Physics 409

A Practical Course in

Experimental Physics

Winter Session 2007-2008

Department of Physics and Astronomy
University of British Columbia
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Contact Information

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COURSE WEB SITE: `http://musr.physics.ubc.ca/p409/`

Important Dates

Thu 06 Sep	Introduction to PHYS 409
Fri 07 Sep	Choose your first experiment!
Mon 10 Sep	Start first experiment.
Mon 24 Sep	Tutorial: how to give a good 10-min talk
Mon 01 Oct	Exp't #1 Presentations, I - TBA
Tue 02 Oct	Exp't #1 Presentations, II - TBA
Thu 04 Oct	Feedback on Presentations; LaTeX tutorial
Mon 08 Oct	*Thanksgiving*, Lab closed
Tue 09 Oct	Draft Reports due
Mon 15 Oct	Draft Reports edited and returned
Tue 16 Oct	Choose your second experiment!
Mon 22 Oct	Final Reports due
Tue 23 Oct	Start second experiment.
Wed 07 Nov	Exp't #2 Presentations, I - TBA
Thu 08 Nov	Exp't #2 Presentations, II - TBA
Mon 12 Nov	*Remembrance Day*, Lab closed
Tue 13 Nov	Feedback on Presentations; Overview of P409B in Spring
Mon 19 Nov	Draft Reports due
Thu 22 Nov	Draft Reports edited and returned
Thu 29 Nov	Final Reports due!

Contents

Introduction to Physics 409

Physics 409 is designed to be a practical introduction to how experimental physics is performed beyond the undergraduate level, whether in industry or within academia. Pursuant to this goal, undergraduate students must learn how to integrate all of their previous training and how to be resourceful when confronted with the unfamiliar. From the standpoint of the student, there are two things that one should want from this course:

- **A Grade.** Enough said; this is a school, after all ...
- **A Letter of Reference.** You will be graduating soon. Whether you are aiming for graduate school or a career in industry, you will need someone within the university to vouch for your abilities. The instructors of laboratory courses are often your best choice when requesting letters of recommendation.

From an instructor's perspective, we want students to learn the following from this course:

- **New Physics.** The phenomena studied in this laboratory may not have been taught in any of your classes; in fact, the experiments may even outpace your theoretical physics education. Seize this opportunity to learn new tricks!
- **Practical Experience.** Learn how to do practical things such as building simple circuits and analyzing real data in a laboratory setting where the situation is frequently less than ideal. Experimental physics, much like life itself, rarely goes according to plan.
- **Communication.** "In science, it is important to be right. But (perhaps) it is more important to be interesting." Wise words from a renowned theorist. All scientists share their data and ideas, but only those who present their work *clearly* and in an *interesting* manner gain recognition (and reap the rewards). Learn the art of telling a good story by writing a *scientific journal article* as opposed to a lab report. Make your oral presentations *clear* and *interesting* so that the audience pays attention and learns from you.

The instructors intend to provide a mature and enjoyable learning environment. We hope that you will become an active student willing to learn new concepts and try new experiments. Above all else, we want you to communicate with us. Feel free to ask for assistance in the laboratory or engage the instructors in a discussion of the theoretical physics involved in your experiment — we are here to make this as profitable an experience as you desire.

Laboratory Notebooks

In order to emphasize the importance of maintaining complete records of one's experimental work, a laboratory notebook is essential. Lab books provide a detailed history of an experiment so that those who come after you may follow your progress, and so that you will have all the information available when preparing your written articles. It will also be an element in evaluating your performance in the laboratory once the course has been completed. A certain degree of organization, neatness and æsthetics will make the information in your lab book more accessible, but we mark mainly on appropriate *content*. (By "appropriate" content we mean anything of note and use; there is always the possibility that something will go wrong and you will have to be able to spot the problem and deal with it in short order, mostly on your own.)

Oral Presentations

A prized virtue among researchers is the ability to give a good 10 minute oral presentation. As you may already know, giving a short talk can often be more difficult than giving a longer speech since you must cover so much in what always seems an inadequate amount of time. Many people imagine that the solution is to speak quickly; however that is the worst possible course of action. In this course the emphasis shall be upon slowly explaining the physics behind an experiment through diagrams, heuristics and (if necessary) the occasional equation. For reference, here are the key elements that should be considered when designing a 10 minute presentation:

- *Never* present long mathematical derivations.
- Use diagrams and pictures to explain difficult concepts.
- Pace your presentation such that you do not use more than one overhead per minute on average.
- Overheads should not contain a large amount of text, rather you should provide the explanations — *do not* read from your slides.
- Use titles and labels on every picture and number the equations.
- Stay focused upon the *take-home message* to be drawn from the presentation.

You will be given a brief talk on "giving a 10 minute presentation" prior to your own presentations. This will also be made available to you on the website. *Nota bene:* All presentations must be emailed to the designated TA or Instructor as a *PowerPoint* (`.ppt`), *OpenOffice* (`.odp`) or `Portable Document Format` (`.pdf`) file **the day before you are to give your talk, no later than 6:00 p.m.**

Written Reports

An unfortunate truth about undergraduate science education is that there is negligible emphasis placed upon developing good writing skills. Too often science students are pressured to produce large quantities quickly, but little feedback is provided concerning the quality of the writing. It is hoped that Physics 409 will help rectify this situation. Therefore, more than adequate time is

given for you to produce a rough draft and final copy of your formal report on each experiment and the formal report will take the form of a journal article.
Submission of Formal Reports

In order to ensure that good writing habits develop and to prepare you for writing scientific journal articles or technical reports, the editing process shall be embedded within the course curriculum. The process will involve submitting laboratory reports twice — a first draft generated by you which will be ruthlessly edited by the instructors and then returned for you to make corrections. This process is much more beneficial than the conventional one of just submitting reports and then receiving a grade. Furthermore, it emulates the use of referees in the submission of research papers to major scientific journals. The following procedure will be followed when submitting laboratory reports:

1. **Write a rough draft** — Writing a rough draft by hand will often make the job easier and will result in a superior final product along with a much higher final grade. Do not sit in front of a computer monitor trying to piece together perfect sentences; rather write whatever comes to mind by hand and then edit on the computer later.

2. Prepare and Submit First Draft — Submit the finished product by the specified date. Reports *must* be prepared using LaTeX. A template is available to you on the website and a portion of a class will be devoted to answering any questions you have about any aspect of using LaTeX. The final product should be a *Portable Document Format* (`.pdf`) file and is to be e-mailed to the designated TA or Instructor, one of whom will be assigned to edit your first draft. **We do not accept hard copies or any other file formats.** The TAs will then go through your reports noting all necessary corrections in spelling, style, grammar, and physics. Your TA will meet with you then to discuss your report before you begin working on your final draft. At this point you will also receive a mark on your draft based on the marking scheme shown below along with any general comments on the report made by the TA; please note that the mark on the draft is merely an indication of the quality of the draft and does not in any way represent a final grade. However, it is hard to provide corrections and helpful suggestions on an unfinished draft. . . .

3. Modify and Submit Second Draft — First drafts will be returned with grammatical errors, ambiguities and structural problems noted. The first draft should be modified in order to meet the concerns and a final fresh draft submitted. Again, please submit drafts in `.pdf` format.

At the end of the procedure, you will be given the completed marking sheet and a written critique based upon the second draft. As the second draft represents your best effort, it will have the most bearing upon your final grade.

Formal Report Style

Physics 409 will emphasize periodical style writing (clear, concise, and relatively short), as opposed to thesis style writing (extremely detailed, relatively long). Therefore, you should choose a particular periodical (PHYSICAL REVIEW, IEEE, *etc.*) and model the structure of your report accordingly. The preferred format is that of the PHYSICAL REVIEW family of journals, for which the TA will provide you with LaTeX software and a documented journal article template.

One particular aspect that deserves special emphasis is the presentation of graphics. Graphs should be labelled clearly and a caption should be provided to tell the reader explicitly what it is they should be concluding from the graph. Much of this is under your control; however we ask that you recognize that many graphing packages place severe limitations upon what you can accomplish. **In particular, we will not accept graphs generated from** ***Microsoft Excel*****.** Please choose more appropriate software for generating graphics.

A Note Concerning *Mathematica:* Quite simply, we don't feel you will find a more powerful PC/UNIX based number crunching package (although *Maple* is pretty good too), but both typically produce horrible graphics. We therefore heartily endorse the use of *Mathematica*, *Maple*, *MatLab* or any of the various Open Source analogues when performing data analysis and we will accept graphs generated by same, but we ask that you please take the time to learn how to label and scale these graphs appropriately, as the default options usually make a mess. We will provide a fitting and graphing tutorial prior to the submission of the first paper.

The Project

The final task (to be completed by those who want 6 credits) is a project of your own design. It will be your responsibility to formulate an experiment that is manageable within both time and budgetary constraints. The purpose of this exercise is to introduce the student to a situation in which there are no explicit instructions — much more akin to real research. M ore details will be made available prior to the end of semester I.

Schedule

A list of due dates has been presented on page 3 of this manual. The course will end in late March, but manage your time carefully.

The TAs for course are available 13:00 → 17:00 on Monday & Tuesday, and 13:00 → 15:45 on Thursday; PHYS 409 has priority on the equipment at these times. The Thursday time has been adjusted to accommodate the weekly Departmental Colloquium, which is of great interest to the instructors and **you are urged to attend**. The Colloquia provide an excellent opportunity to learn about prospective projects for graduate studies. The lab itself is open most days from 09:00 until 17:00 provided Tongkai is in; if you need to be in the lab at times when the TAs are unavailable, please schedule *in advance*with Tongkai and keep in mind that we share some experiments and equipment with PHYS 352 and that they have priority during their scheduled times.

Allocation of Marks

For the 3 credit version of the course (PHYS 409A):

Oral Presentation, Experiment 1	15
Draft Report for Experiment 1	5
Final Report for Experiment 1 2	25
Lab Performance and notebook for Exp't 1	5
Oral Presentation, Experiment 2	15
Draft Report for Experiment 2	5
Final Report for Experiment 2 2	25
Lab Performance and notebook for Exp't 2	5
TOTAL	100

For the marking of the *draft* report, we employ the following scheme:

Component	Criterion	0	1	2
Abstract	*Clear Purpose, Key Results*			
Introduction	*Motivation for Experiment, Background*			
	Clear Objectives			
Theory	*Concise Description of Theory*			
Experimental Methods	*Description of Apparatus*			
	Procedures			
Results and Analysis	*Data Quality*			
	Data Presentation			
	Analysis and Interpretation			
Conclusions	*Summary of Experiment, Results*			

0 = POOR 1 = FAIR 2 = GOOD: see comments on report

For the marking of the *final* report, we employ the following scheme:

Component	Criterion	Weight	Mark
Abstract	*Clear Purpose*	5	
	Key Results	5	
Introduction	*Background and Motivation for Experiment*	6	
	Clear Objectives	3	
Theory	*Concise Description of Theory*	6	
Experimental Methods	*Description of Apparatus*	10	
	Procedures	5	
Results and Analysis	*Data Quality*	10	
	Data Presentation	15	
	Appropriate Error Estimates	5	
	Analysis and Interpretation	15	
Conclusions	*Summary of Experiment and Results*	10	
References	*Adequate Documentation*	5	
Adjustments			
TOTALS		100	

For the marking of *oral presentations*, we employ the following scheme:

Oral Presentation Evaluation

Component	Criterion	Weight	Mark
Delivery	*Clear and Audible*	3	
Visual Aids	*Legible Overheads*	1	
Content	*Clear Purpose*	3	
	Clear Explanation	3	
Time	*Not Exceeding 10 Minutes*	3	
TOTALS		15	

Late Policy for Written Work

As you are a fourth year physics student, we will trust your time management skills. We also understand that you do have other courses and lives to lead, and so there will be times when you may not be able to meet a particular deadline. Therefore, if you have serious problems with meeting any deadline, no matter what your reason, please speak to one of the instructors. Unfortunately, it has proven necessary in the past to invoke a late policy. The late penalty will be 5% per day for all written work.

Miscellaneous

Computer Facilities

The Physics 409 laboratory has a variety of computing facilities available for your use. There are three computers on carts with IEEE-488 bus interfaces and one computer on a cart with a pulse height analyzer. In addition there are three black PCs on the benches North of the entrance to the lab. One of these usually runs Linux, but is dual-booted with Windows XP, which is the operating system on the other black PCs. The PCs on the benches to the South of the entrance are normally reserved for PHYS 352 students.

A colour printer is available for your use if needed (very handy for preparing presentation slides). Ask a TA or Instructor if you need to use it. All of these computers are connected to the Phys409 intranet and to the Hebb building backbone. All the PCs running Windows have X-Win32 and SSH/SFTP software for interfacing with the Physics server. For the Linux machine, this is of course simpler. If you have to log into one of our PCs, then enter '`P409`' as the user and '`p409`' as the password.

Experiment Manuals

To conserve some paper, we have chosen not to print a copy of the entire Physics 409 manual for each student. This document is becoming rather lengthy. Rather, you will be supplied with a copy of the manual for those experiments that you choose to study. Please return these manuals at the end of an experiment, or ask the Instructors if you would like your own copy. An electronic copy of the manual (in `.pdf` format) is available on the website for many of the experiments.

These manuals range from rather lengthy LaTeX documents (mostly prepared by previous PHYS 409 instructors and TAs) to published papers that discuss a similar experiment. Some of the manuals are older and out of date; others are newer and less complete. Most are in some sense "works in progress". None of these manuals provide you with a "recipe" for performing an experiment. Rather, the intention is to supply you with sufficient knowledge for you to make rational choices about how to study a physical phenomenon.

Do not hesitate to seek information from other sources.

Brief Description of Available Experiments

The following are meant to give you some guidance in choosing which experiments you would like to perform this semester. Please ask for a complete experiment manual if you want more details. I have also indicated those experiments which are conceptually or practically difficult, and I encourage those who have excelled thus far in their undergraduate career to try these experiments.

- **Electromagnetic Skin Depth of Metals**

  A fundamental picture of electron conduction in normal metals is presented and then compared to theory. The experiment involves driving screening currents in a metal cylinder by applying a magnetic field and then measuring the attenuation of the field. This experiment should be considered essential for those who wish to study condensed matter physics.

- **Thermal Noise**

  The characteristics of thermal noise in an electrical circuit are examined. This is primarily an equipment-oriented experiment, however it does attempt to measure the fundamental constant k_B via the Nyquist formula.

- **Pulsed Nuclear Magnetic Resonance**

  The fundamentals of NMR are presented in a semiclassical manner and the concepts of spin-lattice and spin-spin relaxation are introduced. Measurements of the relaxation times are made upon a sample of liquid glycerin. This experiment should be regarded as essential for those who wish to study condensed matter physics and *absolutely necessary* for those interested in medical imaging (MRI).

- **Magnetic Resonance Imaging in 1 Dimension (Difficult)**

  Using the principles of NMR, a theoretical framework for imaging along a one dimensional axis is developed. Practical considerations of signal processing are used to determine appropriate experimental parameters and a specially designed sample is imaged. It is necessary that the student at least read and understand the Pulsed Nuclear Magnetic Resonance experiment prior to attempting this experiment.

- **Chaotic Rhythms of a Dripping Faucet**

  This experiment introduces the student to the field of nonlinear dynamics using a relatively simple phenomenon - water dripping through an orifice. The period between drops can become chaotic if the system is driven correctly.

- **Muon Lifetime**

  Measurement of the lifetimes of elementary particles known as muons ($\mu^{\pm}$) produced from the decay of mesons which are created by nuclear reactions between primary cosmic rays and heavy nuclei in the upper atmosphere. Muons which make it to the Earth's surface are stopped in a large scintillator counter and their later decay into electrons (or positrons) is detected by the same counter. This experiment affords the student an opportunity to learn the basics of assembling a particle physics apparatus and to explore some literature on subatomic physics.

• **Atomic Energy States (Frank-Hertz)**

Measurement of the first excited state of mercury using an electron bombardment technique developed by Frank and Hertz. This is a classic experiment that has been retained for its historical value.

• **Electron Spin Resonance (Difficult)**

An introduction to the methods of ESR using frequency domain spectroscopy. An applied dc field is used to split an electron energy level and the resulting linewidths are observed. The line broadening is attributed to many body interactions in a condensed matter system. This experiment is designed for those who wish to study condensed matter physics.

• **The Magnetization of a High Temperature Superconductor (Difficult)**

A new experiment in which the Meissner effect of the high temperature superconductor YBCO ($YBa_2Cu_3O_{7-\delta}$) is quantified using an AC magnetic susceptometer. This experiment involves cryogenics, thermometry, vacuum techniques and small signal detection. At this point in time there is still no microscopic theory for how high temperature superconductivity works, so this is a very modern and relevant experiment.

• **Positron Emission Tomography**

A new experiment in which "back-to-back" gamma rays from electron-positron annihilation following a nuclear β^+ decay are used to image a sample in one dimension.

Recent Additions:

• **Optical Pumping**

Optical Pumping is a widely used and powerful technique for exploring atomic energy states, atomic transitions and atomic collisions using electromagnetism in the form of light, radio frequency, and uniform constant magnetic fields. Using the *TeachSpin* apparatus you can explore temperature dependent cross-sections for photon absorption, zero magnetic field transitions, spin-spin collision processes, field inversion measurements, Rabi oscillation of the atomic magnetic moment, optical pumping times and other atomic physics phenomena.

• **Earth's Field NMR**

The *TeachSpin* apparatus facilitates an understanding of precession, the Curie Law of paramagnetism, spin-lattice relaxation and spin-spin coupling. In this very low-field experiment the polarization signal changes on a "human time scale" of seconds, and precession frequencies are in the audio range.