1	242
SOL	Solitons	1	245
SONO	Sonoluminescence	1	246
SQM	SQUID magnetometer	1	226
STM	Scanning Tunneling Microscope (under development)	1	248
XRF	X-ray fluorescence	1	245
SPEC	Special Projects	0	–

The Professor and TA for each experiment can be found on the Experiments Assignment page on Quercus.

The Professor or TA for an experiment may change, locations may change, and experiments may be added or dropped during the year; check the website and quercus for the most up-to-date information.

All rooms are on the second floor of the North Wing of McLennan Physical Labs.

THE LAB CALENDAR

Contact the APL Coordinator if you notice any errors or issues with this calendar.
All work is due on the specified date,
unless alternate arrangements have been made in advance with the supervising professor.

Date : **Event**

Jan 5 : Available on Quercus

- First Experiment Assignments
- Introductory presentations on
  - Introduction (including Safety and Academic Integrity)
  - *How to do well in the Advanced Physics Lab*"
- PHY 327H and 424H Data Analysis assignment available.

Jan 12 : Begin Experiment 1
Jan 22 : Exp. 1 Progress Check
Jan 26 : PHY 327H and 424H - Data Analysis assignment due.
Feb 2 : Last day to work in lab on Exp. 1.
Feb 4 : Exp. 1 due
Feb 5 : Begin Experiment 2
Feb 15-19 : Reading Week (No regular labs)
Feb 23 : Exp. 2 Progress Check
Mar 5 : Last day to work in lab on Exp. 2.
Mar 8 : Exp. 2 due
Mar 9 : Begin Experiment 3
Mar 19 : Exp. 3 Progress Check
Mar 22 : Formal Report draft due
Mar 30 : Formal Report Peer Review comments due
Apr 1 : Exp. 3 due
Apr 8 : Formal Report final version due
Apr 9 : PHY 327H Design Reflections due
Apr 13-16 : Oral Exam Final Assessments

Marks for late experiments will be reduced at the rate of 5% per business day or portion thereof, unless otherwise arranged in advance with your professor. Marks for late Formal Reports will be penalized 10% per day, and late Data Analysis assignments 25% per day. Progress checks will not be accepted late for credit, unless otherwise arranged **in advance** with your professor. **All work must be turned in and all experiments marked before your oral exam.** There will be a schedule posted a few weeks before so you can sign up for an exam time; you must sign up before the start of the oral exam period.

If you are ill or have a similar valid reason for missing a deadline or needing an extension, please contact the supervising professor or the lab coordinator as soon as possible. Note that the University has suspended the need for a doctor's note or medical certificate for absences if experiencing COVID-19 symptoms.

The online First Meeting Introduction is aimed at familiarizing new students with Advanced Physics Lab organization, procedures and safety, and to give advice on how to do well in the lab and on the Data Analysis assignment due a few weeks into the semester.

The official lab-times for this course are Tuesdays and Fridays 9-12. Your professor or demonstrator is most likely to be available during these times, and it is mandatory that you are regularly in contact with your supervising professor. When the lab is open, you may work on experiments outside the official lab times, subject to COVID-19 capacity restrictions.

You have about 3 weeks to complete each experiment. We expect you to progress steadily through your experiment during these three weeks. By the end of the first week, you should have familiarized yourself with the background physics and all apparatus, made plenty of notes, plans and sketches in your notebook and attempted some preliminary measurements. By the end of the second week, you should have completed at least one data-taking run and gone through all the analysis steps at least once. By the end of the third week you should have some good data with well-understood uncertainties, and most analysis and conclusions well documented.

EVALUATIONS

You must complete three experiments for this course. Each student must also complete one Formal Report, one short peer review of another student's Formal Report draft, and pass the Oral Exam. PHY 327H and 424H students must also turn in a Data Analysis assignment at the beginning of the course. PHY327H (Engineering Science) students must submit a Design Reflection at the end of the course. The marking scheme is as follows:

Grade Component	PHY 327	PHY 424	PHY 426/427/428/429
Experiment marks	57 %	60 %	60 %
Analysis Project	4 %	4 %	
Formal Report and Peer Review	18 %	18 %	20 %
Design Reflection	3 %		
Oral exam	18 %	18 %	20 %

Experiment Marks

Each experiment must be completed and your notebook submitted responsible before work begins on the next experiment. The mark for each experiment consists of a Progress Check Mark (5%), and an Experiment Performance Mark (95%) based on the work in the laboratory, the notebook contents and the interview with a supervising professor. Late submission of your notebook will be penalized 5% per business day or portion thereof, unless otherwise arranged **in advance** with your professor.

- ***Attendance:*** You should attend at least one regular lab period per week when professors and demonstrators are available to help you. Lab students that we do not see do poorly, so you are expected to have **brief meetings with your professor on at least weekly** during the course of your experiment. This meetings will most likely be done electronically.
- ***Progress Check:*** Around the 3rd or 4th regular lab period your supervising professor checks that you are on track and gives feedback on your notebook and your experimental progress. You should upload your notebook and associated files in preparation for this Progress Check. This Progress Check may be done during the lab period, but if not you must contact your professor to arrange it. A progress mark will be assigned. **Late notebooks will receive a zero.**
- ***Work in the Lab*:** The professor in charge of the experiment will have the chance to interact with you several times as you complete each lab. Note that while you are not expected to get everything right the first time without talking to anyone, it is expected that you carefully read the experiment write-up and any necessary references, show initiative and solve problems without excessive help. Students who go beyond the procedures suggested in the write-up, improving the experiment or analysis in some way, will be rewarded.
- ***Notebook*:** The notebook must be bound and include all of the work you did in the lab. (You are allowed to reuse a notebook from a previous lab course.) It should contain a diary-format description of all your activities in the lab as well as purpose, motivation, analysis, final results and conclusions. You should also keep an electronic folder with any plots, data, spreadsheets, code, or other relevant file that is clearly referenced in your notebook.**You may not receive credit for inadequately documented work.** See below for comprehensive notebook guidelines.
- ***Interview*:** After each experiment you will have a short interview with the supervising professor. You are expected to be able to succinctly explain the goals of the experiment and what you actually accomplished. You are expected to understand what you did and to be able to use your notebook to help explain what you did and answer questions. If you are asked why you did something a certain way, it is best not to answer "Because the instructions said so". You are expected to demonstrate understanding of the methods and related physics phenomena.

Note that when we are marking, we are interested in whether your experiments were well done (and well documented). This may include getting correct results, but more importantly it means doing the best job possible, even in the absence of any correct results. This course brings you closer to the real world of research, where things don't always go as planned. A typical Experiment Mark might be based on:

Component	Value
• *Attendance*	10%
• *Effort*	20%
• *Experimental skill*	20%
• *Analysis of data/uncertainty*	9%
• *Understanding of physics and methods*	6%
• *Innovation*	7%
• *Progress Check*	5%
• *Notebook quality**	14%
• *Final Summary Abstract*	6%
• *Interview clarity**	3%

* Note that ***you can't get good marks for good work that we don't know about or can't understand!*** A good notebook is essential for a good mark. The interview can easily affect your mark by much more than the small percentage assigned to "clarity", since the interview helps professors assess many of the other factors contributing to your final mark.

The actual weightings are sensitive to the nature of the experiment and circumstance. For example, if there are problems with the apparatus that are not your fault, less weight (or even zero) would be given to the quality of data and analysis. Conversely, in experiments where good data are easy to get, more weight might be given to the analysis. Leaving the experiment in a mess when you finish will irritate the professor (and the next student) and not help your grade.

Grading Standards

In attempting to maintain uniformity of standards we have agreed on the following description of equivalence between achievement and experiment grades.

A+ (median mark 95%). Outstanding work with deep insight into the physics and considerable initiative in carrying out the experiment or interpreting the results.

A/A- (median mark 85%). Excellent work with demonstrated insight into the physics and some initiative in carrying out the experiment or interpreting the results.

B (median mark 75%). A normal good job, in which the student obtains reasonable experimental results and understands the basic physics underlying the experiment.

C (median mark 65%). An adequate job, with only basic results or analysis and limited understanding.

D (median mark 55%). Marginal performance where the experiment was partially incomplete, excessive assistance was required, or a serious lack of understanding of much of the physics.

Data Analysis Project

At the beginning of the semester, students in PHY 327/424 will be assigned a set of data to analyze. The assignment will come with a list of properties that we wish you to measure and/or discuss. A short one- or two-page report on your results of this project will be due to the Course Coordinator. See the lab calendar for the exact deadline.

Formal Report

Science is useless if it is not communicated, and journal articles are the primary archival way in which this done. In this course students must write a short journal-style Formal Report based on one of the first two experiments that they have completed. The target audience for this report is someone with an undergraduate degree in physics who is not an expert on the experiment. The Formal Report should follow the format of articles in journals such as *Physical Review*. See the course web-site for comprehensive guidelines on how to write a formal report: http://www.physics.utoronto.ca/~phy326/formalguidelines.htm

We ask that students submit a copy of their first draft for **Peer Review** by the deadline specified in the Lab Calendar. You should not put your name on your report. The Course Coordinator will circulate an anonymous copy to another student in the course, chosen randomly.

Each student who submits a First Draft will read and comment on a Formal Report of another. These comments should be *constructive* and may be either typed on separate paper or written directly on the pages of the original Report. The comments should total to somewhere between 200 and 500 words (~ a couple of paragraphs). The comments and annotated reviewed draft should be submitted by the deadline specified in your course Lab Calendar and then they will be forwarded to the authors of the papers. The author will receive the comments about their paper in time to be considered in preparing the final version of the Formal Report. The quality of the comments is worth a small fraction the reviewer's (not reviewee's) Formal Report mark.

The final version of the Formal Report is due by the deadline specified in your course Lab Calendar. Late submission causes the deduction of 10% of the assigned mark for every business day of the delay.

Normally, students will be required to submit their course essays to Turnitin.com for a review of textual similarity and detection of possible plagiarism. In doing so, students will allow their essays to be included as source documents in the Turnitin.com reference database, where they will be used solely for the purpose of detecting plagiarism. The terms that apply to the University's use of the Turnitin.com service are described on the Turnitin.com web site.

If you object to the use of *turnitin.com*, you may submit only a hard-copy of your report, along with your rough work and earlier drafts and notes. Please speak with the Course Coordinator at least one week before the draft report deadline if you prefer to submit a hard copy only.

Plagiarism

Plagiarism is one of the most serious academic offences and is punished by severe penalties at the University of Toronto. Don't do it!

All students in the Advanced Physics Lab are expected to be familiar with the University's rules on Academic Misconduct available from the Student Academic Integrity team, Using Sources and How Not to Plagiarize from the University Writing Centre, and Using Sources Paraphrase and Plagiarism from the Engineering Communication Program. If you are an **Exchange Student** from another university, it is particularly important that you read and understand these University of Toronto policies, since the details may differ in important ways from your home institution. Ignorance of these policies is not accepted as an excuse for plagiarism. If in any doubt about whether what you are doing might be plagiarism, talk to the Lab Coordinator.

Never, never use sources without proper attribution. For example, our experimental write-up is an obvious resource you will use while writing your formal report, but **never copy text or figures from the experiment write-up into your report without careful and detailed attribution**.

Copying while simply changing a few words or reordering sentences is still plagiarism. Improperly copying only one or two sentences from our write-up into your Formal Report is sufficient for you to be brought to the Office of the Dean facing serious sanctions.

Remember, even if clear writing in English is difficult for you, it is better to lose a few marks because of that, instead of plagiarising and possibly getting zero on the Formal Report or the course and risking even worse punishment.

Oral Examination

All students will have an oral exam at the end of the course. This exam will last about 25 minutes in front of a panel of three professors and demonstrators. It will test your understanding of the experiments you have performed. You will be questioned only on the experiments on which you have actually worked. Both the experimental work and the underlying physics will be discussed. Note that the panel may not necessarily contain an expert on the experiment you are asked to discuss, so be prepared to explain the basic ideas and goals of each experiment. **Have all your lab notebooks, plots, and other associated files available.** See the course web site for the guidelines on how to prepare for your oral exam: http://www.physics.utoronto.ca/~phy326/oralguidelines.htm

SAFETY

Safety is everyone's responsibility. The staff do their utmost to ensure a safe learning environment, but in the end **it is your skin**. Students should always consider any potential risks involved in an experiment, e.g. those associated with the use of X-rays, radioactive sources, lasers, ultraviolet light, cryogenic fluids, high voltages, heating elements, heavy equipment, heavy metals, cutting edges, chemicals, particulate dust, intense sound, high pressure gas, or vacuum. **Food and drink are not allowed in the laboratory.** On the course web site there are links to the Health and Safety web site of the Physics Department, which every student should be familiar with. In particular, there is important information on Emergency Responses, Hazards you may encounter in this course, and Safety Training.

Before starting each experiment, **you must read the experiment write-up and note any safety issues** mentioned. If you are unsure about any safety issues, ask the the lab staff. You must use any safety equipment provided, and ask for it if is missing. Immediately contact lab staff if you notice any unexpected safety issues, e.g. a puddle on the floor, an exposed electrical wire, excessive noise, …. All safety related incidents, including close calls, must be reported to lab staff.

COVID-19 Lab Safety

Read and follow the UofT In-Class COVID-19 Guidelines

APL Specific Guidelines

- You must always wear an approved mask.
  Masks with exhalation valves not allowed
- When entering, walking through, and leaving rooms and in the halls, maintain physical distancing as much as possible.
- Never touch another student's experiment or equipment.
- If you use shared equipment, first wipe it down and wash hands before and after using.
- Labs will be closed between experiment to allow viruses to die.
  – i.e. You must get all your data by Day 7.
- Obey any room capacity restrictions.

Safety Equipment

Students must use safety equipment as provided, e.g. safety & laser goggles or glasses, face-shields, gloves, and ear-protectors. If you think you are missing relevant safety equipment, please ask any of the lab staff. Sandals are not safe lab footwear.

Radiation

Any student wishing to perform an experiment involving the use of an X-ray machine must wear a radiation dosimeter. These may be obtained from the APL Technologist in MP 234. Dosimeters are not to be taken home, but returned to Room 234.

Some experiments require the use of radioactive sources. These must be signed out from the APL Technologist in MP 234. Radioactive sources must never be left unsupervised, and must be returned to the APL Technologist whenever the student leaves the lab.

Fire

Students should immediately notify lab staff if they smell any burning odour or see smoke.

If the fire alarm sounds, students **must** immediately exit the building. Do not use the elevator. (Please notify the Lab Coordinator at the beginning of the course if you have mobility issues that might prevent you from using the stairs.) DO NOT RE-ENTER until authorized by Fire or Police Personnel.

LAB PROCEDURES

Experiment sign-up

An Experiment Preference, Contact, & Schedule Sheet is available before the course starts. Please fill this out and email it to the Course Coordinator as soon as possible. Before the first lab period, the experiment for each student will be posted on Experiments Assignments page on Quercus. Subsequent experiments will be posted near the end of the current experiment. Note that if there are free experiments, you are allowed to switch your choices with approval of the lab coordinator. Students in PHY424 and PHY327 must do experiments supervised by 3 different professors.

Not later than the first day of a new experiment, you must contact the supervising instructor for that experiment. This is to ensure the professor knows you are actually starting the experiment and what your schedule is, and so the professor can pass on any important information. It is not uncommon for the experiment writeup to not be completely up-to-date, so it is important to talk to the professor and TA at the beginning of a new experiment.

Attendance

Steady work on your experiment is vital to your success in this course. Although the lab is open Monday through Friday 9:10am-4pm, you are generally expected to be in the lab at least weekly during an official lab period. Missed too many official sessions may result in a reduced experimental mark. Exceptions to this rule may be granted in advance by the professor supervising the experiment. Indeed, some experiments require larger individual blocks of time to complete, and cannot fit into the two 3-hour sessions per week schedule. It is not uncommon for students to have a lecture that conflicts with the lab; please make sure this is indicated on your Contact & Schedule sheet and is brought to the attention of the professor supervising the experiment.

If you unexpectedly miss a lab because of illness or similar problems, please inform the professor supervising your experiment as soon as possible. If you need any ongoing accommodation, please contact the Lab Coordinator at the beginning of the course.

Communications

Notices may be posted from time to time via Quercus or email - please read them. You can contact the professors outside lab hours either by e-mail or phone.

Students are responsible for checking the Quercus website and your official UofT email address regularly. Instructors and TAs will attempt to respond promptly to emails. If you do not receive a response within 1 business day, email again.

Communication - oral and written, in person and electronic - is a critical part of this course. If your English is not fluent, please check out the University of Toronto's English Language Learning resources.

Lab Computers

All experiments have an associated lab computer, but you may wish to bring your own laptop. For temporary saving your files, it is possible to use My Documents folder of the lab computer. **To store data safely, use** either **a USB memory stick** or upload it to Cloud storage. Don't rely on the folder My Documents as it can be erased or overwritten and **important data can be lost forever**. All computers in the laboratory should have Python, MS Office, and MATLAB installed, and some may have other useful software. All lab computers are connected to a free printer in MP 251, but printing is currently discouraged; please use the online materials, and save plots to a folder that can be uploaded along your notebook.

NOTEBOOK GUIDELINES

In the lab, **you must maintain laboratory notebook where you record all observations and preliminary data calculations in your own hand-writing. Your lab notebook must be in journal diary format, with events and thoughts recorded as they occur.** We do not permit writing on loose pieces of paper. The keeping of lab records by students in the Advanced Lab is part of your training. We expect that your notebook will resemble that of a professional scientist or engineer.

Only bound paper notebooks are allowed. You are not allowed to take notes on your laptop/tablet, unless prior written permission has been obtained from the course coordinator and the instructor supervising your experiment. You may, however, record data in your laptop/tablet, as long as this is properly referenced in your notebook.

Your lab notebook is key to your success in this course, so read these guidelines carefully.

WHAT THE NOTEBOOK IS FOR:

The notebook provides both a structure for recording your experimental work and a record of that work. Thus, records and calculations made during the experiment are systematised by being written in the notebook. A neat well organized notebook is very much appreciated, but clarity comes second to completeness. In a research or engineering environment, these scientific records are kept for later use.

For example, a typical research scenario is a data-run on a machine on which a group of 15 researchers work round-the-clock for two weeks. During that time, machine and experimental problems arise and are solved (or not solved), experimental details are changed, sometimes according to the original plan, but also to answer new questions posed by the data obtained. At a later time (sometimes years later) the data from this run is combined with data from other runs, final calculations are made, and a paper is submitted for publication. Months later, the paper gets returned by the journal's referee with comments requesting revisions. The original data and calculations are then used as a basis for revisions. The revised paper then gets published. Finally, ten years later, there is a patent dispute based on findings from the experiment. In the court proceedings, the original lab notes are used as evidence.

Your Advanced Lab notebook is unlikely to figure in a patent fight, but a good notebook will help you do better experiments, write a better formal report, and do better on your final oral exam.

CHOICE AND DESIGN:

One characteristic of a good Advanced Lab experiment is that the student must make many choices that design the experimental process. You are not following a cookbook recipe, so your design choices and the reasoning behind them should be documented in your notebook. e.g. Why did you investigate this physics question? How did you decide how much data to take? Why use this analysis method? How did you modify your plans as you learned more about the experiment? How did you decide when you had finished the experiment?

If your choices turn out to be less than optimal, the reasons why should be noted, and ideas for improved experimental design should be noted.

WHEN ENTRIES ARE MADE IN THE NOTEBOOK:

Whenever you do any work on an experiment, you must be making entries in the notebook. Your notebook record of an experiment should start with a brief description of what the experiment is all about. The next entries should be jottings on your preliminary background reading and investigation. The book should then progress through records of your experimental set-up, should include data (which are both numbers and narrative) and calculations, and end in evaluations and conclusions. **All these entries must be made simultaneously with the actions they describe.** Thus, indications of apparatus idiosyncrasies must be written at the time the idiosyncrasies are observed, not two weeks later.

As a general rule, **if your pen touches paper in the lab, that paper should be a page in your notebook**, or a page (e.g. a printed plot) that will be attached to your notebook. This includes everything: quick calculations, rough notes, reminders, doodling while you wait for your equipment, …. Never erase or use whiteout in your notebook; if you make a mistake or enter incorrect data, simply cross it out but leave it legible. **All documentation** - the notebook, associated plots and computer files - **must be kept until after the end of the course** and be available to your instructor on request.

WHAT SHOULD BE ENTERED IN YOUR LAB NOTEBOOK:

- Lab notebook entries should always be in pen, but pencils are allowed for sketches and diagrams.
- Every page should be sequentially numbered from the beginning of the notebook and have the date at the top. Never tear out any pages or use a notebook with missing pages.
- Dates (and times) should be liberally spread throughout the data/figures/narratives. “When” and “how long” are important experimental information, and they also help you (and your professor) navigate your notebook. Recorded times are sometimes the key to solving problems.
- **Everything you do in the lab should be described**, at least briefly, even if only to note “Started experiment. Playing with equipment to see how it works.”
- **Record all help or information you receive** from any professor, demonstrator, technologist or another student. It is best to note every time you speak with the supervising professor, even if only "11:02 am: spoke with Prof. XXX".

- When you leave the lab, you cannot assume that your experiment will be untouched until you return. For example, a professor or technologist may need to check something out, or a power glitch may erase all your electronic settings. Your notebook must have sufficient information for you to be able to set it back the way you want it when you return.
- Sketches or photographs of apparatus and of important details of apparatus, with at least some dimensions. In most cases, *schematic* representations are preferable to pictorial detail. This is particularly relevant to cabling and circuits.
- Data: numbers, comments and descriptions, systematically entered (in tabular form where possible). All data should be included, even data that failed (with annotation of why they failed). **Error estimates are an important part of your data**. If Data is recorded electronically, e.g. either automatically or entered into a spreadsheet, this should be noted in the notebook and the electronic files clearly named and cross-referenced. Any notable occurences in the data should be mentioned or otherwise annotated, e.g. if you change the system while recording data and the data jumps.
- Preliminary calculations based on the data, preferably also in tabular form, and preferably as extended columns in the data table. You do not have to include detailed arithmetic, although algebraic equations, explaining how each calculated column in the table was found, are useful.
- Preliminary graphs based on preliminary calculations and inserted with the data. Graphs should be well labelled and dated and should be liberally annotated with remarks about any features related to oddities in the data-gathering process.

  NOTE: These preliminary calculations and graphs should always be made while the data is being accumulated. Most experimentalists do a preliminary experiment and analysis to see if it all makes sense and to determine the best way to do the experiment. Then they do what they hope is the *real* experiment.
- Data or settings files, spreadsheets, code, and other electronic files must be clearly named and accurately referenced in your notebook, and uploaded along with your notebook to Quercus for the Progress Check and final experiment marking.
- Final, more elaborate, calculations and graphs (including error analysis). Be liberal with your cross-references, e.g. "Analysis of data from page xx".
- Final comments, conclusions, thoughts about the experiment.

SUMMARY/ABSTRACT:

- **A short (< 300 words) summary abstract must be the last entry before you submit your notebook.** This abstract is in addition to any final analysis and discussion, and should summarize your important accomplishments and results, with page references. When Professors are reading your notebook, this is their starting point. The summary abstract may be handwritten in your notebook or submitted as a separate electronic file that is cited in your notebook.

  For example: *This experiment studied the Cochrane-Wu effect (p.34) using a dysprosium phase compensator (p.37). The signal was too small to be measured with a pico-amplifier, and calibrating the pico-amplifier was very difficult (p.38-47), so several data runs (p. 43, 46, 49) had to be discarded. The results of the successful final data run (p.53) were consistent with Meitner-Laraque theory (p.55-61), but the Kazanga-Kurak constant was measured to be 1.56+/-0.2 (p.61-62), more than 3 standard deviations from the standard literature value of 2.21485(3). The largest contributions to the experimental uncertainty (p.64) were the statistical uncertainties due to the short final data run and the systematic uncertainty in the pico-amplifier calibration (p. 46, 63).*

LENGTH, ORGANIZATION AND WORK DONE OUT OF THE LAB:

Your notebook is your complete record and thus the entry for each experiment must be long enough to allow you to fully reconstruct the experiment from the written record. Note also that organization is essential to work in the lab. It is important for you to learn to plan what you will do and write before you start doing and writing in the lab. It is also important that you organize your work so that a minimum amount of time is spent working on your notebook after you have completed your experimental (and writing) work in the lab. Most of the entries in your lab notebook should be made in the lab. It is very important that you analyze data during the experiment, and not leave it all until the end.

IN GENERAL:

It does little good for you to take great data if the professor marking your notebook can't figure what you have done. **The notebook should be sufficiently complete that anyone reading it will know exactly what you did, what happened and what you think it means**. Note that long summaries of theory or essays on the physics involved are not expected in your notebook. Clear annotations, e.g. "This is wrong, see correct analysis on page XX", "Rough work", "Copied from Handout", are always helpful.

NOTEBOOK MARKING:

When evaluating your notebook for an experiment, professors will not read your notebook in order from start to finish. They will start by reading the summary/abstract and work backwards. They are unlikely to read all of your notebook, but they will expect it to be a complete record of what you did, so they can find any information needed to understand your work and conclusions.

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