# Fall 2022

## Physics

### Subject: Physical Sciences

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### Physical Sciences 2

Mechanics, Elasticity, Fluids, and Diffusion (122575)

*Gregory Kestin*

*Timothy Milbourne*

*Anna Klales*

2022 Fall (4 Credits) **Schedule:** T,TH 0900 AM - 1015 AM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**An introduction to classical mechanics, with special emphasis on the motion of biological systems, from proteins to people. Topics covered include: kinematics, Newton's laws of motion, oscillations, elasticity, random walks, diffusion, and fluids. Examples and problem set questions will often be drawn from the life sciences and medicine.**

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### Physical Sciences 12B

Electromagnetism and Quantum Physics from an Analytic, Numerical and Experimental Perspective (109457)

*Gregorio Ponti*

*Susanne Yelin*

2022 Fall (4 Credits) **Schedule:** MW 0900 AM - 1015 AM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**This is the second term of a two-semester course sequence of introductory physical science and engineering. The focus is on quantitative scientific reasoning, with the second term exploring classical electricity and magnetism. Topics include electrostatics and magnetostatics, analog circuits, electromagnetic fields, optics, and a brief introduction to quantum physics and its applications. Examples are drawn from across the physical sciences and engineering.**

**The course assumes familiarity with mechanics, statistical physics, and computational techniques covered in Physical Sciences 12a offered during Spring Term (see course description). Students will further develop competence in both analytic (using pencil, paper, and multi-variable calculus) and numerical methods (using the Python programming language) to model simple physical systems and to analyze experimental data.**

**The course is aimed at second year students who have an interest in pursuing a concentration in the ciences or engineering. The course includes lecture, laboratory, and discussion components.**

## Physical Sciences 70

Introduction to Digital Fabrication (215717)

*Nathan Melenbrink*

2022 Fall (4 Credits) **Schedule:** TR 0300 PM - 0415 PM

**Instructor Permissions:** Instructor **Enrollment Cap:** 15

**A hands-on introduction to rapid prototyping, integrating physics and engineering, design, computer science and art. Students will learn to safely use software and hardware to fabricate programmable projects. Tools and topics will include electronic circuit design, 3D CAD, programmable microcontrollers, and wireless networking (Internet of Things). Additionally, students will learn operational principles for techniques such as laser cutting, 3D printing, and computer-controlled milling. Students will work with course staff to prepare their design files and remotely operate machines, after which the fabricated components will be mailed to them. Applications may include personal fabrication, product prototyping, fine arts and the creation of scientific research tools. The course will culminate with an individual final project, integrating as many of the weekly topics as possible. Each student will document work on each weekly topic in a personal website, thereby finishing the course with an online portfolio that not only illustrates their new skill sets, but also contributes to a collective repository of knowledge that serves as a foundation for continued learning.**

**Course website: https://tinyurl.com/tasr7b6**

**Related Sections: In addition to class times, the course staff will be available for lab sections scheduled throughout the week. Students are required to attend at least one lab section per week to check in with course staff on their progress, and are otherwise free to attend as many additional sections as they like.**

**Course Notes:**

**Attendance is mandatory since safety training will occur during class times. Class will meet twice each week. The first meeting will consist of a brief review of the previous week's assignment, followed by a short introduction to the current week's topic and assignment. The second meeting will primarily focus on a hands-on training session for the accompanying assignment. Meetings may also include appearances by guest presenters or experts on a particular topic.**

## Subject: Physics

### Physics 15A

Introductory Mechanics and Relativity (111164)

*David Morin*

*Kathryn Ledbetter*

*Timothy Milbourne*

2022 Fall (4 Credits) **Schedule:** TR 1200 PM - 0115 PM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**Newtonian mechanics and special relativity. Topics include vectors; kinematics in three dimensions; Newton's laws; force, work, power; conservative forces, potential energy; momentum, collisions; rotational motion, angular momentum, torque; static equilibrium, simple harmonic motion, damped and driven oscillations; gravitation; fictitious forces; fluids; special relativity.**

**Course Notes:**

**Principles of Scientific Inquiry (PSI) is the laboratory component of Physics 15a. Topics include experimental design, model testing, error analysis, basic programming, oral presentations, and scientific writing. PSI will meet weekly throughout the semester.**

### Physics 15B

Introductory Electromagnetism (111896)

*Cora Dvorkin*

*Mara Prentiss*

2022 Fall (4 Credits) **Schedule:** TR 1200 PM - 0115 PM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**Electricity and magnetism. Topics include electrostatics, electric currents, magnetic field, electromagnetic induction, Maxwell's equations, electromagnetic radiation, magnetic fields in materials, and some basic notions in kinetic theory, entropy, temperature, and phase transition associated with electricity and magnetism.**

**Course Notes:**

**Principles of Scientific Inquiry (PSI) is the laboratory component of Physics 15b. The labs are designed to enhance your understanding of material presented in lectures. They also present applications of electricity and magnetism, as well as offering opportunities to build simple circuits and develop experience using measuring instruments, including oscilloscopes.**

## Physics 15C

Wave Phenomena (124154)

*Matteo Mitrano*

*Gregorio Ponti*

*Markus Greiner*

2022 Fall (4 Credits) **Schedule:** MW 1030 AM - 1145 AM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**Forced oscillation and resonance; coupled oscillators and normal modes; Fourier series; Electromagnetic waves, radiation, longitudinal oscillations, sound; traveling waves; signals, wave packets and group velocity; two- and three-dimensional waves; polarization; geometrical and physical optics; interference and diffraction. Optional topics: Water waves, holography, x-ray crystallography, solitons, music, quantum mechanics, and waves in the early universe.**

**Course Notes:**

**Principles of Scientific Inquiry (PSI) is the laboratory component of Physics 15c. Topics include experimental design, model testing, error analysis, basic programming, oral presentations, and scientific writing. PSI will meet weekly throughout the semester.**

## Physics 16

Mechanics and Special Relativity (111197)

*Norman Yao*

*Kathryn Ledbetter*

*Timothy Milbourne*

2022 Fall (4 Credits) **Schedule:** TR 1200 PM - 0115 PM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**Newtonian mechanics and special relativity for students with good preparation in physics and mathematics at the level of the advanced placement curriculum. Topics include oscillators damped and driven and resonance (how to rock your car out of a snow bank or use a swing), an introduction to Lagrangian mechanics and optimization, symmetries and Noether's theorem, special relativity, collisions and scattering, rotational motion, angular momentum, torque, the inertia tensor (dynamic balance), gravitation, planetary motion and a little glimpse of quantum mechanics.**

**Course Notes:**

**Principles of Scientific Inquiry (PSI) is the laboratory component of Physics 16. Topics include experimental design, model testing, error analysis, basic programming, oral presentations, and scientific writing. PSI will meet weekly throughout the semester. Emphasis is placed on collaborative teaching and learning. Many class materials are Mathematics notebooks.**

## Physics 19

Introduction to Theoretical Physics (207005)

*Jacob Barandes*

2022 Fall (4 Credits) **Schedule:** MWF 0300 PM - 0415 PM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**Physics 19 is a comprehensive introduction to the foundations of theoretical physics, with a first-principles approach to its five main areas: analytical mechanics, thermodynamics, fields, relativity, and quantum theory.**

**The course is aimed especially at those who are considering pursuing advanced study of physics in the concentration, as an option alongside Physics 15A and Physics 16. (Most physics concentrators start by taking either Physics 15A, 16, or 19.) The course is also meant for undergraduate and graduate students in other fields of study—such as math, philosophy, astronomy, biology, chemistry, computer science, and engineering—who are interested in developing a better understanding of physics either to serve the needs of their own academic work or as a first step toward switching their area of study to physics.**

**Course Notes: The purpose of the course is to present the foundations of modern theoretical physics in a welcoming setting for students from a variety of backgrounds. The course is intended to present a clear, faithful picture of what theoretical physics looks like. We will derive nearly everything from scratch in as self-contained a manner as possible—with occasional exceptions for special cutting-edge examples. We will also introduce all the necessary mathematics along the way.**

**Specific topics will include Newtonian mechanics, chaos, perturbation theory, orbital mechanics, the Lagrangian and Hamiltonian formulations, the connection between symmetries and conservation laws, statistical physics and thermodynamics, electromagnetism, special relativity, relativistic gravitation, black holes, and an extensive introduction to quantum theory. In-class discussions will regularly address relevant issues in the history and philosophy of physics, as well as the conceptual implications of our modern physical theories for making sense of the world around us.**

## Physics 20

Introduction to Computational Physics (220605)

*Efthimios Kaxiras*

*Logan McCarty*

2022 Fall (4 Credits) **Schedule:** TR 0945 AM - 1100 AM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**This course is a systematic introduction to computing with python and jupyter notebooks designed for concentrators in physics and related fields. The course consists of two parts: 1. Basics: essential elements of computing, including types of variables, lists, arrays, iteration and control flow (for, while loops, if statement), definition of functions, recursion, file handling and simple plots, numerical differentiation, fitting of curves and error analysis, plotting and visualization tools in higher dimensions. 2. Advanced: root finding, series expansions, numerical integration, solving simple ordinary and partial differential equations, use of random numbers for sampling and simulations, such as Monte Carlo integration and random walks. Applications of the numerical methods involve problems from mechanics, electromagnetism, and other branches of physics. Course work consists of attending lectures and labs, weekly homework assignments, a mid-term project and a final project; while work is developed collaboratively, coding assignments are submitted individually.**

**Course Notes:**

**Lectures meet concurrently with APMTH 10, although sections, homework and project assignments are different between the two courses.**

## Physics 90R

Supervised Research (111672)

*David Morin*

2022 Fall (4 Credits)

**Schedule:** TBD

**Enrollment Cap:** n/a

**Instructor Permissions:** Instructor

**Primarily for selected concentrators in Physics, or in Chemistry and Physics, who have obtained honor grades in Physics 15 and a number of intermediate-level courses. The student must be accepted by some member of the faculty doing research in the student's field of interest. The form of the research depends on the student's interest and experience, the nature of the particular field of physics, and facilities and support available. Students wishing to write a senior thesis can do so by arranging for a sponsor and enrolling in this course.**

**Course Notes:**

**A list of possible faculty sponsors and their fields is available in Lyman 238 and on the Physics Department Web page. Course enrollment forms may be obtained from Lyman 238.**

## Physics 91R

Supervised Reading Course for Undergraduates (110569)

*David Morin*

2022 Fall (4 Credits)

**Schedule:** TBD

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**Open to selected concentrators in Physics, Chemistry and Physics, and other fields who wish to do supervised reading and studying of special topics in physics. Ordinarily such topics do not include those covered in a regular course of the Department. Honor grades in Physics 15 and a number of intermediate-level courses are ordinarily required. The student must be accepted by a member of the faculty.**

**Course Notes:**

**A list of possible faculty sponsors and their fields is available in Lyman 238 and on the Physics Department's website. Course enrollment forms may be obtained from Lyman 238.**

## Physics 95

Topics in Current Research (111967)

*Robert Westervelt*

2022 Fall (4 Credits)

**Schedule:** M 1030 AM - 1145 AM

W 0700 PM - 0815 PM

**Instructor Permissions:** None

**Enrollment Cap:** n/a

**This tutorial is based on the Wednesday Night Seminars. Each Wednesday, two Harvard faculty members introduce their research to interested students, including undergraduates enrolled in the course, as well as graduate students who would like to learn about the topics investigated. The talks illustrate how research is done, and provide examples of projects graduate students might study if they join the group. Before each seminar, the enrolled students read examples of previous work, and they present and discuss the concepts. In the course, students learn how to express scientific concepts verbally, and in writing for their final report. The course is aimed at juniors and seniors who are familiar with the basics in classical mechanics, electricity and magnetism, and quantum mechanics.**

**Course Notes: Primarily for junior and senior concentrators, however interested sophomores are welcome.**

## Physics 113

Electronics for Physicists (216641)

*Melissa Franklin*

*Paul Horowitz*

*Kathryn Ledbetter*

2022 Fall (4 Credits) **Schedule:** WF 0130 PM - 0500 PM

**Instructor Permissions:** Instructor **Enrollment Cap:** 16

**Introduction to electronics for the physical sciences, focusing on skills applicable to laboratory work. Topics include instruments (multimeter, oscilloscope, function generator, power supply), analog circuits (amplifiers, filters, integrators), digital logic, analog/digital interfaces, noise reduction, PID control, and microcontrollers. Emphasis on circuit understanding and use of laboratory instrumentation. The class meets twice weekly, with an hour of lecture/discussion, followed by lab.**

## Physics 123A

Laboratory Electronics – Analog Circuits (218166)

*David Abrams*

2022 Fall (4 Credits) **Schedule:** T, TH 0130 PM - 0530

**Instructor Permissions:** Instructor **Enrollment Cap:** PM 20

**A lab-intensive introduction to analog electronic circuit design. Develops circuit intuition and debugging skills through daily hands-on lab exercises, each preceded by class discussion, with minimal use of mathematics and physics. Moves quickly from passive circuits, to discrete transistors, then concentrates on operational amplifiers, used to make a variety of circuits including integrators, oscillators, regulators, and filters.**

**Course Notes:**

**Physics 123a is the same course as Physics 223a; if you are a graduate student, please enroll in 223a. Limited to 20 students. The digital portion of the course, 123b/223b is offered in the spring semester.**

## Physics 141

The Physics of Sensory Systems in Biology (121885)

*Aravinthan Samuel*

2022 Fall (4 Credits) **Schedule:** TR 0900 AM - 1015 AM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**Living organisms use sensory systems to inform themselves of the sights, sounds, and smells of their surrounding environments. Sensory systems are physical measuring devices, and are therefore subject to certain limits imposed by physics. Here we will consider the physics of sensory measurement and perception, and study ways that biological systems have solved their underlying physical problems. We will discuss specific cases in vision, olfaction, and hearing from a physicist's point of view.**

## Physics 143A

Quantum Mechanics I (108465)

*Louis Deslauriers*

2022 Fall (4 Credits) **Schedule:** TR 1030 AM - 1145 AM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**Introduction to nonrelativistic quantum mechanics: uncertainty relations; Schrödinger equation; Dirac notation; matrix mechanics; one-dimensional problems including particle in box, tunneling, and harmonic oscillator; angular momentum, hydrogen atom, spin, Pauli principle; and if time allows: time-independent perturbation theory; and scattering.**

## Physics 143B

Quantum Mechanics II (111731)

*Lisa Randall*

2022 Fall (4 Credits) **Schedule:** MW 1200 PM - 0115 PM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**Introduction to path integrals, identical particles, many-electron theory, WKB approximation, time-dependent perturbation theory, scattering theory, relativistic quantum mechanics, and basics of quantum information.**

## Physics 145

Elementary Particle Physics (117719)

*Girma Hailu*

2022 Fall (4 Credits) **Schedule:** WF 1030 AM - 1145 AM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**Introduction to elementary particle physics. Emphasis on concepts and phenomenology rather than on detailed calculational development of theories. Starts with the discovery of the electron in 1897 and ends with the theoretical motivations for the Higgs boson, and attempts to cover everything important in between. Students will also have a brief experience of particle physics research using Atlas experiment open data.**

## Physics 151

Mechanics (111231)

*Arthur Jaffe*

2022 Fall (4 Credits) **Schedule:** TR 1200 PM - 0115 PM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**One can consider this course as a general introduction and overview to theoretical physics, even though it centers on the theoretical aspects of classical mechanics. We will study problems in the mechanics of particle motion and also problems in continuum mechanics, including classical field theory. We will consider linear systems and non-linear ones. We stress the role of conserved quantities in studying the laws of physics, and emphasize the relation between conserved quantities and symmetry. We study Langrangian and Hamiltonian mechanics from the point of view of their relation to different fields of physics, including quantum theory. We discuss soliton solutions to some non-linear classical equations. Time permitting, we will discuss other non-linear phenomena that are important in physics.**

## Physics 191

Advanced Laboratory (121993)

*Isaac Silvera*

*Amir Yacoby*

2022 Fall (4 Credits) **Schedule:** TR 0130 PM - 0530 PM

**Instructor Permissions:** Instructor **Enrollment Cap:** n/a

**Students will engage in the practice and discussion of experimental science by completing three projects, drawn from the fields of condensed matter, atomic, optical, nuclear, and/or particle physics. Laboratory techniques, theoretical understanding, data analysis methods, and scientific reading and writing skills are developed in collaboration with a lab partner, and with guidance from a team of experimental physics faculty and staff. Students will learn to write the results of each project in a format that is appropriate for a peer-reviewed journal. Available experiments range from classics of the twentieth century such as relativistic mass of the electron, lifetime of the muon, superfluid helium, and the quantum Hall effect, to topics of current interest such as slow light, nitrogen-vacancy centers in diamond, superconductivity and the Meissner effect, and optical tweezers.**

**Course Notes: A substantial amount of outside reading is expected. Physics 191 is the same course as Physics 247; if you are a graduate students, please enroll in 247.**

## Physics 195A

Introduction to Solid State Physics (112107)

*Julia Mundy*

2022 Fall (4 Credits) **Schedule:** MW 0300 PM - 0415 PM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**The physics of crystalline solids and their electric, magnetic, optical, and thermal properties. Designed as a first course in solid-state physics. Topics: free electron model; Drude model; the physics of crystal binding; crystal structure and vibration (phonons); x-ray diffraction; electrons in solids (Bloch theorem) and electronic band structures; metals and insulators; semiconductors (and their applications in pn junctions and transistors); magnetism; superconductivity.**

**Course Notes: Physics 195a is also offered as Applied Physics 195a. Students may not take both for credit.**

## Physics 223A

Laboratory Electronics – Analog Circuits (218167)

*David Abrams*

2022 Fall (4 Credits) **Schedule:** TR 0130 PM - 0530 PM

**Instructor Permissions:** Instructor **Enrollment Cap:** 20

**A lab-intensive introduction to analog electronic circuit design. Develops circuit intuition and debugging skills through daily hands-on lab exercises, each preceded by class discussion, with minimal use of mathematics and physics. Moves quickly from passive circuits, to discrete transistors, then concentrates on operational amplifiers, used to make a variety of circuits including integrators, oscillators, regulators, and filters.**

**Course Notes:** **Physics 223a is the same course as Physics 123a; if you are an undergraduate student, please enroll in 123a. Limited to 20 students. The digital portion of the course, 123b/223b is offered in the spring semester.**

## Physics 247

Laboratory Course in Contemporary Physics (145024)

*Isaac Silvera*

*Amir Yacoby*

2022 Fall (4 Credits) **Schedule:** TR 0130 PM - 0530 PM

**Instructor Permissions:** Instructor **Enrollment Cap:** n/a

**Students will engage in the practice and discussion of experimental science by completing three projects, drawn from the fields of condensed matter, atomic, optical, nuclear, and/or particle physics. Laboratory techniques, theoretical understanding, data analysis methods, and scientific reading and writing skills are developed in collaboration with a lab partner, and with guidance from a team of experimental physics faculty and staff. Students will learn to write the results of each project in a format that is appropriate for a peer-reviewed journal. Available experiments range from classics of the twentieth century such as relativistic mass of the electron, lifetime of the muon, superfluid helium, and the quantum Hall effect, to topics of current interest such as slow light, nitrogen-vacancy centers in diamond, superconductivity and the Meissner effect, and optical tweezers.**

**Course Notes:** **A substantial amount of outside reading is expected. Physics 247 is the same course as Physics 191; if you are an undergraduate, please enroll in 191.**

## Physics 251A

Advanced Quantum Mechanics I (111314)

*C. Vafa*

2022 Fall (4 Credits)

**Instructor Permissions:** None **Schedule:** WF 1030 AM - 1145 AM

**Enrollment Cap:** n/a

**Basic course in nonrelativistic quantum mechanics. Review of wave functions and the Schrödinger Equation; Hilbert space; the WKB approximation; central forces and angular momentum; spins and their addition, measurement theory; the density matrix; perturbation theory.**

## Physics 253A

Quantum Field Theory I (122930)

*Xi Yin*

2022 Fall (4 Credits) **Schedule:** T, TH 0130 PM - 0245 PM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**Introduction to relativistic quantum field theory. This course covers quantum electrodynamics. Topics include canonical quantization, Feynman diagrams, spinors, gauge invariance, path integrals, ultraviolet and infrared divergences, renormalization and applications to the quantum theory of the weak and gravitational forces.**

## Physics 262

Statistical Mechanics (110526)

*Vinothan Manoharan*

2022 Fall (4 Credits) **Schedule:** MWF 1200 PM - 0115 PM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**Basic principles of statistical physics with applications including: the equilibrium properties of classical and quantum gases; phase diagrams, phase transitions and critical points, as illustrated by the gas-liquid transition and simple magnetic models; Bose-Einstein condensation.**

**Course Notes:** **Also offered as Applied Physics 284. Either course can be used to satisfy the statistical mechanics requirement in the Physics PhD program or the Applied Physics model PhD program.**

## Physics 268AR

Information Theory for Physicists (122818)

2022 Fall (4 Credits) **Schedule:** F 0130 PM - 0415 PM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**This course describes a universal framework applied to black holes, stock markets, brain research, Google search algorithm, self-driving cars, etc. Topics: Entropy of a gas and entropy of the English language. Communication theory, hypothesis testing and relative entropy. Exorcising Maxwell demon and Landauer principle. Quantum information theory and entanglement entropy. Area law and Bekenstein bound. New second laws of thermodynamics.**

**Course Notes:** **This course will be taught by Prof. Gregory Falkovich, Pollak Professorial Chair in Physics at the Weizmann Institute of Science, Rehovot, Israel.**

## Physics 271

Topics in the Physics of Quantum Information (121970)

*Mikhail Lukin*

2022 Fall (4 Credits) **Schedule:** MW 1030 AM - 1145 AM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**Introduction to physics of quantum information, with emphasis on ideas and experiments ranging from quantum optics to condensed matter physics. Background and theoretical tools will be introduced. The format is a combination of lectures and class presentations.**

## Physics 286

Inference, Information Theory, Learning and Statistical Mechanics (138516)

*Sharad Ramanathan*

2022 Fall (4 Credits) **Schedule:** T, TH 0130 PM - 0245 PM

**Instructor Permissions:** Instructor **Enrollment Cap:** 35

**This course focuses on the modern applications of Statistical Mechanics. We will learn the basics of information theory, coding and compression. We will next learn about Bayesian Inference, priors and maximizing entropy, which will naturally lead us to regularization and compressed sensing. We will then cover learning: support vector machines, vc dimension, supervised, reinforcement and unsupervised learning. These topics, which build on each other, will be taught using examples in the primary literature with an emphasis on applying the framework we develop. Applications will be taught through problems in genomics, neuroscience, geophysics and engineering.**

**Course Notes:** **Physics 286 is also offered as Applied Physics 286. Students may not take both for credit.**

## Physics 287A

Introduction to String Theory (111191)

*Daniel Jafferis*

2022 Fall (4 Credits) **Schedule:** T, TH 0300 PM - 0415 PM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**Introduction to the perturbative formulation of string theories and dualities. Quantization of bosonic and superstrings, perturbative aspects of scattering amplitudes, supergravity, D-branes, T-duality and mirror symmetry. Also a brief overview of recent developments in string theory.**

## Physics 295A

Introduction to Quantum Theory of Solids (127980)

*Subir Sachdev*

2022 Fall (4 Credits) **Schedule:** MWF 1200 PM - 0115 PM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**This is an introductory graduate level course in solid-state physics. Lattices and symmetries. Phonons. Electronic Structure of Crystals. Metals, semiconductors, and insulators will be covered. Electrical, optical, and thermal properties of solids will be treated based on an atomic scale picture and using the independent electron approximation. Additional topics from the theory of interacting electrons, including introduction to magnetism and superconductivity, and an introduction to topological insulators.**

## Physics 296

Mesoscale and Low Dimensional Devices (214614)

*Philip Kim*

2022 Fall (4 Credits) **Schedule:** T, TH 0130 PM - 0245 PM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**Concepts of condensed matter physics are applied to the science and technology of beyond-CMOS devices, in particular, mesoscale, low-dimensional, and superconducting devices. Topics include: quantum dots/wires/wells and two-dimensional (2D) materials; optoelectronics with confined electrons; conductance quantization, Landauer-Buttiker formalism, and resonant tunneling; magneto oscillation; integer and fractional quantum Hall effects; Berry phase and topology in condensed matter physics; various Hall effects (anomalous, spin, valley, etc.); Weyl semimetal; topological insulator; spintronic devices and circuits; collective electron behaviors in low dimensions and applications; Cooper-pair boxes and superconducting quantum circuits.**

**Course Notes:** **Also offered as Applied Physics 296.**

## Physics 297

Professional Writing for Scientists and Engineers (217830)

*Daniel Needleman*

*Suzanne Smith*

2022 Fall (4 Credits) **Schedule:** R 0300 PM - 0500 PM

**Instructor Permissions:** Instructor **Enrollment Cap:** 15

**This class leads students to develop their skills in the critical reading and writing of science and engineering. Genres will include research articles, grant proposals, school/fellowship/job applications, or lay abstracts & press releases for the non-scientific public. Crucially, students will be empowered not only to achieve their own writing goals, but also to break down these learned skills and impart them to others, as effective collaborators and mentors of younger students.**

# Spring 2023

## Subject: Physical Sciences

### Physical Sciences 3

Electromagnetism, Circuits, Waves, Optics, and Imaging (122576)

*Melissa Franklin*

2023 Spring (4 Credits) **Schedule:** T, TH 0900 AM - 1015 AM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**This course is an introduction to electromagnetism, digital information, waves, optics and sound. Topics covered include: electric and magnetic fields, electrical potential, circuits, simple digital circuits, wave propagation in various media, microscopy, sound and hearing. The course will draw upon a variety of applications to the biological sciences and will use real-world examples to illustrate many of the physical principles described. There are six laboratories.**

**Course Notes:**

**This course is part of an integrated introduction to the physical sciences intended for students who plan to pursue a concentration in the life sciences and/or satisfy pre-medical requirements in Physics. May not ordinarily be taken for credit in addition to Physics 15b**

### Physical Sciences 12A

Mechanics and Statistical Physics from an Analytic, Numerical and Experimental Perspective (109274)

*Anna Klales*

2023 Spring (4 Credits) **Schedule:** MWF 0900 AM - 1015 AM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**This is the first term of a two-semester introductory course in physics. The focus is on quantitative scientific reasoning, with the first term exploring Newtonian mechanics. Topics include kinematics, linear and rotational motion, forces, energy, momentum, collisions, gravitation, oscillations, waves, and a brief introduction to statistical physics. Examples are drawn from across the physical sciences and engineering.**

**Students will gain competence in both analytic (using pencil, paper, and single-variable calculus) and numerical methods (using the python programming language) to model simple physical systems and to analyze experimental data.**

**The course is aimed at first year students who have an interest in pursuing a concentration in the sciences or engineering. The course includes lecture, laboratory, and discussion components.**

**Course Notes:**

**Physical Sciences 12a may not be taken for credit by students who have passed Physics 15a or 16.**

## Physical Sciences 70

Introduction to Digital Fabrication (215717)

*Nathan Melenbrink*

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| 2023 Spring (4 Credits) | | **Schedule:** | T, TH 0300 PM - 0415 PM |
| **Instructor Permissions:** | Instructor | **Enrollment Cap:** | 15 |

**A hands-on introduction to rapid prototyping, integrating physics and engineering, design, computer science and art. Students will learn to safely use software and hardware to fabricate programmable projects. Tools and topics will include electronic circuit design, 3D CAD, programmable microcontrollers, and wireless networking (Internet of Things). Additionally, students will learn operational principles for techniques such as laser cutting, 3D printing, and computer-controlled milling. Students will work with course staff to prepare their design files and remotely operate machines, after which the fabricated components will be mailed to them. Applications may include personal fabrication, product prototyping, fine arts and the creation of scientific research tools. The course will culminate with an individual final project, integrating as many of the weekly topics as possible. Each student will document work on each weekly topic in a personal website, thereby finishing the course with an online portfolio that not only illustrates their new skill sets, but also contributes to a collective repository of knowledge that serves as a foundation for continued learning.**

**Course website: https://tinyurl.com/tasr7b6**

**Related Sections: In addition to class times, the course staff will be available for lab sections scheduled throughout the week. Students are required to attend at least one lab section per week to check in with course staff on their progress, and are otherwise free to attend as many additional sections as they like.**

**Course Notes:**

**Attendance is mandatory since safety training will occur during class times. Class will meet twice each week. The first meeting will consist of a brief review of the previous week's assignment, followed by a short introduction to the current week's topic and assignment. The second meeting will primarily focus on a hands-on training session for the accompanying assignment. Meetings may also include appearances by guest presenters or experts on a particular topic.**

# Physics

## Subject: Physics

### Physics 15A

Introductory Mechanics and Relativity (111164)

*David Morin*

2023 Spring (4 Credits) **Schedule:** T, TH 1200 PM - 0115 PM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**Newtonian mechanics and special relativity. Topics include vectors; kinematics in three dimensions; Newton's laws; force, work, power; conservative forces, potential energy; momentum, collisions; rotational motion, angular momentum, torque; static equilibrium, simple harmonic motion, damped and driven oscillations; gravitation; fictitious forces; fluids; special relativity.**

**Course Notes:**

**Principles of Scientific Inquiry (PSI) is the laboratory component of Physics 15a. Topics include experimental design, model testing, error analysis, basic programming, oral presentations, and scientific writing. PSI will meet weekly throughout the semester.**

### Physics 15B

Introductory Electromagnetism (111896)

*Carlos Arguelles Delgado*

*Amir Yacoby*

2023 Spring (4 Credits) **Schedule:** T, TH 1200 PM - 0115 PM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**Electricity and magnetism. Topics include electrostatics, electric currents, magnetic field, electromagnetic induction, Maxwell's equations, electromagnetic radiation, magnetic fields in materials, and some basic notions in kinetic theory, entropy, temperature, and phase transition associated with electricity and magnetism.**

**Course Notes:**
**Principles of Scientific Inquiry (PSI) is the laboratory component of Physics 15b. The labs are designed to enhance your understanding of material presented in lectures. They also present applications of electricity and magnetism, as well as offering opportunities to build simple circuits and develop experience using measuring instruments, including oscilloscopes.**

## Physics 15C

Wave Phenomena (124154)

*John Huth*

*Mara Prentiss*

2023 Spring (4 Credits) **Schedule:** MW 1030 AM - 1145 AM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**Forced oscillation and resonance; coupled oscillators and normal modes; Fourier series; Electromagnetic waves, radiation, longitudinal oscillations, sound; traveling waves; signals, wave packets and group velocity; two- and three-dimensional waves; polarization; geometrical and physical optics; interference and diffraction. Optional topics: Water waves, holography, x-ray crystallography, solitons, music, quantum mechanics, and waves in the early universe.**

**Course Notes: Principles of Scientific Inquiry (PSI) is the laboratory component of Physics 15c. Topics include experimental design, model testing, error analysis, basic programming, oral presentations, and scientific writing. PSI will meet weekly throughout the semester.**

## Physics 90R

Supervised Research (111672)

*David Morin*

2023 Spring (4 Credits) **Schedule:** TBD

**Instructor Permissions:** None **Enrollment Cap:** n/a

**Primarily for selected concentrators in Physics, or in Chemistry and Physics, who have obtained honor grades in Physics 15 and a number of intermediate-level courses. The student must be accepted by some member of the faculty doing research in the student's field of interest. The form of the research depends on the student's interest and experience, the nature of the particular field of physics, and facilities and support available. Students wishing to write a senior thesis can do so by arranging for a sponsor and enrolling in this course.**

**Course Notes:**
**A list of possible faculty sponsors and their fields is available in Lyman 238 and on the Physics Department Web page. Course enrollment forms may be obtained from Lyman 238.**

## Physics 91R

Supervised Reading Course for Undergraduates (110569)

*David Morin*

2023 Spring (4 Credits) **Schedule:** TBD

**Instructor Permissions:** None **Enrollment Cap:** n/a

**Open to selected concentrators in Physics, Chemistry and Physics, and other fields who wish to do supervised reading and studying of special topics in physics. Ordinarily such topics do not include those covered in a regular course of the Department. Honor grades in Physics 15 and a number of intermediate-level courses are ordinarily required. The student must be accepted by a member of the faculty.**

**Course Notes: A list of possible faculty sponsors and their fields is available in Lyman 238 and on the Physics Department's website. Course enrollment forms may be obtained from Lyman 238.**

## Physics 95

Topics in Current Research (111967)

*Isaac Silvera*

2023 Spring (4 Credits)

**Schedule:** M 0300 PM - 0415 PM
W 0730 PM - 0845 PM

**Instructor Permissions:** Instructor

**Enrollment Cap:** n/a

**This tutorial is based on the Wednesday Night Seminars. Each Wednesday, two Harvard faculty members introduce their research to interested students, including undergraduates enrolled in the course, as well as graduate students who would like to learn about the topics investigated. The talks illustrate how research is done, and provide examples of projects graduate students might study if they join the group. Before each seminar, the enrolled students read examples of previous work, and they present and discuss the concepts. In the course, students learn how to express scientific concepts verbally, and in writing for their final report. The course is aimed at juniors and seniors who are familiar with the basics in classical mechanics, electricity and magnetism, and quantum mechanics.**

**Course Notes: Primarily for junior and senior concentrators, however interested sophomores are welcome.**

## Physics 113

Electronics for Physicists (216641)

*Masahiro Morii*

*Kathryn Ledbetter*

2023 Spring (4 Credits)

**Schedule:** WF 0130 PM - 0415 PM

**Instructor Permissions:** Instructor

**Enrollment Cap:** 20

**Introduction to electronics for the physical sciences, focusing on skills applicable to laboratory work. Topics include instruments (multimeter, oscilloscope, function generator, power supply), analog circuits (amplifiers, filters, integrators), digital logic, analog/digital interfaces, noise reduction, PID control, and microcontrollers. Emphasis on circuit understanding and use of laboratory instrumentation. The class meets twice weekly, with an hour of lecture/discussion, followed by lab.**

**Recommended Prep:**

**Some familiarity with resistance, capacitance, inductance, and dc circuits (e.g., Physics 12B, 15B, or equivalent) is helpful; no prior coursework or experience with electronics is required.**

## Physics 123B

Laboratory Electronics - Digital Circuits (124108)

*David Abrams*

2023 Spring (4 Credits) **Schedule:** T, TH 0130 PM - 0530 PM

**Instructor Permissions:** Instructor **Enrollment Cap:** 10

**A lab-intensive introduction to digital electronic circuit design. Develops circuit intuition and debugging skills through hands-on lab exercises, each preceded by class discussion, with minimal use of mathematics and physics. After a short introduction to the basics of electronic circuits and MOSFET switches, we move onto digital devices including logic families, Boolean arithmetic, combinatorial and sequential circuits including finite state machines. We continue with analog-digital interfacing, the use of microcontrollers in embedded systems and programmable logic devices (FPGAs ). We will also discuss data conversion techniques.**

**Course Notes:**

**Physics 123b is the same course as Physics 223b; students may not take both for credit. If you are a graduate student, please enroll in 223b. Limited to 10 students. The analog portion of the course, 123a/223a is offered as a separate course in the fall semester**

## Physics 129

Energy Science (125656)

*Lene Hau*

2023 Spring (4 Credits) **Schedule:** T, TH 0130 PM - 0245 PM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**Non-fossil energy sources are important for our future. In lectures, we cover main subjects to which students with a background in physics, engineering, or physical chemistry could make paradigm changing contributions: photovoltaic cells, nuclear power, and photosynthesis. Further subjects are covered in student projects. Fundamentals of electrodynamics, statistical/thermal physics, and quantum mechanics are taught as needed to give the students an understanding of the topics covered.**

## Physics 137

Conceptual Foundations of Quantum Mechanics (218289)

*Jacob Barandes*

2023 Spring (4 Credits) **Schedule:** T, TH 0130 PM - 0245 PM

**Instructor Permissions:** Instructor **Enrollment Cap:** 20

**Quantum theory is our best-tested and most predictive scientific theory by many quantitative measures. The theory reliably accounts for the measurement results of atomic clocks and particle accelerators to many decimal places, and much of our modern technology relies on it. However, the theory's standard textbook postulates are controversial, and there is still no consensus over what precisely the theory entails about the world. This course will cover the century-long effort to resolve these mysteries and others, a story that features fantastical notions like parallel universes, pilot waves, quasi-probabilities, alive-and-dead cats, and spooky action at a distance.**

**Topics: In the first part of the course, we will review some history, lay out the textbook postulates of quantum theory, and cover how to use the theory in practice. In the second part of the course, we will examine the internal logic of the theory, ultimately explaining why the theory's traditional axioms are not universally regarded as internally consistent or complete. In the third part of the course, we will examine various attempts to patch up and re-interpret the theory to solve these consistency problems. As we proceed, we will continually refer back to relevant questions in philosophy, including debates over metaphysics, instrumentalism, scientific realism, determinism, epistemology, and the meaning of probability.**

## Physics 143A

Quantum Mechanics I (108465)

*Louis Deslauriers*

2023 Spring (4 Credits) **Schedule:** TR 1030 AM - 1145 AM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**Introduction to nonrelativistic quantum mechanics: uncertainty relations; Schrödinger equation; Dirac notation; matrix mechanics; one-dimensional problems including particle in box, tunneling, and harmonic oscillator; angular momentum, hydrogen atom, spin, Pauli principle; and if time allows: time-independent perturbation theory; and scattering.:**

## Physics 153

Electrodynamics (111822)

*Philip Kim*

2023 Spring (4 Credits) **Schedule:** MW 1200 PM - 0115 PM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**Aimed at advanced undergraduates. Emphasis on the properties and sources of the electromagnetic fields and on the wave aspects of the fields. Course starts with electrostatics and subsequently develops the Maxwell equations. Topics: electrostatics, dielectrics, magnetostatics, electrodynamics, radiation, wave propagation in various media, wave optics, diffraction and interference. A number of applications of**

## Physics 175

Laser Physics and Modern Optical Physics (121941)

*Markus Greiner*

2023 Spring (4 Credits) **Schedule:** WF 0130 PM - 0245 PM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**Introduction to laser physics and modern optical physics aimed at advanced undergraduates. Review of electromagnetic theory and relevant aspects of quantum mechanics. Wave nature of light. Physics of basic optical elements. Propagation of focused beams, optical resonators, dielectric waveguides. Interaction of light with matter, introduction to quantum optics. Lasers. Physics of specific laser systems. Introduction to nonlinear optics. Modern applications.**

## Physics 181

Statistical Mechanics and Thermodynamics (143450)

*Girma Hailu*

2023 Spring (4 Credits) **Schedule:** TR 1200 PM - 0115 PM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**This course provides an introduction to statistical mechanics and thermal physics. It surveys the fundamental elements of classical and quantum statistical mechanics (ensembles and partition functions) and thermodynamics (temperature, heat, work, free energy) and their application to a variety of physical systems. Topics covered may include heat engines, solid-state physics, blackbody radiation, phase transitions, physical chemistry, stellar physics, quantum information, Bose-Einstein condensation, and transport phenomena.**

**Course Notes:**

**May not be taken for credit in addition to Engineering Sciences 181.**

## Physics 191

Advanced Laboratory (121993)

*Jenny Hoffman*

*Matteo Mitrano*

2023 Spring (4 Credits) **Schedule:** T, TH 0130 PM - 0530 PM

**Instructor Permissions:** Instructor **Enrollment Cap:** n/a

**Students will engage in the practice and discussion of experimental science by completing three projects, drawn from the fields of condensed matter, atomic, optical, nuclear, and/or particle physics. Laboratory techniques, theoretical understanding, data analysis methods, and scientific reading and writing skills are developed in collaboration with a lab partner, and with guidance from a team of experimental physics faculty and staff. Students will learn to write the results of each project in a format that is appropriate for a peer-reviewed journal. Available experiments range from classics of the twentieth century such as relativistic mass of the electron, lifetime of the muon, superfluid helium, and the quantum Hall effect, to topics of current interest such as slow light, nitrogen-vacancy centers in diamond, superconductivity and the Meissner effect, and optical tweezers.**

**Course Notes: A substantial amount of outside reading is expected. Physics 191 is the same course as Physics 247; if you are a graduate students, please enroll in 247.**

## Physics 195B

Introduction to Quantum Materials and Devices (218288)

*Robert Westervelt*

2023 Spring (4 Credits) **Schedule:** MWF 0300 PM - 0415 PM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**This course provides an introduction to quantum materials and devices, including low-dimensional materials, single and double quantum dots, Josephson junctions, and graphene. Their behavior is explained using quantum and semiclassical transport, the Coulomb blockade, and superconductivity. Quantum devices offer new approaches for electronics and photonics.**

**Course Notes:**

**Formerly ENGSCI 171. Physics 195b is also offered as Applied Physics 195b. Students may not take both for credit.**

## Physics 201

Data Analysis for Physicists (161201)

*Vinothan Manoharan*

2023 Spring (4 Credits) **Schedule:** MWF 1030 AM - 1145 AM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**This course covers methods for analyzing experimental data. Students will learn a Bayesian framework for statistical inference, modern computational methods such as Markov-chain Monte Carlo techniques, and the application to problems in particle physics, biophysics, condensed matter, applied physics, astrophysics, and other fields. The course emphasizes an intuitive, principled approach to data analysis and will involve discussions of ethics and reproducible research.**

**Course Notes:**

**This course is suitable for students with limited or rusty programming skills. Students with more advanced programming skills may wish to take APMTH 207 or ENG-SCI 255.**

## Physics 210

General Theory of Relativity (114266)

*Daniel Jafferis*

2023 Spring (4 Credits) **Schedule:** MW 0300 PM - 0415 PM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**An introduction to general relativity: the principle of equivalence, Riemannian geometry, Einstein's field equation, the Schwarzschild solution, the Newtonian limit, experimental tests, black holes.**

**Recommended Prep:**

**Physics 143a (quantum mechanics), 151 (mechanics) and 153 (electromagnetism), and Mathematics 21 (multivariable calculus) or equivalents.**

## Physics 211BR

Quantum Black Holes (117201)

*Andrew Strominger*

2023 Spring (4 Credits) **Schedule:** W 0300 PM - 0500 PM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**An introduction to our current understanding of the quantum theory of black holes. Topics include: Hawking radiation, the Bekenstein-Hawking entropy/area law, quantum entanglement, two and three-dimensional black holes, microstate counting, asymptotic symmetries, soft hair, holography, chaos bounds and Kerr/CFT. A central focus will be the 'information paradox' concerning the relations between general relativity, quantum mechanics and thermodynamics.**

**Course Notes:**

**The actual start time for the course will be 4:00pm, and the course will end at 6:00pm.**

## Physics 212

Cosmology (203431)

*Cora Dvorkin*

2023 Spring (4 Credits) **Schedule:** T, TH 1030 AM - 1145 AM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**Graduate course on Physical Cosmology. Topics will include: the physics of Inflation, Cosmic Microwave Background anisotropies, evidence for Dark Matter, discovery of the accelerated expansion of the Universe, primordial gravitational waves, gravitational lensing, likelihood analysis, structure formation.**

## Physics 216

Mathematics of Modern Physics (127815)

*Arthur Jaffe*

2023 Spring (4 Credits) **Schedule:** TR 1030 AM - 1145 AM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**Introduction to mathematical methods relevant for understanding quantum field theory beyond perturbation theory. Topics include algebras of linear operators on Hilbert space, representation theory, semi-definite programming, and topological quantum field theory.**

## Physics 218

Quantum Chaos and Localization (110678)

*Eric Heller*

2023 Spring (4 Credits) **Schedule:** TR 1030 AM - 1145 AM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**The important subject of quantum ergodicity and thermalization is under active investigation. This course is designed to address the questions that arise, developing the fundament tools right up to the research frontier. Chaos theory, Anderson localization, scarring, random matrix theory, decoherence, entanglement, and measurement theory are considered. As much as possible, this course will adopt a seminar format, with student discussion and presentations becoming more important as the term progresses.**

## Physics 223B

Laboratory Electronics - Digital Circuits (109346)

*David Abrams*

2023 Spring (4 Credits) **Schedule:** TR 0130 PM - 0530 PM

**Instructor Permissions:** Instructor **Enrollment Cap:** 10

**A lab-intensive introduction to digital electronic circuit design. Develops circuit intuition and debugging skills through hands-on lab exercises, each preceded by class discussion, with minimal use of mathematics and physics. After a short introduction to the basics of electronic circuits and MOSFET switches, we move onto digital devices including logic families, Boolean arithmetic, combinatorial and sequential circuits including finite state machines. We continue with analog-digital interfacing, the use of microcontrollers in embedded systems and programmable logic devices (FPGAs ). We will also discuss data conversion techniques.**

**Course Notes: Physics 223b is the same course as Physics 123b; students may not take both for credit. If you are a graduate student, please enroll in 223b. Limited to 10 students. The analog material will be offered as a separate course at a later date.**

## Physics 230

Active Matter (220552)

*L Mahadevan*

2023 Spring (4 Credits) **Schedule:** F 1200 PM - 0245 PM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**Active matter describes out of equilibrium systems that consume energy to do work and become functional. Understanding their behavior and function has implications for biology and complex systems across scales, from cells to ecosystems, e.g., morphogenesis, collective behavior of flocks and herds, neurodynamics of locomotion, etc. The tools and concepts needed include non-equilibrium statistical mechanics, kinetic theory, soft matter, and hydrodynamics; methods for the analysis of the models include scaling, coarse-graining (homogenization, renormalization) and computational algorithms (for stochastic and deterministic DE). This course will provide an introduction to the questions, techniques and successes of this exploding field that cuts across the physical and biological sciences.**

**Course Notes: Open to PhD students and [AB/SM students or advanced undergraduate students] by permission of instructor. Physics 230 is also offered as Applied Math 230. Students may not take both for credit.**

## Physics 232

Advanced Electromagnetism (112263)

*Girma Hailu*

2023 Spring (4 Credits) **Schedule:** MWF 0300 PM - 0415 PM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**Maxwell's equations in macroscopic media, conservation laws, Green's functions, time-dependent solutions and radiation, scattering and diffraction, and gauge invariance. Time permitting: geometrical optics and caustics, negative refractive index materials and radiation from rapidly accelerating charges.**

## Physics 247

Laboratory Course in Contemporary Physics (145024)

*Jenny Hoffman*

*Matteo Mitrano*

2023 Spring (4 Credits) **Schedule:** T, TH 0130 PM - 0530 PM

**Instructor Permissions:** Instructor **Enrollment Cap:** n/a

**Students will engage in the practice and discussion of experimental science by completing three projects, drawn from the fields of condensed matter, atomic, optical, nuclear, and/or particle physics. Laboratory techniques, theoretical understanding, data analysis methods, and scientific reading and writing skills are developed in collaboration with a lab partner, and with guidance from a team of experimental physics faculty and staff. Students will learn to write the results of each project in a format that is appropriate for a peer-reviewed journal. Available experiments range from classics of the twentieth century such as relativistic mass of the electron, lifetime of the muon, superfluid helium, and the quantum Hall effect, to topics of current interest such as slow light, nitrogen-vacancy centers in diamond, superconductivity and the Meissner effect, and optical tweezers.**

**Course Notes:**

**A substantial amount of outside reading is expected. Physics 247 is the same course as Physics 191; if you are an undergraduate, please enroll in 191.**

## Physics 251B

Advanced Quantum Mechanics II (111876)

*Susanne Yelin*

2023 Spring (4 Credits) **Schedule:** TR 0130 PM - 0245 PM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**Path integrals; relativistic quantum mechanics and quantum fields; identical particles; scattering theory; quantum information theory.**

## Physics 253B

Quantum Field Theory II (115442)

*Xi Yin*

2023 Spring (4 Credits) **Schedule:** WF 0130 PM - 0245 PM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**A continuation of Physics 253a. Topics include: the renormalization group, implications of unitarity, Yang-Mills theories, spontaneous symmetry breaking, weak interactions, anomalies, and quantum chromodynamics. Additional advanced topics may be covered depending on time and interest.**

## Physics 254

The Standard Model (109328)

*Matthew Reece*

2023 Spring (4 Credits) **Schedule:** MW 0900 AM - 1015 AM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**The Standard Model of particle physics: theory and experimental implications. Topics include nonabelian gauge theory, spontaneous symmetry breaking, anomalies, the chiral Lagrangian, QCD and jets, collider physics and simulation, the Higgs at the LHC.**

## Physics 264 Section: 1

Lie Algebras in Particle Physics (203512)

*Howard Georgi*

2023 Spring (4 Credits) **Schedule:** T, TH 1200 PM - 0115 PM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**Lie algebras and their representations are indispensible tools in quantum mechanics. Starting from the operator treatment of angular momentum, this course explores some of the (many) useful approaches to this subject with applications in various areas of physics.**

## Physics 265

Statistical Mechanics of Spin Glasses and Neural Networks (220597)

*Haim Sompolinsky*

2023 Spring (4 Credits) **Schedule:** MW 0300 PM - 0415 PM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**The course will survey advanced statistical physics approaches in the study of complex natural and artificial systems, spanning theory of spin glasses, random matrices, random dynamical systems, random graphs, and neural networks, with applications to the physics of spin glasses, chaos in random circuits, memory and learning in recurrent and deep neural networks. Surveyed methods include Replica Theory, Dynamic Mean Fields, Cavity and Message Passing, Kernels and Gaussian Processes.**

## Physics 295B

Quantum Theory of Solids (127979)

*Subir Sachdev*

2023 Spring (4 Credits) **Schedule:** T 0300 PM - 0545 PM

**Instructor Permissions:** None **Enrollment Cap:** n/a

**A course on the application of the principles of many-particle quantum mechanics to the properties of solids. The objective is to make students familiar with the tools of second quantization and diagrammatic perturbation theory, while describing the theory of the electron liquid, the BCS theory of superconductivity, and theory of magnetism in metals and insulators. Modern topics on correlated electron systems will occupy the latter part of the course.**

**Course Notes:**

**Physics 295b is also offered as Applied Physics 295b. Students may not take both for credit.**

## Physics 297

Professional Writing for Scientists and Engineers (217830)

*Jenny Hoffman*

*Suzanne Smith*

2023 Spring (4 Credits) **Schedule:** W 0300 PM - 0500 PM

**Instructor Permissions:** Instructor **Enrollment Cap:** 20

**This class leads students to develop their skills in the critical reading and writing of science and engineering. Genres will include research articles, grant proposals, school/fellowship/job applications, or lay abstracts & press releases for the non-scientific public. Crucially, students will be empowered not only to achieve their own writing goals, but also to break down these learned skills and impart them to others, as effective collaborators and mentors of younger students.**