Objective: PHY242 Spring 2022

Lecture: Tuesdays 9:25 - 10:40 am
Lab Section 1: Tuesdays 1:10 - 4:00 pm
Lab Section 2: Thursdays 9:25 - 12:15 am
Lab Section 3: Thursdays 1:10 - 4:00 pm

Course Title: Research in High Precision Spectroscopy
Instructor: Will Williams, wwilliams@smith.edu Postdoc: tbd
Office Hours: to be posted on Moodle

Readings: (all textbooks are provided by the Physics department)
- Experimental Physics by Walter Fox Smith
- An Introduction to Error Analysis by John R. Taylor
- Supplements written by Will
- Guidelines for Writing a Scientific Paper by Celia M. Elliott

Course Description: This course will give you a practical introduction to experimental atomic physics by having you do real, publishable research. While this course-based-research program is focused on high precision spectroscopy, you will gain skills that can be generally applied to investigational science in experimental design, experimental iteration/systematic error analysis, data analysis, and writing scientific papers for publication. In addition, you will learn about basic atomic physics and quantum mechanics, atom/light interactions, optics, and gain a basic understanding in how experiment and theory interact to further our knowledge of nature.

Learning goals: By the end of PHY242, my goals for you are:
1) Experimental skills: I want you to:
   a. Recognize and be able to design basic spectroscopic experiments, including saturated absorption spectroscopy and grating spectrometers.
   b. Understand different methods for measuring the frequency of a laser to high precision, including wavemeters and frequency combs.
   c. Learn how to use important scientific equipment, including an oscilloscope, lock-in amplifier, and a PID controller.
   d. Document your work, especially on (a) and (b), but since a lot of learning happens in (c), you should document some of that too.
2) Theoretical skills: I want you to:
   a. Understand basic atomic properties, including discreet energy levels, fine structure, and hyperfine structure.
   b. Learn basic data analysis techniques, including error propagation, fitting of data, statistical uncertainties, and systematic uncertainties.
3) Writing skills: I want you to:
   a. Write scientific results for submission to a peer-reviewed journal. While an ambitious goal of each group is to submit a paper for publication in a peer-reviewed journal, each group will write up their results as work ready for submission, regardless of the final progress of the group. The writing of the scientific paper will be heavily assisted by Professor Williams and/or the postdoc.
4) Other skills:
   a. Most of learning goal 1) will help further develop your critical thinking skills. Some of the most important skills a physicist has is the ability to decompose complicated problems into smaller problems, assess results, and debugging. Through the learning goals outlined in 1),
How PHY242 is structured for learning:
Theory: one synchronous 75-minute meeting each week and one asynchronous 50-minute meeting each week (2 hour, 5 minutes total)
Experimental: one 2 hour, 50 minute meeting each week
Total class time: 295 minutes (4 hours, 55 minutes)

This course has a theory portion and an experimental portion. The synchronous theory portion of the class is Tuesday morning from 9:25 - 10:40 am. This time will be spent learning background knowledge and working on course modules. Each week will have a different topic with assigned homework from these topics. In addition to the synchronous theory class, there is also an asynchronous portion. Once a week, each group will meet with for 50 minutes to a) discuss progress, b) develop a “plan of action” for their next experimental session, c) assign tasks to be done before their next meeting, d) update the lab notebook with these tasks, and e) write a short report to be given to Professor Williams and/or the postdoc. It is encouraged that these meetings happen during a different experimental section where Professor Williams and/or the postdoc will be available,¹ but I recognize this may be hard to schedule.

Because there is one laser source for all experiments,² there are 3 sections for the experimental portion of this course, one for each group. Each group will have their own experimental setup. Each group will meet and work on their experiment for the full 2 hours and 50 minutes each week at their assigned lab time. Given this time constraint, it is imperative that you arrive prepared and ready to go.

While groups can only use the calibrated laser source during their assigned section, the groups can meet at any time and use the non-calibrated laser source, including during another groups assigned section. This laser source, while a bit harder to use and has no frequency calibration, can be used to setup the experiment and study certain systematic effects. Additional meeting times to use the calibrated laser can also be scheduled with Professor Williams or the postdoc.

The modules: The theory portion of this course will contain both mini lectures and course modules. The course modules will allow you to explore concepts more in depth. The modules will include additional readings, using premade computer programs, writing programs, building simple spectroscopy experiments, and working on group problems. We have about 75 minutes per week to spend together synchronously for this purpose, so, it is very important that you are successful in your class preparation each week, which is done outside of synchronous class time.

Since this is a 4-credit course, and Smith expects you to spend an average of ~12 hours per week on this course, we will have an average of ~7 hours of asynchronous work to do each week outside of class time so that you will be well prepared for the ~5 hours we will spend together. Those 7 hours will be used for class preparation, homework, or meeting with your group to work on your experiment outside of the assigned synchronous times. I will assign the bulk of the reading/viewing to happen between each Thursday’s class and the following Tuesday’s class, though there will occasionally be at least some things to read/view between Tuesday and Thursday each week. Before we meet on any given Tuesday or

¹ Priority will be given to the experimental group assigned to that section.
² High precision spectroscopy requires a well behaved, calibrated laser. Our laser is a frequency doubled titanium-sapphire laser calibrated by a frequency comb, both topics we will learn about in the theory part of the class. This laser system, which is housed in McConnell B01, is state-of-the-art and cost over $500,000. This is why we have to have 3 sections 😊
Thursday, I expect you will have read or watched and engaged with the materials I have posted. There will also be some short self-test problems for most reading/viewing assignments and Pre-Class-Check-In’s (PCCIs) where you can test your understanding of the posted materials. Self-test problems will have solutions available to you after you submit your work. To receive full credit for self-test problems, you must look at the solution and write a short paragraph comparing your solution to the posted solution. I will check your reflections regularly.

Self-Assessments: There will be 4 self-assessments taken through-out the semester. The intent of the self-assessment is to help you identify areas of improvement and re-focus your commitment and engagement in the experimental portion of the course.

Weekly Homework: You will receive approximately one homework assignment per week. Typically, the weekly homework will be due one week after it is assigned. The weekly homework assignments and due dates will be handed out during class as well as posted on the website. Unless approved beforehand, late homework will receive at most half credit. Homework greater than one week late will not be accepted. You may work with others on the homework; however, what you submit must represent your own understanding of the problem.

The Final Project: At the end of the semester, each group will complete one of the following:
- A final poster presentation on their experimental work
- A journal quality paper ready for submission

The journal paper will be written in conjunction with either Professor Williams or the postdoc. If the project is completed by the end of the semester, we will submit the work to a peer-reviewed journal for publication.

Breakdown of your course grade:
Attendance and active participation in the synchronous class time will account for 30% of your course grade. This includes documentation of your work, which will typically happen once per week during your experimental section and the asynchronous theory portion of the course. Proper documentation will be discussed during the synchronous theory portion of the course. I highly encourage you to check in often about what your current grade is and how to improve it in this area.

Your final course grade is made up of 6 parts:
- 10% - Preparation, including the pre-class check-ins
- 10% - Self-test assignments
- 10% - Self-assessment
- 20% - Homework
- 30% - Attendance and active participation in the synchronous sessions
- 20% - Final projects

It is in your best interest to work with and support others. However, all turned in work must be your own. We will be using the standard Smith College rubric for final course grades (A = 93 or higher, A- = 90 or higher, B+ = 87 or higher, etc.).

Disabilities: I do not require a letter from ODS. If you have an accommodation, you just need to tell me what that accommodation is. You do not have to tell me your disability!! Frankly, it is none of my business. I 100% trust you and want to provide you the support you need to succeed. If you prefer, you can also contact the Office of Disability Services at ods@smith.edu to provide me a letter.
Preliminary schedule:

Week 1:
- Theory: Atomic structure
- Experimental: Discharge sources
- Readings: Supplement by Will

Week 2:
- Theory: Documentation Part 1, Doppler Spectroscopy
- Experimental: Saturated Absorption Spectroscopy
- Readings: Experimental Physics Chapter 10, Supplement by Will

Week 3:
- Theory: Documentation Part 2, Background needed for Saturated Absorption Spectroscopy
- Experimental: Saturated Absorption Spectroscopy
- Readings: Experimental Physics Chapter 11, Supplement by Will

Week 4:
- Theory: Saturated Absorption Spectroscopy
- Experimental: Calibrated spectrum
- Readings: Experimental Physics Chapter 11, Supplement by Will

Week 5:
- Theory: Data Analysis & Statistical Uncertainties Part 1
- Experimental: Calibrated spectrum
- Readings: Experimental Physics Chapter 4, Supplement by Will

Week 6:
- Theory: Data Analysis & Statistical Uncertainties Part 2
- Experimental: Calibrated spectrum
- Readings: An Introduction to Error Analysis Chapter 2, Supplement by Will

Week 7:
- Theory: Systematic Uncertainties Part 1
- Experimental: Calibrated spectrum
- Readings: An Introduction to Error Analysis Chapter 4, Supplement by Will

Week 8:
- Theory: Iterating experiments
- Experimental: Calibrated spectrum, Iteration Part 1
- Readings: An Introduction to Error Analysis Chapter 4, Supplement by Will

Week 9:
- Theory: Systematic Uncertainties Part 2
- Experimental: Calibrated spectrum, Iteration Part 2
- Readings: An Introduction to Error Analysis Chapter 5, Supplement by Will

Week 10:
- Theory: Systematic Uncertainties Part 3
- Experimental: Calibrated spectrum, Iteration Part 3
- Readings: An Introduction to Error Analysis Chapter 12, Supplement by Will

Week 11:
- Theory: The structure of science papers Part 1
- Experimental: Final data run Part 1
- Readings: Guidelines for Writing a Scientific Paper by Celia M. Elliott

Week 12:
- Theory: The structure of science papers Part 2
- Experimental: Final data run Part 2
- Readings: Guidelines for Writing a Scientific Paper by Celia M. Elliott
Week 13:
  Theory: Quantum electrodynamics
  Experimental: Final data run Part 3
  Readings: Supplement by Will
Week 14:
  Theory: Final presentations
  Experimental: Final data Part 4 (if needed), final presentations, paper submission (if applicable)