

Fall 2000

Durkin

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## **Methods of Experimental Physics**

### **(Physics 416)**

#### **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!

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 running NT located in Smith 3081. You will be given an NT and VAX (mainframe) accounts 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 (no games please!). For convenience I have chosen FORTRAN on VAX as the "official" programming language of Physics 416. Each PC will also have a word processor (MICROSOFT WORD) and a graphing program (KALEIDAGRAPH). You are free to use other software packages if you have access to them.

### **Coursework:**

*All classes will be held in SMITH 3081*

Lectures: Tuesday 12:30-1:30 (usually)

Laboratory: Tuesday 1:30-3:30

Thursday 12:30-3:30

Office Hour: Wednesday 1:30-2:30

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 130 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 four homework sets and each set will be worth 6.25% of the course grade. The homework sets will be distributed about every two weeks. There will also be short laboratory write-ups required that will 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 FORTRAN 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 labs is 5 points/day. 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 at a level suitable for this course. You will find that we sometimes jumps from chapters to chapters but this should not create a problem in reading the book since the lecture notes already explain the topics in quite details. The lectures follow the sequence in the prior text, *Statistics*, by Barlow, which organizes the topics in a more logical manner. Although Barlow is an excellent text, it often goes into more depth than necessary and

hence we choose Taylor as the textbook. Most of the homework problems will be taken from Barlow's book. Listed below are additional books that you may want to consult throughout the course. Copies of some of these books are located in SM3081.

**Some Good Supplementary Textbooks:**

*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

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I can be found in my lab almost anytime between 7:30 A.M. and 5:00 P.M. There is no need to make an appointment to see me. Just drop by and I will momentarily stop what I am doing to help you. You should not hesitate to ask for my help.

## Physics 416 Course Outline

Week 1 (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 (KaleidaGraph) to plot, graph, and histogram data.

Week 2 (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  $\pi$ . More practice with computer programming and data analysis.

Week 3 (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 dices to illustrate the binomial distribution.

Week 4 (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 5 (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. 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 6 (Taylor: 5.7-5.8, 8.1-8.5, 10.6, 12.1-12.3 = 31 pages)

Lecture on advanced methods of determining parameters from experimental data. Introduce "least squares fitting" and the  $\chi^2$  test. Determine the energy levels of  $\text{Na}^{22}$ ,  $\text{Co}^{60}$  and  $\text{Cs}^{137}$ . Calibrate the electronics used in the nuclear physics experiments using a linear least squares fit.

Week 7 (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. In the lab measure the gamma ray energy spectrum from the radioactive sources.

Week 8 (Taylor: 6.1-6.2 = 5 pages)

Lecture on error on the mean. Advanced topics in least squares fitting. 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 9 (Taylor: 8.6, 11.4 = 7 pages)

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.

Week 10

Use Monte Carlo method to simulate the half-life experiment.

## 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 Kaleidagraph
  - Monte Carlo method
    - Writing programs in FORTRAN
    - Generating probability distributions
    - Simulation of physics experiments
- II Determining  $\pi$  by throwing darts and by computer simulation
  - Compound experiment with dices
    - Generating a binomial probability distribution by throwing 12 dices
- III Generating a normal distribution in an experiment (Central Limit Theorem)
  - Generating the normal distribution using a computer
- IV 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

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