**Syllabus**  
**Physics 457W Experimental Physics**

**Instructor:** Dr. Kirstin Purdy-Drew  
122/123 Osmond (office hours by appointment)

**Teaching Assistant:** Jianxiao Zhang (Peter)

**Class:** Tuesday and Thursday 1:25-4:25 in 309 Osmond and 310 Osmond

**Required Material:** Handouts are provided on Angel page  
Scientific Lab Notebook from Bookstore (numbered pages, graphing paper, bound)

**Suggested Material:** Experiments in Modern Physics by Adrian C. Melissinos  
Get a free (75 day) trial of Kaleidagraph (the curve fitting software in the classroom):  

**Goals:**

1. Learn experimental techniques and fundamental physics guiding four experimental systems
2. Document experimental procedures, data collection using proper laboratory notebook techniques
3. Understand and properly discuss measurements using analysis techniques including curve fitting, uncertainty estimates, and error propagation.
4. Present measured results and demonstrate physical understanding of your experimental system(s) using formal scientific writing techniques by way of writing four lab reports.
5. Assess scientific writing technique through peer review of lab reports and reading of published scientific papers.
6. Learn data acquisition and analysis techniques common in research labs.
7. Learn to use and manipulate common laboratory equipment through reading of manuals.
8. Learn to search for and find references and resources to aid in understanding new physics concepts and/or equipment independently
9. Understand and incorporate responsible conduct of research ethics into class through homework, notebook recording, and discussion.

**Organization:**

- Students will do experiments in teams of two.
- Students will do 3 short and 1 long experiments, or two long experiments (advanced option – instructor approval and prior lab experience required)
- For short experiments, each team is required to choose one experiment from each of the three categories (see below).
- In addition to working on experiments, there will be extra activities (discussions, homework, etc.) dedicated to the following topics:
  - Responsible conduct of research
  - Understanding your data (error analysis and uncertainty) and curve fitting
  - Proper notebook writing
  - Proper citation
  - Peer review of lab reports
- Final lab reports will be submitted via Angel. Paper copies of reports will also be submitted for peer review. Final lab reports are due Wednesday of Finals Week.
Lab Notebook:
Accurately recording your daily experimental processes and numerical measurements as they happen is crucial to scientific experimentation, and will follow you throughout your future careers. You need to purchase a good notebook – those with permanent binding and pages numbered. You should be able to purchase one in the University Bookstore. All of your experimental procedures, observations, troubleshooting, data, analysis, explanations and justifications should be included in your lab notebook as it happens.

Lab Report:
The lab report is an important component of the course. There will be 4 (2) lab reports submitted. Each lab report will be expected to follow the format given on “scientific writing” handouts. While the data will be shared by two team members, each student will write his/her own lab report.

Content should focus on explaining the measurements which were done from the perspective of presenting it to a fellow student. You will present the background for your experiment, the details of how you did the experiment, your data, what your measurements actually mean (analysis) and how they compare to the scientific consensus. Because your aim is to describe this to a peer, your papers will be peer-reviewed by a student before they are graded by your instructor. Because of this, it is crucial that you provide good peer reviews and submit completed reports. A fraction of each report grade will be based on a combination of your submitted paper for peer review (which should be a final draft) and your peer review of others’ papers.

Final drafts of papers should be submitted on Angel. Drafts for peer review should be submitted on paper for the peer review process and on Angel if you want feedback from Dr. Drew.

Presentation:
At the end of the semester, all groups will be expected to present their final experiment in a 10 minute oral presentation. Presentations will be done as a group, and should incorporate all aspects of the experiment with emphasis on what you did, and your understanding of the physics guiding your experiment.

Grading:
457W
5% homework/ in-class assignments/safety training/participation in class discussion/ attendance
15% notebook (first 3 labs)
75% lab reports (15%,15%,15%, 30%)
For first 3 experiments:
   2% peer review participation (pre and post)
   13% final report
5% Presentation

General Grading Guidelines:
Guidelines for Notebook, peer review, and lab report grading will be given during the semester.
**Schedule:**

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<th>Activity 1</th>
<th>Activity 2</th>
<th>Grade/Homework</th>
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<tr>
<td>8/26,8/28</td>
<td>Experiment 1/Welcome / Introduction to uncertainty</td>
<td>Experiment 1 Scientific ethics and notebooks</td>
<td>Graded activity 8/26</td>
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<tr>
<td>9/2,9/4</td>
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<td>Graded activity, 9/4</td>
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<td>Experiment 2/ Writing Quiz/ discuss peer review</td>
<td>Experiment 2 / practice peer review / report 1 due for review</td>
<td>9/16 Quiz on Science of Scientific Writing 9/18 peer review homework due</td>
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<td>Experiment 2/ review of report 1 due</td>
<td>Experiment 2/ discussion of paper writing/ ethics and proper citation</td>
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<td>10/7,10/9</td>
<td>Experiment 3/ report 2 due for review/ go over areas of concern in homework</td>
<td>Experiment 3/ review of report 2 due</td>
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<td>10/14,10/16</td>
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<td>10/28,10/30</td>
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<td>Experiment 4/ final report 3 due</td>
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<td>11/11,11/13</td>
<td>Experiment 4</td>
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<td>Notebook submission 11/13</td>
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<td>11/25,11/27</td>
<td>Thanksgiving</td>
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<td>Experiment 4/ “How to give a presentation”</td>
<td>Experiment 4</td>
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<td>12/9,12/11</td>
<td>Final Presentations/ optional peer review for report 4</td>
<td>Final Presentations/ return of report 4 reviews</td>
<td>Final report due Wednesday of Finals Week</td>
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**Note to Students with Disabilities.**

Penn State welcomes students with disabilities into the University's educational programs. If you have a disability-related need for reasonable academic adjustments in this course, contact the Office for Disability Services (ODS) at 814-863-1807 (V/TTY). For further information regarding ODS, please visit the Office for Disability Services Web site at [http://equity.psu.edu/ods/](http://equity.psu.edu/ods/).

In order to receive consideration for course accommodations, you must contact ODS and provide documentation (see the documentation guidelines at [http://equity.psu.edu/ods/guidelines/documentation-guidelines](http://equity.psu.edu/ods/guidelines/documentation-guidelines)). If the documentation supports the need for academic adjustments, ODS will provide a letter identifying appropriate academic adjustments. Please share this letter and discuss the adjustments with
you instructor as early in the course as possible. You must contact ODS and request academic adjustment letters at the beginning of each semester.

**Experiments:**

**Fundamental Constants:**

**Speed of Light**

The velocity of light is one of the most important and intriguing constants of nature. Whether the light comes from a laser on a desk top or from a distant star, the speed of light is constant. The speed of light is also important for other reasons. It establishes an upper limit to the speed of any object, according to Einstein’s special theory of relativity, and objects moving near the speed of light follow physical laws which are drastically different from Newton’s laws. Some of the most accurate early measurements of the speed of light were those made by Albert Michelson between 1926 and 1929, using methods similar to those employed here.

**Current Balance**

The current balance is used to measure the force of repulsion between identical oppositely directed currents in parallel conductors.

**Cavendish Experiment**

In 1665, Isaac Newton proposed that all bodies attract each other, according to his famous law: $F = G \frac{m_1 m_2}{r^2}$, where $G$ is the gravitational constant, $m_1$ and $m_2$ are the masses of the two bodies and $r$ is the distance that separates their centers of mass. In 1798, Henry Cavendish constructed a device to measure $G$, using a torsional balance and masses. In this experiment, we will use the method of Cavendish to measure $G$.

**Millikan Oil Drop Experiment**

The electric charge carried by any object such as an elementary particle cannot take arbitrary values, but in fact is quantized: it can take on only an integer multiple of a fundamental value $e = 1.602 \times 10^{-19}$ C. This fact was first discovered experimentally by Robert Millikan in 1909, using an apparatus of his devising conceptually very similar to the one you will use in this experiment. His technique utilizes tiny oil droplets …

**Brownian Motion**

This experiment explores the relationship between the microscopic collisions of molecules of water with a micron sized spherical particle, and the macroscopically measured quantities, like viscosity and temperature. By observing and recording the thermal motion (Brownian Motion) of the sphere, you will be able to calculate Avogadro's number 6.02E23.

**X-ray Absorption**

When electromagnetic radiation is incident upon a material, part of the radiation is absorbed, part is transmitted and part is reflected. Due to the small wavelength of x-rays part of x-ray absorbance is due to the photoelectric effect. This results in interesting material-dependent absorption and transmission of x-rays through thin materials.

**Resonance and Interference:**

**Driven (Damped) Harmonic Oscillators**

Harmonic oscillators play a very important role in physics, and so it is necessary that you understand them well. In this experiment, you will be able to explore damped and driven harmonic motion with the Driven Harmonic Motion Analyzer (DHMA). The analyzer displays the frequency at which it is driving the mass-spring system and measures the amplitude and period of the oscillations. The operation and setup procedures are described in detail in the manual. Be sure to follow the setup procedures carefully before performing each of these experiments.

**Electron Spin Resonance (ESR)**
A free electron has spin $\frac{1}{2}$, which means the stationary states in an applied magnetic field have components of spin angular momentum parallel to the field of $\pm \frac{\hbar}{2}$. There is a corresponding magnetic moment $\mu = \pm \frac{1}{2} g \mu_B$.

**X-ray Diffraction**

When electromagnetic radiation is incident upon a periodic array of scattering centers, there are certain discrete directions for the incident ray that result in strong reflections. This is because of constructive interference of the radiation scattered from each of the centers. The directions for which these strong reflections occur are related through the Bragg law to the geometry of the arrangement. Therefore, measurements of the angles and intensities of the Bragg reflections can be used to deduce the arrangement and spacings of the scatterers.

**Chaos**

Explore the properties of a chaotic pendulum.

**Ultrasound**

Medical ultrasound technology uses refraction and reflection of sound waves in material to discern visibly hidden objects.

**Quantum effects:**

**Mosley's Law**

This experiment explores the relationship between x-ray absorption, fluorescence and atomic number.

**Franck-Hertz Experiment**

The Franck-Hertz experiment verifies that the atomic electron energy states are quantized by observing maxima and minima in transmission of electrons through mercury vapor. The variation in electron current is caused by inelastic electron scattering that excites the atomic electrons of mercury. The 1925 Nobel prize in physics was awarded jointly to Franck and Hertz for their discovery of the laws governing the impact of an electron on an atom.

**High TC Superconductors**

High-temperature superconductors exhibit superconducting behavior, e.g., the Meissner effect, zero resistance, etc., at temperatures which can be attained using liquid nitrogen. Below the critical temperature, the superconducting state may be destroyed by applying a large enough current or magnetic field. This occurs at the critical current density or the critical magnetic field, respectively.

**Electron Spin Resonance (ESR)**  (repeat)

**Millikan Oil Drop Experiment**  (repeat)

**Long Experiment:**

**Optics and Blackbody Radiation**

Three experiments will be performed. (1) blackbody radiation from a tungsten (W) filament. (2) optical absorbance and (3) photoluminescence of a molecular liquid (dye molecules).

**Compton Scattering**

In 1923 Compton discovered that when a beam of x-rays of well-defined wavelength is scattered through an angle by sending the radiation through a metallic foil, the scattered radiation contains a component of a well-defined wavelength which is longer than the original wavelength. This phenomenon is called the Compton effect.

**Mössbauer Effect**

measuring changes in the nuclear spectrum of $^{57}$Fe in different materials to determine the local magnetic and electronic environment. See G. Wertheim, Mössbauer Effect: Principles and

**Raman Effect**

**Muon Lifetime**
measure speed of cosmic-ray muons and infer relativistic effects; measure the lifetime of muons decaying at rest.

**Hall Effect**
determine the properties of charge carriers and the band gap in semiconductors. See Preston & Dietz, Chapter 17.

**Mosley's Law**
This experiment explores the relationship between x-ray absorption, fluorescence and atomic number.

**Saturated Absorption Spectroscopy**
This experiment used a tunable diode laser to measure the frequency shifts of hyperfine excited states in the Rubidium atom, as well as other properties of Rubidium.

**Nuclear Magnetic Resonance (NMR)**
Nuclear Magnetic Resonance (NMR) is a phenomenon which involves the magnetic moment of nuclei processing about a static magnetic field. If this nuclear spin system is exposed to a second oscillating magnetic field at the processing frequency, we can observe a resonance in the coupling. In this experiment, we use RF pulse sequences to probe NMR. We can prepare spins in a certain orientation and watch them relax to random orientation. NMR is a fundamental example of a resonance phenomenon and is also a technologically important tool, such as in medicine NMR imaging of diseased tissue.

**Electron Spin Resonance (ESR)**
Instead of probing the spin resonance phenomenon with nuclear spins in an external field, electron spin resonance (ESR) involves the resonance of the unpaired electron spin states. Because the electron spin moment is much larger than the nuclear magnetic spin moment, we have to use larger frequency microwaves to excite the resonance in an external laboratory magnetic field.

**Atomic Force Microscopy**
Obtain atomic resolution images with the atomic force microscope.

**Open Ended Projects**
There are a number of options for doing an independent project related to developing new experiments. Please discuss with the instructor during the first half of the semester if this is something you and your partner might be interested in pursuing. The types of projects available vary and depend on your individual background. Participation in an Open Ended Project requires a 1 page proposal which is incorporated into your final lab report grade.
Safety and Responsibility:

Clean up your area: at the end of each class make sure that you have returned all your equipment to its appropriate location. If you do not know where that is ASK! Your TA must approve your areas cleanliness before you may leave.

Special considerations:

- Current balance – the lids on the liquid conductor must be returned and lifted so there is no tension on the wire
- SHM and Chaos: the springs must be removed so there is no tension on them
- Multi-meters, tape, tools, etc.: Must be returned to the general tool box at the front of the classroom when you are done using them.

Lasers:

Any student using a laser other than a HeNe laser (Optics, Laser Tweezers, Raman, Absorption Spectroscopy) must complete the online laser safety training here: [http://www.ehs.psu.edu/training/laser_safety/General_Laser_safety.htm](http://www.ehs.psu.edu/training/laser_safety/General_Laser_safety.htm) and include a copy of your certificate in the experiment folder. You must also register for the online training through EHS [https://apps.opp.psu.edu/ehs_training/course_list.cfm](https://apps.opp.psu.edu/ehs_training/course_list.cfm) (sign in and register for laser safety under the “Radiation” section). You are also required to obtain experiment specific training and sign the laser safety sheet in the back of the folder. Your TA/instructor will do the experiment specific training.

Students must wear the proper safety goggles at all times when the laser is on. If you have questions ask your instructor/TA.

Chemicals:

Any student touching any chemicals (Raman, Optics, NMR and Laser Tweezers) must take the online portion of the chemical safety training here:

- [http://www.ehs.psu.edu/training/chemical_safety/Introduction_to_Safety.htm](http://www.ehs.psu.edu/training/chemical_safety/Introduction_to_Safety.htm)
- [http://www.ehs.psu.edu/training/chemical_safety/Chemical_Safety.htm](http://www.ehs.psu.edu/training/chemical_safety/Chemical_Safety.htm)
- [http://www.ehs.psu.edu/training/chemical_safety/hazwaste.htm](http://www.ehs.psu.edu/training/chemical_safety/hazwaste.htm)
- [http://www.ehs.psu.edu/training/chemical_safety/emergency_preparedness.htm](http://www.ehs.psu.edu/training/chemical_safety/emergency_preparedness.htm)

If you work in a research lab you may have already done this at which point you can bring your certificate to class for exemption, or if you haven’t done this you might like to do it officially, if so then complete the registration and in-person components of the training as described here: [https://apps.opp.psu.edu/ehs_training/course_list.cfm](https://apps.opp.psu.edu/ehs_training/course_list.cfm) (under Laboratory Safety Training (initial))

- All chemicals must be stored properly and returned to their proper storage location when not in use. If you find any improperly stored chemicals or waste containers notify the TA and they must rectify it
- All chemical waste must be placed in properly labeled containers. TA’s are required to inspect waste area weekly.
- All trash and/or sharps must be placed in the proper waste receptacle. Glass and sharp objects go in the red sharps box by the Raman experiment. Everything else does NOT go in the sharps box – there are trash cans located throughout the classroom, and chemical waste disposal sites in each classroom.
- If you do not know what is correct or if the waste containers are full – notify your TA/instructor to rectify the situation.

**Radiation:**

There is NO food or beverages allowed in 310 Osmond due to the radioactive sources. Failure to follow this rule will result in failure of the class.

All students using the Mossbauer or Compton experiments must complete the online portion of the radiation safety training here: [http://www.ehs.psu.edu/radprot/Rad_Safety_Initial.pdf](http://www.ehs.psu.edu/radprot/Rad_Safety_Initial.pdf) and take the exam here: [http://www.ehs.psu.edu/radprot/Examination_Answer_Sheet.pdf](http://www.ehs.psu.edu/radprot/Examination_Answer_Sheet.pdf) and submit it to your TA/instructor.

Students using either of the x-ray sources should read the appropriate safety information available in the manual.

**Other:**

Failure to properly follow chemical, radiation and laser safety guidelines can result in a negative impact on your grade. You will only have limited warning before this will occur.

The responsibility to follow these rules is yours, if you ever feel you are unable to follow these rules because of the equipment available in the classroom, or if you have questions you must tell your TA and/or instructor and they will help rectify the situation.

**Responsible conduct of Research:** An important part of this course is to introduce you to the general expectations of being a responsible scientist. This includes understanding the guidelines for responsible research given to us from organizations at all levels, understanding the difference between acceptable and unacceptable research conduct, and understanding the consequences of improper research conduct from all perspectives.

As described in [The Penn State Principles](http://www.pennstate.edu/policy/computeruse/) academic integrity is the basic guiding principle for all academic activity at Penn State University, allowing the pursuit of scholarly activity in an open, honest, and responsible manner. We expect that each student will practice integrity in regard to all academic assignments and will not tolerate or engage in acts of falsification, misrepresentation, or deception. To protect the fundamental ethical principles of the University community and the worth of work completed by others, we will record and report to the office of Judicial Affairs all instances of academic dishonesty.

The University and [Departmental policy](http://www.psu.edu/ufs/policies/47-00.html#49-20) regarding academic integrity can be found on the course web page with links to the faculty senate policy.