Physics 470, Experimental Physics

Palash Banerjee

1 Basic information

Course title	Experimental Physics, Physics 470.
Instructor	Palash Banerjee.
Contact	SCI B-201, palash.banerjee@uwsp.edu
Open lab	MW 1 — 3 pm, Th 10 am - 12 noon.
Pre-requisite	Physics 300 *is* required
Textbook	*Experiments in Modern Physics*, Melissinos and Napolitano,
Required	Research laboratory notebook

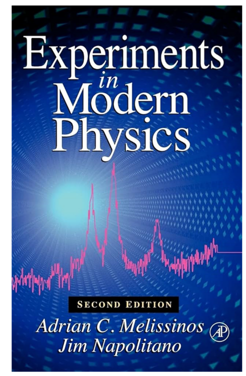

Figure 1: Your textbook, "Experiments in Modern Physics" 2nd ed., by Melissinos & Napolitano.

2 Course description and objectives

In this course, you will apply your knowledge of physics and mathematics in a laboratory setting. You will design and build experiments and learn how to make them work. You will collect data and construct mathematical models to explain your results. You will discover the mathematical models will not agree perfectly with your experimental results. Therefore, you will learn how to describe this discrepancy using the statistical theory of uncertainities. Finally, you will document your work in notebooks and write technical reports and manuscripts. This writing is how your discoveries will reach a wider audience. This is how most technical research and development work is organized. The purpose of this course is to introduce you to this way of working.

3 Required items

1. The bookstore should have a proper bound research grade notebook with numbered pages. The page size should be $11\frac{3}{4} \times 9\frac{1}{4}$ inches. Your notebook should look like this: `http://amzn.to/XRk7hD`. Please do not buy a cheap notebook.

2. We will use python for all of our plotting and analysis. Please download a python distribution such as Win Python from `https://winpython.github.io/` version 3.9.10.0 which will download and install a complete scientific python software stack. Having it on a usb drive will give you a portable tool that works everywhere.

Figure 2: Your research laboratory notebook available at the UWSP bookstore, or from Amazon.

4 Course assignments

1. Laboratory notebook: You must maintain a laboratory notebook that documents your work clearly. You will turn in your notebook for evaluation after each experiment. Please be conscientious in maintaining a detailed notebook as you work.

2. Small group discussions: I will meet with each group separately for upto 45 minutes every other week. These meetings are for us to discuss all aspects your project. Mostly I just want to have a physics conversation with you and enquire about your progess. Sometimes, I will also use

Day	Time
Mon	1 — 3 pm
Wed	1 — 3 pm
Thu	10 am — 12 noon

Table 1: Times when I am available for small group discussions. Please sign up for a 45 minute slot once every other week.

these meetings to provide the theory background for your experiment. Please look at my schedule and sign up for these meetings — you must attend each meeting, contribute to the conversation, and have something new and interesting to report on.

3. Reports: You will write a short report for each Junior Lab and a longer manuscript for each Senior Lab.

4. Homeworks: I will assign homeworks based on the content of the experiments and the lectures. These homeworks will be due every Monday at 2 pm. You may expect 12 ± 1 such assignments during the semester. All the homeworks count equally and no score will be dropped.

5. Celebration: We will all celebrate your accomplishments by hosting a poster presentation the last week of class. I plan to invite an external audience for this occasion.

6. Exams: Did you notice that I have no exams in this course?

5 *Grading and evaluation*

I will calculate your grade based on a weighted percentage of your scores as shown in Table 2. Your final letter grades will be determined as shown in Table 3.

I do not grade on a curve. Scores will be rounded up according to the following example: 86.6 – 86.9% will be rounded up to 87% and become a B+, but 86.0 – 86.5% will remain at 86% and will earn a B.

Assignment	Value
Laboratory notebook	25%
Homeworks	25%
Small group discussions	15%
Reports & manuscripts	25%
Poster celebration	10%

Table 2: Each assignment category contributes a weighted percentage to your overall grade.

Total score	Grade
93% and above	A
90–92%	A-
87–89%	B+
83–86%	B
80–82%	B-
77-79%	C+
73–76%	C
70–72%	C-
67–69%	D+
60–66%	D
below 60%	F

Table 3: Your final letter grades will be determined based on this table.

6 *General course policies*

1. If you are going to be late on an assignment, please let me know. I will accept only one late assignment and no excuses are needed. Subsequent late assignments will not be accepted.

2. No make-up labs will be offered and no make-up exams will be offered.

3. Make-up work will only be accepted in the case of absences that occur due to death in the immediate family, illness with a note from the appropriate health care professional, religious observance, an event in which you officially represent the University of Wisconsin-Stevens Point and the event directly conflicts with an exam or lab. Such absences must be approved with documenting materials prior to the date of absence.

4. Please *do not* copy each others homeworks, class assignments, laboratory reports, and manuscripts and pass them off as your own. You may collaborate but your work must be your own. If I find two or more assignments very similar to each other, I will be forced to give all such assignments a zero.

5. Food and drinks are not permitted in the laboratory.

6. I do not assign work for extra credit and there are no bonus points that you can earn.

7 List of experiments

YOUR ADVANCED LAB consists of a variety of experiments and projects. Each project introduces you to a nice mix of clever instrumentation, interesting physics, and advanced mathematics. The advanced mathematics is necessary since the goal of each project is for you to construct a mathematical model that describes the experiment. Your ability to construct these models is known as *connecting the mathematics and physics to the hardware*. This is a difficult skill to acquire and requires lots of time and patience. I have high hopes for all of you and want to give you the best and most advanced physics education. So even though these projects will be challenging, we will try with all our might and give our very best.

7.1 Junior Lab

Junior Lab	Experiment
1	Magnetization of a disc
2	RLC circuits

Table 4: The two Junior Labs you must all do.

The first mini project you will all do is to determine the magnetization of a disc. And the second mini project you will all do is to determine frequency and phase response of RLC circuits. I will use these mini projects to set some expectations, introduce you to the instruments, show you how to use python for data analysis in a reproducible way, and introduce you to technical writing. These two mini projects will take up roughly the first three weeks of our time. A short manuscript will be due at the end of each mini project.

7.2 Senior Lab

Division	Project Number
Curve Fitting (CFD)	Lectures
Theory (ThD)	Small group discussions
Laser Optics (LOD)	1, 3
Spectroscopy (SpD)	2, 9
Advanced Mechanics (AMD)	7, 10
Signals (SiGD)	5, 6
Compu. Analytics (CAD)	11
Quantum Operations (QOpsD)	4, 8

Table 5: Physics 470 is organized into Divisions and you will spend a few weeks in each Division acquiring different skills and learning new things.

The Senior Lab is the heart of this course and you will complete three major projects. Each project lasts roughly three weeks. If you need more time, I expect you will come to the lab on your own and do what is necessary to meet the deadlines. I may even join you at these extra times to help move your project along. The list below describes the various senior lab projects available this year.

1. Magneto-optic effect. In this project, you will measure how a magnetic field rotates the plane of polarized light as it passes through glass. You will learn the electronics and physics behind a photodetector, and discover how applying a Taylor series expansion can help you make better measurements. You will also learn how linear algebra can be used to represent the states of polarized light. Let no one tell you that series expansion methods and linear algebra are not useful in a physics lab.

2. Gamma photon spectroscopy. In this project you will measure the energy spectrum of very high energy gamma photons that are emitted by a cesium nucleus as it decays to it ground state. You will learn the special methods used to detect these gamma photons. These methods involve a scintillator, a single photon detector, and a rack full of fast electronics. And to understand what the electronics is measuring, you need to develop a relativistic theory of how the gamma photons collide with the electrons within the scintillator. Quantum mechanics and special relativity in action all in one experiment — wow.

3. Laser interferometer with feedback control. In this project, you will recreate and build a mini version of the Laser Interferometric Gravita-

tional Observatory (LIGO). Although you will not be able to detect gravitational waves, you will be able to monitor the tiny movement of a large mirror with exquisite precision. Along the way you will learn about phase shifts and the complex notation, the eight degrees of freedom needed to properly align an interferometer, and how to use feedback control to stabilize the output of the interferometer. One of my favorite experiments.

4. Single photon interference — an experiment that shouldn't work but it does. In this project, you will measure a two-slit interference pattern using such a weak optical source that only one photon passes through the apparatus at any given time. You will learn to operate a single photon detector and learn about Poisson signals which look like noise. The fact that you can even measure an interference pattern will appear strange and make you very uneasy. To help explain, I will teach you some quantum field theory (QFT) in one lecture. You will then use QFT to build an analytical model to explain your strange results. The model will work but your uneasiness will haunt you for a long time.

5. In pursuit of the zero. In this project, you will measure the resistance of a wire at low temperatures. As you slowly cool the wire sample down, you will observe the dramatic effect of superconductivty where the resistance of the sample vanishes and becomes zero below a certain critical temperature. And a superconducting wire can host persistent currents — an impossible physics effect that you can measure for yourself.

6. How low is low? In this project, you will measure an extremely tiny signal buried amidst a much larger noisy background. You will learn the mathematical description of noise and some clever signal processing techniques. You will even get to operate a lockin amplifier which is the crown jewel of all physics instruments. You might even set the record for the smallest signal ever measured at UWSP.

7. The gyroscope. In this project, you will study the angular momentum vector of a heavy disc which is constrained to spin about a nonstationary axis. You will also learn how to embed accelerometers and inertial sensors onto instruments and read them out using a micrcontroller. These embedded sensors will let you measure the precession and nutation of the spinning disc and you will construct an advanced mechanics vector model to explain your measurements.

8. A two level spin system. In this project, you will use radiofrequency fields to control the spin state of a proton in a magnetic field. If your control field is set up correctly, you will be able to put the proton spin into a superpositon of its eigenstates and measure its time evolution. You might even measure the famous spin echo and construct a single qubit quantum gate.

9. Muon observatory. In this project you will measure the flux of cosmic muons that strike the roof of the SCI building. You will learn to operate a single photon detector and calibrate its performance. You will also learn the principle of coincidence counting and use it to distinguish real muon events from background noise. With some luck, you will also be able to study the decay of muons into a neutrino and an electron and

measure the muon lifetime. A CERN style experiment without leaving Point.

10. Magneto-mechanical oscillator. In this project, you will construct an oscillator that will respond to magnetic fields. This response is described by a differential equation. By measuring this response over a range of frequencies, you will end up solving the differential equation. You will also learn how to overcome friction in the system by constructing a feedback controller. This will make the oscillator operate unattended in autonomous mode with no loss in amplitude. If you design the feedback controller correctly, the system will maintain its oscillations in perpetuity, long after you have graduated.

11. Gradient media. In this project, you will create a refractive index gradient media using a thermoelectric cooler and a slab of polished glass. You will study the properties of the gradient medium by measuring the bending of laser light. The bending is described by a partial differential equation (pde). You will learn some mathematical methods used to solve a pde such as separation of variables and fourier series. And you will also be able to connect these results to the bending of stellar light by a heavy star. A tabletop experiment with rich mathematics and connections to stellar objects — isn't physics wild?

8 Expectations

PHYSICS 470 IS YOUR CAPSTONE COURSE and is meant to provide a final experience to your time as a physics major. Therefore the goals and structure of this course are a little different than your other courses. You may expect the following <u>from</u> me — firstly, I will teach you some interesting pieces of physics and mathematics and show you how to apply this knowledge in an experimental physics environment. Secondly, I will provide appropriate and exciting technical challenges and help you meet them. Thirdly, I will provide you with a structure in which you can work independently at your own pace, and I will help you meet deadlines. Finally, I will help you produce technical work and documents of the highest quality of which you can be very proud.

I also have some expectations from <u>you</u> as physics seniors — firstly, I expect you will treat your physics laboratory notebook as the most important thing in your life. Secondly, I expect you will participate in the small group discussions and be prepared with a complete notebook so we can have a lively and productive meeting. Thirdly, I expect you will not suffer silently and will ask me to help when stuck. Finally, I expect you will produce technical documents of the highest quality by following the instructions and exercising your own creativity and judgment.

9 Course schedule

Week	Experiments	Lecture
(1) Jan 21	Introduction and setup; Junior Lab 1.	Theory for Junior Lab 1.
(2) Jan 28	Notebooks and scripts for reproducible science; Junior Lab 2	Theory for Junior Lab 2.
(3) Feb 4	Technical writing; (end Junior Lab)	Measurement uncertainties.
(4) Feb 11	Senior Project I	Propagation of uncertainties.
(5) Feb 18	(continued)	Statistical engineering I — curve fitting & residuals.
(6) Feb 25	(continued)	(continued)
(7) Mar 3	Laboratory methods I — signals and fourier transforms	Poisson distribution.
(8) Mar 10	Senior Project II	(continued)
(–) Mar 17	Spring break	
(9) Mar 24	(continued)	The statistical properties of light.
(10) Mar 31	(continued)	(continued)
(11) Apr 7	Laboratory methods II	Statistical engineering II — even more curve fitting.
(12) Apr 14	Senior Project III	(continued)
(13) Apr 21	(continued)	Statistical engineering III - non linear least squares fitting
(14) Apr 28	(continued)	(continued)
(15) May 5	Review, critique, reflection and presentations.	
(16) May 12	Reflection and final manuscript, Wed May 17, 2:45 — 4:45 pm in SCI A-201.	