Fall 2018

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Methods of Experimental Physics
(Physics 3700)

Class Goals:

As incredible as it might sound physics is a science that is based on experiment. No matter how mathematically elegant or intuitively obvious a theory might be it lives or dies depending on experimental verification. Such comparison, however, is only valid when the uncertainties in the measurement are correctly estimated. Therefore it is important that early in your scientific careers you get aquatinted with the experimental tools and procedures that are common in the laboratory environment. With this in mind the goal of this class is to introduce you to many of the methods of experimental physics that allow us to differentiate the crackpots from the geniuses! Even if you will not work in physics research related field in the future, you will find many applications in daily life!

This course stresses data analysis in a physics laboratory setting. We will start with some fundamental concepts from probability and statistics and build on them until we are doing very sophisticated things like non-linear least squares curve fitting and computer simulation of experiments. For more details on the subjects and experiments covered in the class see the course outline.

The use of computers is integrated throughout the course. Each student will have access to a PC. You will be given an account on the first day of class. Throughout the course we will use the computers in a variety of ways including control of experiments, simulation of experiments, writing programs, and word processing. Each PC will also have a word processor (MICROSOFT WORD) and graphing programs (e.g. sciDAVis, KALEIDAGRAPH).

Course Web Site: www.physics.ohio-state.edu/~gan/teaching/fall18/3700.html

Coursework:

Lecture: Mendenhall 174		*Lab: SMITH 2064*
Lectures:	Monday	10:20-11:15
Laboratory:	Mon, Tues, Thurs	1:00-5:00
Office Hour:	Wednesday	11:30-12:30

This class contains both a lecture and laboratory component. The emphasis of the class is on lab work. However approximately an hour a week will be devoted to introducing and discussing the material necessary to perform the lab exercises. I expect students to have a physics background at the level of the Physics 1200 sequence and a calculus background at the level of familiarity with derivatives and integrals.

Grades:

Your course grade will be determined using the following weighting scheme:

Homework:	25%
Lab reports:	50%
Final Exam:	25%

There will be six homework sets and each set will be worth 4.17% of the course grade. The homework sets will be distributed about every two weeks. There will also be short laboratory write-ups required that make up 50% of your grade. Your lab report must be written using a word processor. Each lab will have a set of questions and/or exercises associated with it. Your lab report will be the answers to these questions/exercises plus a listing of any programs written. These lab exercises will vary in scope from simple tasks such as graphing data to complex tasks such as writing computer programs to analyze the data you have taken. It is my hope that all lab work will be completed within the usual working hours of the class. The penalty for late homework and lab is 5 points/day. Outside class hours, please submit your lab report/homework to the main office of PRB in which a receptionist will time stamp your papers. The final exam, worth 25% of the course grade, will cover all the material covered in lecture and lab.

Course Textbook:

The textbook for this course is:

An Introduction to Error Analysis, by John Taylor

This is a textbook that explains data and error analysis at a level suitable for this course. However, the ordering of the chapters in this book is not the same as the order that topics will be discussed in class. Detailed lecture notes will be provided as a supplement to the text. The lectures follow the sequence in the prior text, *Statistics*, by Barlow, which organizes the topics in a more logical manner. While this is an excellent text, it was not popular with students as they felt that it was not at the appropriate level for this class. Listed below are additional books that you may want to consult throughout the course. Copies of some of these books are located in the lab and the Science and Engineering Library.

<u>Some Good Supplementary Textbooks:</u>

Statistics, Barlow
Probability and Statistics, an Introduction through Experiments, Berkeley
Data Reduction and Error Analysis for the Physical Sciences, Bevington and Robinson
Probability and Statistics for Engineering and the Sciences, Devore
Statistics for Nuclear and Particle Physics, Lyons
Introduction to the Practice of Statistics, Moore and McCabe
The Art of Experimental Physics, Preston and Dietz
Practical Physics, Squires

Physics 3700 Course Outline

Week 1-2 (Taylor: 1.1-1.4, 2.1-2.4, 4.1-4.3, 5.1-5.2 = 31 pages)

Introduction to the concepts of probability and statistics. Discrete and continuous probability distributions. Define some common terms such as mean, mode, median and variance. Discuss statistical and systematic errors in the context of modern physics experiments. Familiarization with laboratory equipment (computers and associated software). Some simple experiments with coins and dices. Introduction to the use of random numbers using the computer. Use the computer (e.g. sciDAVis) to plot, graph, and histogram data.

Week 3-4 (Taylor: 1.5-1.6, 3.1-3.2, 10.1-10.4 (pg. 232), 11.1-11.2 (pg. 250) = 18 pages)

Lecture on the binomial and Poisson probability distributions. Compound experiment with dices. Throw darts (both real and virtual) to estimate π. More practice with computer programming and data analysis.

Week 5-6 (Taylor: 4.4-4.5, 5.3-5.4, 10.4 (pg. 232)-10.5, 11.2 (pg. 250)-11.3 = 19 pages)

Lecture on the normal (Gaussian) distribution. Discuss the relationship between the binomial, Poisson, and normal distributions. Introduce the central limit theorem. More complicated experiment with dice to illustrate the binomial distribution. Experiment with cosmic rays to demonstrate Poisson distribution.

Week 7 (Taylor: 2.5, 2.7-2.9, 3.3-3.11, 4.6 = 43 pages)

Lecture on propagation of errors in physics experiments. Perform experiment that generates a normal distribution. Generating the normal distribution using a computer.

Week 8 (Taylor: 2.6, 5.5-5.6, 7.1-7.3 = 18 pages)

Lecture on the determination of parameters from experimental data. Define weighted average. Introduce the concept of Maximum Likelihood. Demonstrate the propagation of errors in the resistor experiment.

Week 9 (Taylor: 5.7-5.8, 8.1-8.5, 106, 12.1-12.3 = 31 pages)

Lecture on advanced methods of determining parameters from experimental data. Introduce "least squares fitting" and the χ^2 test. Start to set up several nuclear physics experiments that will be used the rest of the course. These experiments will also familiarize the students with the concepts of computer controlled data acquisition.

Week 10 (Taylor: 12.4-12.5 = 7 pages)

Lecture on the techniques of hypothesis testing to compare the experimental data to theoretical expectations. Introduce parametric and non-parametric testing. Discussion of confidence levels using examples from several areas of physics. Determine the energy levels of Na^{22}, Co^{60} and Cs^{137}. Calibrate the electronics used in the nuclear physics experiments using a linear least squares fit.

Week 11 (Taylor: 6.1-6.2 = 5 pages)

Lecture on error on the mean. Advanced topics in least squares fitting. In the lab measure the gamma ray energy spectrum from the radioactive sources.

Week 12 (Taylor: 8.6, 11.4 = 7 pages)

Fit the measured energy spectrum to a "complicated" function (e.g. a Gaussian line shape + a linear background) using the techniques discussed in lecture.

Week 13-14

Use Monte Carlo method to simulate the half-life experiment. Measure the half-life of a radioactive isotope. Set up and start to perform an experiment that illustrates the exponential probability distribution and allows the half-life of a radioactive isotope to be measured.

Summary of Laboratory Experiments

I Simple experiments with coins and dices

- Can you predict the outcome of a coin?
- Is your coin or die "loaded"?
- Generating a binomial probability distribution by throwing one or two dices

Data analysis using "canned" software such as sciDAVis

Monte Carlo method

- Writing programs
- Generating probability distributions
- Simulation of physics experiments

II Determining π by throwing darts and by computer simulation

Compound experiment with dices

- Generating a binomial probability distribution by throwing 12 dices
- Generating a Poisson distribution using cosmic rays

III Generating a normal distribution in an experiment (Central Limit Theorem)

Generating the normal distribution using a computer

VI Computer controlled data acquisition

Measurement of the energy levels of radioactive sources

Fitting the measured energy levels to calibration the electronics

V Measurement of the gamma ray energy spectrum

Fitting the measured gamma ray energy spectrum to determine the energy resolution

VI Measurement of the half-life of a radioactive isotope

Simulate the half-life decay distribution using a Monte Carlo technique

GE Requirement: The data analyses above are designed to satisfy the GE Data Analysis requirement.

Academic Misconduct: Not to report academic misconduct is itself regarded as academic misconduct (AM). Everyone in the university community has a duty to report suspected AM.

Students with Disability: Please contact Prof. Gan at the start of the semester so that arrangements can be made to accommodate you. Students needing the services provided by the Office for Disability Services (ODS) will need to be certified by that office. The ODS is located in 150 Pomerene Hall, 1760 Neil Avenue; telephone 292-3307, TDD 292-0901; http://www.ods.ohio-state.edu/.

Acknowledgment: This material is adapted from the course developed by Prof. Richard Kass.