Special Physics Course Offerings, 2020–2021

The following special Physics courses will be offered during the 2020–2021 academic year. Each course is described in more detail in the following pages.

Quantum Computing
Phys 427/Phys 575, Autumn 2020
Instructor: Boris Blinov

Syllabus:

Week 1: Brief review of quantum mechanics; qubits and their representations.

Week 2: Entanglement.

Week 3: Quantum logic gates.

Week 4: Quantum computing architectures.

Week 5: Quantum algorithms. Exam 1.

Week 6: Physical realizations of qubits.

Week 7: Quantum information.

Week 8: Cryptography, quantum key distribution; teleportation.

Week 9: Single photons, EPR pairs.

Week 10: Error correction, fault tolerance. Exam 2.

Prerequisites: Phys 225 and Phys 227.

Textbook: "A Short Introduction to Quantum Information and Quantum Computation" by M. Le Bellac (Cambridge University Press, 2006). This is where most homework problems will come from.

Homework: Weekly, graded. Submitted online only, via Canvas dropbox. One late assignment (by no more than one week) will be accepted.

Exams: Two take-home, 24-hour exams, one in the middle and one at the end of the quarter. No make-up exams.

Course grade is 40% HW + 40% each exam = 120%.

Course Announcement PHYS 428 3 credits
Applications of Modern Physics in Medicine Autumn 2020- Prof. Miller

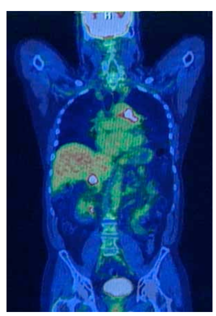
Many remarkable medical technologies, diagnostic tools, and treatment methods have emerged as a result of modern physics discoveries—including X-rays, radiation treatment, laser surgery, high-resolution ultrasound scans, computerized tomography (CT) scans, and magnetic resonance imaging. This course describes the fundamental physical principles underlying these technological advances, emphasizing their applications to the practice of medicine.

The medical applications of fundamental principles of physics are presented to students who are considering careers in medical physics, biophysics, medicine, or nuclear engineering.

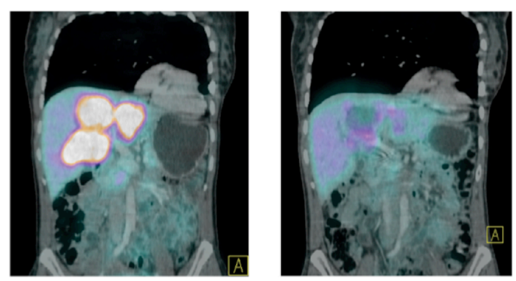
The course will cover aspects of modern physics dealing with propagation of particles-photons, electrons, protons, neutrons and nuclei through matter and the methods used to generate the particles. Properties of atoms and nuclei relevant for medical applications will be reviewed. Explanations of particular physical phenomena will be followed by descriptions of the applications of these phenomena in medicine. The aim is to allow students to understand the physical processes underlying medical applications of modern physics.

Topics include: interactions of particles with matter, applications of X-rays, radiobiology, radiation oncology, use of radioactive sources in medicine, use of protons, neutrons and nuclei in cancer therapy, magnetic resonance imaging.

Textbook- Applications of modern physics in Medicine, M. Strikman, K.Spartalian, M.Cole, Princeton U. Press, 2015. Prereq: PHYS225 Method of evaluation: 1 or 2 exams and a paper



PET/CT image



Case II: Response of multiple liver lesions after i.a. therapy with 14 GBq Bi-213-DOTATOC

Advanced Data Analysis Techniques for Large Datasets
Phys 434, Autumn 2020
Instructor: Miguel Morales

An introduction to advanced data analysis techniques through a set of computational laboratories. Topics include non-Gaussian statistics, determining the significance of a detection, identifying and mitigating systematic effects in large data sets, data visualization, and collaborative software development. Final two laboratories apply what we have learned to real world data sets. Taught as a senior capstone, and assumes fluency in either python or MATLAB. Prerequisite: Phys 334.

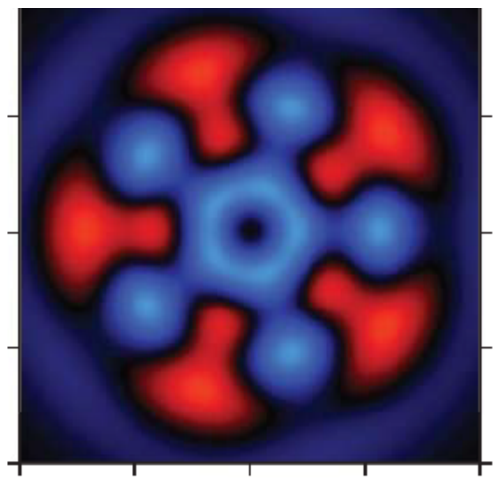
Topics:

Welcome & basic statistics
git & GitHub
Introduction to non-Gaussian statistics
AND, OR, and convolutions
Asking a statistical question
Trials factor
More statistical examples, Feldman-Cousins
Finding the background
Using metadata
Worries, data exploration, and finding systematics
The Road Ahead
Introduction to the LHC & HERA data sets
Parameters & Confidence Intervals
Jackknife tests
Selection Bias
LHC data analysis primer
21 cm Cosmology & putting it all together

Introduction to Quantum Optics for Scientists and Engineers

Fall 2020, TTh 3:30-5:20
Course number: EE539*
Instructor: Kai-Mei Fu

Superposition of vacuum and 5-photon state
Hofheinz et al., Nature 2009



In the past two decades, the interaction of light and matter has reached an unprecedented level of control, enabling us to begin to realize technologies based on quantum mechanics. This course aims to give students the analytic and computational tools to understand and simulate current state-of-the-art quantum optics experiments.

The course consists of

- Introduction/review of the quantum mechanics operator formalism (2 weeks)
- Non-classical light (2 weeks)
- Atom-classical field interaction (2 weeks)
- Atom-quantum field interaction (2 weeks)
- CQED applications (2 weeks)

The coursework consists of 7 problem sets and 1 final presentation.

The only requirement for EE539 is a strong background in linear algebra. Quantum mechanics and electromagnetism is helpful, but not necessary. Prior graduate students have come from EE, physics, chemistry, and materials science. Undergraduates should have completed PHY324 and PHYS325, or have permission from the instructor.

*Register for PHY576 if EE539 is full.

Introduction to Scientific Instrumentation
Phys 232, Winter 2021
Instructor: Prof. G. Seidler, seidler@uw.edu

3 credits, remote-only offering
Prerequisites: PHYS123, PHYS334
Enrollment limit: 25
Can be substituted for senior lab requirement

The design and use of scientific instrumentation is central to the mission of the physical and biological sciences. This involves a journey starting with project definition and then traveling through instrument design, iterative improvement, user interface optimization, experiment design, data collection, and statistical analysis, to finally reach conclusion. The purpose of this class is to give an introduction to this process with an emphasis on building core skills in software, computer integration with microprocessor automation, data collection, data analysis and statistics, and hands-on experience with the construction and improvement of apparatus.

The first offering of this class will therefore split time between several major components. First, we will emphasize instruction in the Python environment, touching on each of basic programming skills, data presentation, and statistical analysis, all using standard Python classes and libraries. Second, this will be a 'flipped lab' where every student will have, in their home study space, their own Arduino microprocessor and associated components needed to implement a transmission spectrophotometer or optical fluorescence spectrometer while using the Python environment to interface the microprocessor via USB port. Third, the students will gain strong skills in data reduction and graphical presentation, enabling effective presentation of experimental results, including (virtual) in-class presentation. The major class project for each student or small collaborative pod will be the iterative development, testing, and application of their spectrometer including its integration with the Python environment to achieve both a complete user interface for data collection and also a well-documented analysis pipeline for data analysis and presentation of results.

Grading will be based on homework (70%) and the final course project (30%).

Notes:

1) Students will need to have access to a relatively modern computer with a standard operating system allowing installation of *conda*, *Jupyter*, and *pyFirmata*. Students are strongly urged to investigate these constraints well before the Winter 2021 quarter starts.
2) There will be a $50 lab fee, which will cover the Arduino board and all other course-relevant components (such as for the photometer). A 'kit' style package will be delivered to each enrolled student. If delivery of such a package will be complicated by customs requirements, please contact the instructor during the Autumn 2020 term.

Raman Spectroscopy, Physics 576A Winter 2021
Instructor: Xiaodong Xu

This course will cover Raman spectroscopy application in understanding a wide range of material properties. We will learn the basics of group theory, and how to use group theory to count Raman modes and analyze the Raman optical selection rules based on the symmetry of the system. We will then introduce the application of Raman spectroscopy to understand several material properties, including semiconductors, magnets, superconductors, and charge density waves. Students will have opportunity to form a small group to present the application of Raman in system of their own interest. We will also design and perform a group project, using the equipment in the Xu group: Raman optical study of a 2D materials with application of strain. All students will analyze the data and write a report based on the experimental results.

Group theory + Application to Raman spectroscopy (week 1-4)

- Group theory basics
- Raman selection rules (Raman Active, Infrared Active, …)
- Modes Assignment

Application of Raman (week 5-9, including group presentation)

- Magnetic order
- Superconductivity
- Topological insulator

Group project: (Week 1-7)

- Raman spectroscopy to investigate 2D materials. We focus on CDW superconductor: $NbSe_2$ (Amplitude+ Higgs mode). We will try to investigate the competition of CDW and superconductivity with strain control.

Time line of the project

- week 1-2: develop and test strain setup
- Week 3 –7: Load strain setup and perform Raman spectroscopy
- Week 7-10: Data Analysis and write up the report.

Textbook:

(1) Group Theory and Quantum Mechanics by Michael Tinkham;

(2) Group Theory: Application to the Physics of Condensed Matter by Mildred Dresselhause, Gene Dresselhaus, and Ado Jario.

Scale Invariance, Topological Phase Transitions and Invariants
Phys 578, Winter 2021
Instructor: Marcel den Nijs

Topological phenomena, in particular quantum phase transitions with non-local order parameters and TKNN invariant type Berry phases, are at the center of current research. Examples are found in, two dimensional quantum materials, biophysics, quantum information, and non-equilibrium processes. These build directly on research from the 2nd half of the last century. The purpose of this course is to provide graduate students essential background and core materials.

We start with an overview of scale invariance as it emerged around 1960 in experimental work on phase transitions. Scale invariance is the consequence of divergent correlation lengths by strongly fluctuating degrees of freedom. This plays out similarly in most current research. Scale invariance was first observed in experimental data and theoretical series expansions and then explained about 1965 by Kadanoff in terms of "block spin invariance", followed in 1971 by the formulation of renormalization theory (RT) by Wilson and Fisher, while merging with similar ideas and phenomena in particle theory.

Scale invariance is linked to fractal type geometric structures, and RT's can be viewed in retrospect as recursive reformulations of partition functions and correlation functions based on the definition of fractal dimensions, such that exact and approximative methods give the values of the scaling dimensions. We will review RT from this geometric perspective.

Molecular field theory methods date back to van der Waals. They fail fundamentally describing strongly fluctuating collective phenomena and scale invariant systems. These methods are still with us today in, e.g., Landau theory, density functional theory, and effective field theory. We will review the reasons for why they fail.

Next we will discuss examples of topological phase transitions, starting with two dimensional equilibrium critical phenomena, vortices in He films, crystalline surface roughening, and Kosterlitz-Thouless phase transitions. Followed by VBS type phase in quantum spin chains. These phenomena lack local order parameters but display string-like topological order instead. In the current literature on topological insulators it is often claimed that topological phase transitions are fundamentally different from the classic ones with local order parameters, classified by molecular field theories. This is actually not true for most examples I studied in detail. Duality type transformations map topological order into local order. We will review examples of these.

One of the holy grails of current research is to find extensions to higher dimensions of the exact methods that allowed us earlier to determine the exact scaling properties of all one dimensional quantum, and two dimensional classical equilibrium phase transitions. These methods come under several equivalent or complementary names, including, Coulomb gas methods, conformal invariance, and Luttiner-Tomanaga liquid bosonization. We will review aspects of these methods.

Statistical physics of living systems

The advent of high-throughput techniques is transforming biology into a fully quantitative and theory-rich science. For example, recent advancements in genetic sequencing has opened new avenues to study cellular processes at short time scales at the level of individual organisms, and on longer evolutionary time scales at the level of species and populations. Statistical physics is the right language to describe complex biological systems with many degrees of freedom, and is being used to uncover principles of molecular motions, protein folding, evolution of populations, or to interpret biological data. The main focus of this course is to explore recent work in biology in conjunction with topics in statistical physics and information theory. By highlighting examples from a broad range of biological phenomena, the course will cover topics on information theory and optimality, probabilistic inference, non-equilibrium processes in biology, and evolutionary dynamics. Inspired by these topics, students will work in groups on small projects and will present their work at the end of the quarter.

The course is co-listed as Phys 428 and Phys 578. The class assignments and the final project will be assessed differently for the graduate and the undergraduate level students.

Pre-requisite: Phys 328 (or equivalents).

Tentative course syllabus:

Week 1 **Efficient representation: Introduction to information theory**

Week 2 **Does biology care about bits?**

Week 3 **Optimizing information flow in biological systems I**

Week 4 **Optimizing information flow in biological systems II**

Week 5 **Statistical inference: physics meets large biological data I**

Week 6 **Statistical inference: physics meets large biological data II**

Week 7 **Sensitivity and speed in biology: non-equilibrium processes in biology**

Week 8 **Stochastic molecular evolution**

Week 9 **Non-equilibrium molecular evolution**

Week 10 **Student presentation**

Recommended reading:

Biophysics: Searching for Principles (William Bialek); Princeton University Press, 2012

Information theory, inference, and learning algorithms (David McKay); Cambridge University Press, 2003.

Modern Analysis Techniques for Large Data Sets
Phys 576, Spring 2021
Instructor: Miguel Morales

While analyzing large datasets is nothing new for physicists, in the last few years there have been major advancements in the tools and techniques available. Team taught by Miguel Morales (Physics) and Bryna Hazelton (eScience), the goal of this class is to introduce students to current techniques and best practices in the statistically rigorous analysis of large data sets. The class is organized around four themes: practical statistics, advanced data visualization, building collaborative analysis code, and advanced data analysis practices (see below for details).

The class is open to graduate students, postdocs, research groups, and seniors with permission. Evaluation will be based on homework and projects, and students are encouraged to use their own data for the projects to enhance their current research.

Prof. Miguel Morales has experience in particle physics, astrophysics, and cosmology data analysis, and is considered an international expert in the analysis of 21 cm cosmology data. Senior Research Scientist Bryna Hazelton has worked on everything from cosmology to botany to homelessness as part of the eScience Institute. She is a co-author of the open source and peer reviewed pyuvdata software package, and has developed the reference analysis pipeline for analyzing Epoch of Reionization radio cosmology data.

Topic list (not in syllabus order):

Advanced practical statistics
Foundations
non-Gaussian and non-analytic statistics
Maximum likelihood
Feldman-Cousins and extensions
Issues with large data sets and trials
Practical considerations
Determining background distributions from data
Systematic errors
End-to-end error propagation (including non-Gaussian extensions)
Parameters, covariance, Fischer Matrices, non-linear effects, and the art of parametrization
Asking statistically valid questions
How to mathematically formulate your question(s)
Case studies of mistakes in the literature
Jackknife and null tests
Data visualization
Features of high quality visualizations
Data density
Classes of plots, and their pros and cons
Meta information and drillability
Scaling & color
Animations and movies
Developing a consistent visual language
Accessibility considerations (e.g. colorblind, pattern recognition, etc.)
Visualizations for data exploration and hunting systematics
Turning statistical questions into plots

Developing plots for data rampages
Visualizations for instrument and data monitoring
Sparklines, comparisons with nominal performance
Notebooks and dashboards
Visualizations for presentations and publications
Developing plots as a teaching tool
Specific concerns for presentations and publication plots
Case studies of valuable visualization techniques
Tools and best practices for building collaborative analysis pipelines
Using GitHub to your advantage
Branching and merging for collaborative data analysis
Unit testing
Git hashes, metadata, and analysis provenance
Collaborative development of analysis tools
Issue tracking
Issue assignment and managing releases
Pull requests
Shared libraries for enhanced communication
Publishing peer reviewed code
Advanced data analysis practices
Making sure your analysis is right
Analysis level unit tests
Designing a thicket of tests
Tracing your analysis as it evolves
The golden master development pattern
Analysis jackknifes, and testing below the thermal noise
Tiered testing with data as part of the development cycle
Improving your analysis (hunting systematics, biases, calibration errors, and subtle analysis mistakes)
Turning questions into tests
Newtons method of isolating issues
Interrogating your data for systematics and biases (question driven data rampages)

FAQs:

What constitutes a large data set? The short answer is if it is large for you, it counts. What is big data varies wildly by field, but the statistical and analysis issues are effectively the same whether you have 1,000 data points or 10^{15}.

What format will the projects take? If you have your own data, the projects will be applying the techniques we learn to your data. And for the final project you will propose what you plan to do, so it should be directly applicable to your research.

Is prior knowledge of any particular coding language expected? We are carefully language agnostic. Many examples will be in python, but we frequently use Matlab, IDL, C, and have experience in a variety of other languages. Do the projects and homework in whatever you are comfortable in.

Does this count as a graduate distribution requirement? Yes, it should count regardless of your area of study.