FALL 2021

Faculty of Arts and Sciences

Course Catalog Preview

Subject: Physical Sciences (PHYSCI)

Physical Sciences 2 — Mechanics, Elasticity, Fluids, and Diffusion (122575)

Gregory Kestin

Timothy Milbourne

2021 Fall (4 Credits) **Schedule:** TR 0900 AM - 1015 AM

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

Physical Sciences 12B — Electromagnetism and Quantum Physics from an Analytic, Numerical and Experimental Perspective (109457)

Camille Gomez-Laberge

Susanne Yelin

2021 Fall (4 Credits) **Schedule:** MW 0900 AM - 1015 AM

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 sciences or engineering. The course includes lecture, laboratory, and discussion components.

Subject: Physics (PHYSICS)

Schedule: TR 1200 PM - 0115 PM

Physics 15A Introductory Mechanics and Relativity (111164)

David Morin
Amir Yacoby
Kathryn Ledbetter
Timothy Milbourne
James Mitchell

2021 Fall (4 Credits) **Schedule:** TR 1200 PM - 0115 PM

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.

Physics 15B Introductory Electromagnetism and Statistical Physics (111896)

Cora Dvorkin
Mara Prentiss
Timothy Milbourne

2021 Fall (4 Credits) **Schedule:** TR 1200 PM - 0115 PM

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.

Physics 15C Wave Phenomena (124154)

Melissa Franklin Markus Greiner Anna
Klales James Mitchell

2021 Fall (4 Credits) **Schedule:** MW 1030 AM - 1145 AM

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.

Physics 16 Mechanics and Special Relativity (111197)

Howard Georgi, Amir Yacoby, Kathryn Ledbetter,
Timothy Milbourne, James Mitchell
2021 Fall (4 Credits) **Schedule:** TR 1200 PM - 0115 PM

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.

Physics 19 Introduction to Theoretical Physics (207005)

Jacob Barandes

2021 Fall (4 Credits) **Schedule:** MWF 0300 PM - 0415 PM

A comprehensive introduction to the foundations of theoretical physics, with a first-principles approach to its five main areas: analytical dynamics, fields, statistical mechanics, relativity, and quantum theory. Specific topics and examples include Newtonian mechanics, chaos, celestial mechanics, electromagnetism, the Lagrangian and Hamiltonian formulations, the connection between symmetries and conservation laws, relativistic gravitation, black holes, and quantum information. In-class discussions regularly addresses 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 90R Supervised Research (111672)

David Morin

2021 Fall (4 Credits) **Schedule:** TBD

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.

Physics 91R Supervised Reading Course for Undergraduates (110569)

David Morin

2021 Fall (4 Credits) **Schedule:** TBD

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.

Physics 95 Topics in Current Research (111967)

Robert Westervelt

2021 Fall (4 Credits) **Schedule:** M 0300 PM - 0415 PM
W 0730 PM - 0845 PM

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.

Physics 123A Laboratory Electronics – Analog Circuits (218166)

David Abrams

2021 Fall (4 Credits) **Schedule:** TR 0130 PM - 0530 PM

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.

Physics 141 The Physics of Sensory Systems in Biology (121885)

Aravinthan Samuel

2021 Fall (4 Credits) **Schedule:** TR 0900 AM - 1015 AM

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)

John Doyle

Louis Deslauriers

2021 Fall (4 Credits) **Schedule:** TR 1030 AM - 1145 AM

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

2021 Fall (4 Credits) **Schedule:** WF 0130 PM - 0245 PM

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)

Carlos Arguelles Delgado

2021 Fall (4 Credits) **Schedule:** WF 1030 AM - 1145 AM

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

2021 Fall (4 Credits) **Schedule:** TR 1200 PM - 0115 PM

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)

Jenny Hoffman

Matteo Mitrano

2021 Fall (4 Credits) **Schedule:** TR 0130 PM - 0530 PM

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 and optical tweezers.

Physics 195A Introduction to Solid State Physics (112107)

Julia Mundy

2021 Fall (4 Credits) **Schedule:** MW 0300 PM - 0415 PM

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.

Physics 223A Laboratory Electronics – Analog Circuits (218167)

David Abrams

2021 Fall (4 Credits) **Schedule:** TR 0130 PM - 0530 PM

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.

Physics 247 Laboratory Course in Contemporary Physics (145024)

Jenny Hoffman

Matteo Mitrano

2021 Fall (4 Credits) **Schedule:** TR 0130 PM - 0530 PM

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 and optical tweezers.

Physics 251A Advanced Quantum Mechanics I (111314)

Matthew Reece

2021 Fall (4 Credits) **Schedule:** MW 1030 AM - 1145 AM

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)

Matthew Schwartz

2021 Fall (4 Credits) **Schedule:** TR 0130 PM - 0245 PM

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 253CR Quantum Field Theory III (118459)

Daniel Jafferis

2021 Fall (4 Credits) **Schedule:** TR 1200 PM - 0115 PM

This course will cover a variety of topics related to conformal field theories, including: an introduction to conformal field theories and the conformal bootstrap with an emphasis on greater than two dimensions; large N expansions; the a-theorem; analytic bootstrap methods; a self-contained introduction to the AdS/CFT correspondence.

Physics 254 The Standard Model (109328)

Girma Hailu

2021 Fall (4 Credits) **Schedule:** TR 1030 AM - 1145 AM

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 262 Statistical Mechanics (110526)

Vinothan Manoharan

2021 Fall (4 Credits) **Schedule:** MWF 1200 PM - 0115 PM

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.

Physics 268AR Special Topics in Quantum Matter (122818)

Ashvin Vishwanath

2021 Fall (4 Credits) **Schedule:** F 1200 PM - 0245 PM

This is a special topics course on quantum systems of many particles. Two criteria are applied when selecting topics. First, experimental relevance and second, that they illustrate a central concept of quantum many body physics such as: (i) the importance of locality (ii) symmetry and its spontaneous breaking, (iii) gauge theories, deconfinement and higher form symmetries (iv) anomalies and their role in condensed matter, (v) topological stability, (vi) quantum information and the phases of matter. These foundational physical concepts which will be developed in the context of well-defined microscopic models, of quantum spins, electrons in solids or atoms in optical lattices. Where appropriate, we will introduce relevant mathematical tools and quantum field theory (QFT) to describe some of these phenomena, which will also help demystify QFT in a physical setting free from 'infinities'. This course will make contact with recent research directions such as topological phases, quantum criticality and dualities.

Planned Topics:
1.The 1+1D transverse field Ising model - duality, fermionization, chiral symmetry and anomaly. Experimental realization of "E8" in CoNb2O6.
2. Continuous symmetry breaking in 2+1D. Goldstone modes and the Anderson Tower. The Mott-superfluid transition. Boson-Vortex Duality.
3. Non-perturbative tools such as large-N approach, matrix product states, anomalies and bosonization.
4. Symmetry and Topological Phases . - Integer quantum Hall effect and Chern insulators. The periodic table of topological insulators and superconductors. Anomalies and edge states.
5. Emergent Gauge Theories and topological order. Chern Simons theories. Fractional quantum Hall states and gapped quantum spin liquids. Topological quantum entanglement. Emergent electromagnetism in quantum magnets and "Spin-ice".
6. Special Topics (if time permits): Conformal invariance.

Evaluation:
(a) Assignments (3-4 in total)
(b) work in groups of 2-3 on (b1) research project with individual written report due at the end of the course and (b2) short presentation on a course topic during class. There will be no examinations.

Suggested Text Books:
1. Gauge Fields and Strings: A. Polyakov
2. Quantum Field Theory of Many Body Systems: X. G. Wen
3. Quantum Information Meets Quantum Matter: Bei Zeng et al
4. Geometry, Topology and Physics: M. Nakaha

Physics 285B Modern Atomic and Optical Physics II (118509)

Mikhail Lukin

2021 Fall (4 Credits) **Schedule:** MW 1030 AM - 1145 AM

Introduction to quantum optics and modern atomic physics. The basic concepts and theoretical tools will be introduced. Topics will include coherence phenomena, non-classical states of light and matter, atom cooling and trapping and atom optics. The second of a two-term subject sequence that provides the foundations for contemporary research.

Physics 287A Introduction to String Theory (111191)

Xi Yin

2021 Fall (4 Credits) **Schedule:** TR 0300 PM - 0415 PM

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)

David R. Nelson

2021 Fall (4 Credits) **Schedule:** MWF 1200 PM - 0115 PM

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 297 Professional Writing for Scientists and Engineers (217830)

Jenny Hoffman

Suzanne Smith

2021 Fall (4 Credits) **Schedule:** W 0300 PM - 0500 PM

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 2022

Physical Sciences 3 Electromagnetism, Circuits, Waves, Optics, and Imaging (122576)

Melissa Franklin, Gregory Kestin, Camille Gomez-Laberge

2022 Spring (4 Credits)

Schedule: TR 1200 PM - 0115 PM

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.

Physical Sciences 12A Mechanics and Statistical Physics from an Analytic, Numerical and Experimental Perspective (109274)

Efthimios Kaxiras, Camille Gomez-Laberge, Anna Klales

2022 Spring (4 Credits)

Schedule: MWF 0900 AM - 1015 AM

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.

Physical Sciences 70 Introduction to Digital Fabrication (215717)

Nathan Melenbrink

2022 Spring (4 Credits)

Schedule: TR 0300 PM - 0415 PM

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.

Subject: Physics (PHYSICS)

Physics 15A Introductory Mechanics and Relativity (111164)

Julia Mundy
Amir Yacoby
Kathryn Ledbetter
Timothy Milbourne

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

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.

Physics 15B Introductory Electromagnetism and Statistical Physics (111896)

Carlos Arguelles Delgado
Amir Yacoby
Timothy Milbourne

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

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.

Physics 15C Wave Phenomena (124154)

John Huth
Mara Prentiss

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

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.

Physics 90R Supervised Research (111672)

David Morin

2022 Spring (4 Credits) **Schedule:** TBD

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.

Physics 91R Supervised Reading Course for Undergraduates (110569)

David Morin

2022 Spring (4 Credits) **Schedule:** TBD

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.

Physics 95 Topics in Current Research (111967)

Eric Mazur

2022 Spring (4 Credits) **Schedule:** M 0300 PM - 0415 PM
W 0430 PM - 0545 PM

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.

Physics 113 Electronics for Physicists (216641)

Masahiro Morii

Anna Klales

Kathryn Ledbetter

2022 Spring (4 Credits) **Schedule:** WF 0130 PM - 0430 PM

Introduction to electronics tailored for students studying Physics. The course focuses on skills that are applicable to physics laboratory work, including passive filters, op-amp circuits, and analog-to-digital interfaces. Emphasis is placed on safe and effective use of lab equipment and on the ability to read schematics and realize it quickly. The class will meet twice a week, each meeting starting with a 1-hour lecture followed by a 2-hour lab.

Physics 123B Digital Electronics (124108)

David Abrams

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

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.

Physics 125 Widely Applied Physics (120167)

David Morin

HARVARD UNIVERSITY

2022 Spring (4 Credits) **Schedule:** WF 1200 PM - 0115 PM

Uses physics to analyze important technologies and real-world systems. Stresses estimation and "back of the envelope" calculations, as are commonly used by research physicists. New physical concepts are introduced as necessary. Example topics: energy production and storage, nuclear physics, nuclear power and weapons, health effects of radiation, risk analysis, airplanes, spy satellites, rockets, fluids, water waves, mechanical design and failure, global warming, and cosmology. Emphasis is on developing physical intuition and the ability to do order-of-magnitude calculations.

Physics 129 Energy Science (125656)

Lene Hau

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

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

Physics 131 Computational Neuroscience (217838)

Haim Sompolinsky

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

Follows trends in modern brain theory, focusing on local neuronal circuits as basic computational modules. Explores the relation between network architecture, dynamics, and function. Introduces tools from information theory, statistical inference, and the learning theory for the study of experience-dependent neural codes. Specific topics: computational principles of early sensory systems; adaptation and gain control in vision, dynamics of recurrent networks; feature selectivity in cortical circuits; memory; learning and synaptic plasticity; noise and chaos in neuronal systems.

Physics 137 Conceptual Foundations of Quantum Mechanics (218289)

Jacob Barandes

2022 Spring (4 Credits) **Schedule:** TBD

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)

Melissa Franklin

Louis Deslauriers

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

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

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

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 electrodynamics and optics in modern physics are discussed.

Physics 160 Introduction to quantum information (214446)

Mikhail Lukin

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

Introduction to quantum information science, including quantum computation, communication and metrology. Emphasis on fundamental principles, experimental implementations and applications. Background and theoretical techniques will be introduced.

Physics 175 Laser Physics and Modern Optical Physics (121941)

Markus Greiner

2022 Spring (4 Credits) **Schedule:** WF 0130 PM - 0245 PM

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)

Susanne Yelin

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

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.

Physics 191 Advanced Laboratory (121993)

Jenny Hoffman

Matteo Mitrano

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

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 and optical tweezers.

Physics 195B Introduction to Quantum Materials and Devices (218288)

Robert Westervelt

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

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.

Physics 201 Data Analysis for Physicists (161201)

Vinothan Manoharan

2022 Spring (4 Credits) **Schedule:** MWF 1030 AM - 1145 AM

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.

Physics 210 General Theory of Relativity (114266)

Daniel Jafferis

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

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.

Physics 216 Mathematics of Modern Physics (127815)

Xi Yin

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

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 220 Fluid Dynamics (110144)

L Mahadevan

2022 Spring (4 Credits) **Schedule:** WF 0430 PM - 0545 PM

From statistical to continuum mechanics. Geometry of motion. Strain, strain rate, polarity and nematicity. Vorticity. Conservation laws. Stress - passive and active. Symmetry, invariance and constitutive equations. Dimensional analysis and scaling. Navier-Stokes, Toner-Tu and Nematodynamic equations. Experimental hydrodynamics. Solutions for simple flow states. Boundary layers (and engineering flows). Rotating flows (and geophysics). Thin film flows (and environmental physics). Active matter flows (and biophysics). Similarity and singularity. Linear and nonlinear waves in passive and active fluids- acoustics, shocks, water waves, bird flocks. Flow instabilities. Mixing and turbulence.

Physics 223B Electronics for Scientists (109346)

David Abrams

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

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.

Physics 232 Advanced Electromagnetism (112263)

Girma Hailu

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

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

2022 Spring (4 Credits) **Schedule:** TBD

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 and optical tweezers.

Physics 251B Advanced Quantum Mechanics II (111876)

Matthew Reece

2022 Spring (4 Credits) **Schedule:** TR 0130 PM - 0245 PM

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

Physics 253B Quantum Field Theory II (115442)

Matthew Schwartz

2022 Spring (4 Credits) **Schedule:** WF 0130 PM - 0245 PM

A continuation of Physics 253a. Topics include: states and local operators, the analytic S-matrix, IR divergence, effective action, non-Abelian gauge theories, renormalization group, spontaneous symmetry breaking and effective field theory, anomalies, and non-perturbative aspects of quantum field theories.

Physics 268BR Renormalization Group Methods in Condensed Matter Physics (160744)

David R. Nelson

2022 Spring (4 Credits) **Schedule:** MWF 1030 AM - 1145 AM

Renormalization group ideas have had a major impact on condensed matter physics. We plan to develop and illustrate the theory by studying at least three of the following topics: (1) critical phenomena near four dimensions; (2) quantum critical points in Heisenberg spins; (3) flexural phonons in free-standing graphene; and (4) the fluid dynamics of the forced Navier-Stokes equations.

Physics 287BR The String Landscape and the String Swampland (114008)

C. Vafa

2022 Spring (4 Credits) **Schedule:** R 1200 PM - 0245 PM

A selection of topics from current areas of research on string theory with focus on String Landscape constructions and restrictions on effective field theories for consistency of quantum gravity (the Swampland program).

Physics 289R Topics in Mathematical Physics (118733)

Arthur Jaffe

2022 Spring (4 Credits) **Schedule:** TR 0130 PM - 0245 PM

Over the past few years, the development of new mathematical picture languages led to insights in several fields, including quantum information, entanglement, entropy, error correction, uncertainty principles, Fourier analysis, and fusion algebras. This course will overview a number of these directions and develop several of these topics from scratch and in depth, relating them to statistical mechanics models and to quantum field theory.

Physics 295B Quantum Theory of Solids (127979)

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

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.

Physics 297 Professional Writing for Scientists and Engineers (217830)

Suzanne Smith

Daniel Needleman

2022 Spring (4 Credits) **Schedule:** W 0300 PM - 0500 PM

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.