Department of Physics Courses

About Course Numbers:

Each Carnegie Mellon course number begins with a two-digit prefix that designates the department offering the course (i.e., 76-xxx courses are offered by the Department of English). Although each department maintains its own course numbering practices, typically, the first digit after the prefix indicates the class level: xx-1xx courses are freshmen-level, xx-2xx courses are sophomore level, etc. Depending on the department, xx-6xx courses may be either undergraduate senior-level or graduate-level, and xx-7xx courses and higher are graduate-level. Consult the Schedule of Classes (https://enr-apps.as.cmu.edu/open/SOC/SOCServlet/) *each semester for course offerings and for any necessary pre-requisites or co-requisites.*

33-100 Basic Experimental Physics

All Semesters: 6 units
This course provides students with a basic introduction to experimental physics. The content of the course and the particular experiments to be carried out are chosen to be especially useful for students who intend to work in the health sciences. Specific topics will range from mechanics to nuclear and atomic physics. This course is specifically geared toward pre-health students.

33-101 Physics First Year Seminar

Fall and Spring
Various seminars are offered that introduce first-year students to current topics of modern physics. These are mini courses that meet for half a semester. In the past, seminar topics have included: Science and Science Fiction, Astrophysics, Black Holes, Cosmology and Supernovae, Elementary Particles, and The Building Blocks of Matter. These seminars are open only to MCS first year students.

33-104 Experimental Physics

All Semesters: 9 units
This course provides first year students and sophomores with an introduction to the methods of experimental physics. Particular emphasis is placed on three aspects of experimentation: laboratory technique, including both the execution and the documentation of an experiment; data analysis, including the treatment of statistical and systematic errors and computer-aided analysis of experimental data; and written communication of experimental procedures and results. The concepts and skills for measurement and data analysis are acquired gradually through a series of experiments covering a range of topics from mechanics to nuclear and atomic physics.

33-114 Physics of Musical Sound

Spring: 9 units
An introduction to the physics and psychophysics of musical sound. Elementary physics of vibrating systems. Propagation of sound: traveling waves, reflection, and diffraction. Addition of waves: interference and beats. Anatomy of the ear and the perception of sound: loudness, pitch, and timbre. Standing waves and natural modes. Qualitative description of general periodic systems by Fourier analysis: the harmonic series and complex musical tones. The acoustics of musical instruments including percussion instruments, such as drums, bars, and struck and plucked strings; and instruments exhibiting self-sustained oscillations, including bowed strings, blown pipes, reeds, brasses, and singing. Intervals and consonance, musical scales, tuning and temperament. Basic room and auditorium acoustics. There are no formal prerequisites, but some previous musical experience will be useful.

33-115 Physics for Future Presidents

Fall: 9 units
Countless topics of social and political importance are intimately related to science in general and physics in particular. Examples include energy production, global warming, radioactivity, terrorism, and space travel. This course aims to provide key bits of knowledge based on which such issues can be discussed in a meaningful way, i.e., on the level of arguments and not just vague beliefs. We will cover an unusually wide range of topics, including energy, heat, gravity, atoms, radioactivity, chain reactions, electricity, magnetism, waves, light, weather, and climate. The course is open for all students at CMU.

33-120 Science and Science Fiction

Fall and Spring: 9 units
We will view and critique the science content in a selection of science fiction films, spanning more than 100 years of cinematic history, and from sci-fi TV shows from the past 50+ years. Guided by selected readings from current scientific literature, and aided by order-of-magnitude estimates and careful calculations, we will ponder whether the films are showing things which may fall into one of the following categories: Science fiction at the time of production, but currently possible, due to recent breakthroughs. Possible, in principle, but beyond our current technology. Impossible by any science we know. Topics to be covered include the future of the technological society, the physics of Star Trek, the nature of space and time, extraterrestrial intelligence, robotics and artificial intelligence, biotechnology and more.

33-121 Physics I for Science Students

Fall and Spring: 12 units
This calculus-based course combines the basic principles of mechanics with some quantum physics and relativity to explain nature on both a microscopic and macroscopic scale. The course will build models to describe the universe based on a small number of fundamental physics principles. Some simple computer modeling will be done to develop insight into the solving of problems using Newton's laws. Topics covered will include vectors, momentum, force, gravitation, oscillations, energy, quantum physics, center of mass motion, rotation, angular momentum, statistical physics, and the laws of thermodynamics. No computer experience is needed. Examples illustrating basic principles being presented will be taken from physics, chemistry, and biology. This course has a co-requisite of 21-120.

33-122 Physics II for Biological Sciences & Chemistry Students

Fall and Spring: 9 units
This is the second course in the introductory physics sequence for chemistry and biological science majors. The course will consist of eight portions covering (1) electrostatics and dynamics, (2) electrical circuits, (3) magnetism, (4) waves, (5) optics, (6) diffusive motion, and (7) hydrostatic forces and flow. Emphasis will be put on the application of the underlying physical principles in the study of biology and chemistry. This course has a co-requisite of 21-122.
Prerequisites: (33-121 and 21-120) or (33-151 and 21-120) or (33-141 and 21-120) or (33-111 and 21-120) or (33-131 and 21-120) or (33-106 and 21-120)

33-124 Introduction to Astronomy

Fall: 9 units
Astronomy continues to enjoy a golden age of exploration and discovery. This course presents a broad view of astronomy, straightforwardly descriptive and without any complex mathematics. The goal of the course is to encourage non-technical students to become scientifically literate and to appreciate new developments in the world of science, especially in the rapidly developing field of astronomy. Subjects covered include the solar system, stars, galaxies and the universe as a whole. The student should develop an appreciation of the ever-changing universe and our place within it. Computer laboratory exercises will be used to gain practical experience in astronomical techniques. In addition, small telescopes will be used to study the sky. This course is specifically geared toward non-science/engineering majors.

33-141 Physics I for Engineering Students

Fall and Spring: 12 units
This is a first semester, calculus-based introductory physics course. Basic principles of mechanics and thermodynamics are developed. Topics include vectors, displacement, velocity, acceleration, force, equilibrium, mass, Newton's laws, gravitation, work, energy, momentum, impulse, torque and angular momentum, temperature, heat, equations of state, thermodynamic processes, heat engines, refrigerators, first and second laws of thermodynamics, and the kinetic theory of gases. This course has a co-requisite of 21-120.

33-142 Physics II for Engineering and Physics Students

Fall and Spring: 12 units
This is the second half of a two-semester calculus-based introductory physics sequence for engineering and physics students. Two fifths of the course covers electricity, including electrostatics and electric fields, Gauss' law, electric potential, and simple circuits. Two fifths cover magnetism, including magnetic forces, magnetic fields, induction and electromagnetic radiation. One fifth of the course covers mechanical waves (including standing and traveling waves, superposition, and beats) and electromagnetic waves (including mode of propagation, speed, and other properties). This course has a co-requisite of 21-122.
Prerequisites: (33-106 and 21-120) or (33-141 and 21-120) or (21-120 and 33-111) or (33-131 and 21-120) or (33-151 and 21-120) or (21-120 and 33-121)

33-151 Matter and Interactions I

Fall: 12 units
For students with a strong physics background who are interested in using calculus-based mechanics to learn about topics such as dark matter, particle physics, and quantum phenomena, Matter and Interactions I provides an excellent alternative to Physics for Science Students. This course places great emphasis on constructing and using physical models, with a special focus on computer modeling to solve problems. Throughout the course, both traditional analytics techniques and scientific computing will be used to solve mechanical problems going from planetary systems, spring-based systems and nuclear scattering. Topics covered include Newton's Laws, microscopic models of solids, energy, energy quantization, mass-energy equivalence, multi particle systems, collisions, angular momentum including quantized angular momentum, kinetic theory of gases and statistical mechanics. Students conduct team research projects that will be presented at a departmental poster session at the end of the semester. This course has a co-requisite of 21-122.
Prerequisite: 21-120

33-152 Matter and Interactions II

Spring: 12 units
A more challenging alternative to 33-142, Physics II for Engineering and Physics Students. There is an emphasis on atomic-level description and analysis of matter and its electric and magnetic interactions. Topics include: Coulomb's law, polarization, electric field, plasmas, field of charge distributions, microscopic analysis of resistor and capacitor circuits, potential, macroscopic analysis of circuits, Gauss' law, magnetic field, atomic model of magnetism, Ampere's law, magnetic force, relativistic issues, magnetic induction with emphasis on non-Coulomb electric field, Maxwell's equations, electromagnetic radiation including its production and its effects on matter, re-radiation, interference. There will also be computer modeling, visualization and desktop experiments.
Prerequisites: (33-151 and 21-122) or (21-122 and 33-131)

33-201 Physics Sophomore Colloquium I

Fall: 2 units
This course (together with 33-202) is designed to give students an overview of the field of Physics and to help students make knowledgeable choices in both their academic and professional careers. We discuss several of the subfields of Physics in order to give students an understanding of the types of activities, from research to industrial applications, in each. Over the two semesters, we typically discuss six subfields in some detail with the goal of providing a minimal literacy in the relevant concepts and language. The course consists of one classroom lecture per week plus one hour per week of reading and/or problem solving.

33-202 Physics Sophomore Colloquium II

Spring: 2 units
This course is the second in a sequence (following 33-201) designed to give students an overview of the field of Physics and to help students make knowledgeable choices in both their academic and professional careers. We discuss several of the sub-fields of Physics in order to give students an understanding of the types of activities, from research to industrial applications, in each. Over the two semesters, we typically discuss six subfields in some detail with the goal of providing a minimal literacy in the relevant concepts and language. The course consists of one classroom lecture per week plus one hour per week of reading and/or problem solving.

33-211 Physics III: Modern Essentials

Fall and Spring: 10 units
Physics III is primarily for third-semester students of physics, including all physics majors, but is open to any qualified student who wants an introduction to the physics of the 20th century. The course will have a strong component of Special Relativity, dealing with kinematics and dynamics, but not electricity and magnetism. (See 33-213 description.) It will introduce students to a conceptual theory, which is mathematically simple but (initially) non-intuitive. The course also provides a broad exposure to quantum phenomena and early quantum theory without getting overly mathematical. It leads into the more formal Quantum Physics course (33-234).
Prerequisites: 33-112 or 33-152 or 33-132 or 33-142 or 33-107 or 33-122

33-213 Mini-Course in Special Relativity

Fall and Spring: 4 units
This course spans the first six weeks of 33-211, Physics III: Modern Essentials and should not be taking by students intending to major in physics. It treats the mechanics aspects of special relativity, including topics such as simultaneity, the Lorentz transformation, time dilation, length contraction, space-time geometry, resolving some famous puzzles, and the momentum, mass, and energy relations. The Electricity and Magnetism portions of the subject are deferred until the junior/senior courses in E and amp;M (33-338/33-339). Students may not take this class if they have successfully completed 33-211.
Prerequisites: 33-152 or 33-122 or 33-107 or 33-132 or 33-142 or 33-112

33-224 Stars, Galaxies and the Universe

Fall: 9 units
The study of astronomy has blossomed over the past few decades as a result of new ground-based and space-based telescopes, and with the advantage of fast computers for analysis of the huge quantities of data. As our astronomical horizon expands, we are still able to use the laws of physics to make sense of it all. This course is for students who want to understand the basic concepts in astronomy and what drives astronomical objects and the universe. The course emphasizes the application of a few physical principles to a variety of astronomical settings, from stars to galaxies to the structure and evolution of the universe. Introductory classical physics is required, but modern physics will be introduced as needed in the course. The course is intended for science and engineering majors as well as students in other disciplines with good technical backgrounds. Computer lab exercises will be used to gain practical experience in astronomical techniques. In addition, small telescopes are available for personal sign-out for those who would like to use them, and outdoor observing sessions will be organized as weather permits.
Prerequisites: 33-131 or 33-111 or 33-141 or 33-151 or 33-106 or 33-121

33-225 Quantum Physics and Structure of Matter

Fall: 9 units
This course introduces the basic theory used to describe the microscopic world of electrons, atoms, and photons. The duality between wave-like and particle-like phenomena is introduced along with the deBroglie relations which link them. We develop a wave description appropriate for quanta which are partially localized and discuss the interpretation of these wavefunctions. The wave equation of quantum mechanics is developed and applied to the hydrogen atom from which we extrapolate the structure of the Periodic Table. Other materials-related applications are developed, for example, Boltzmann and quantum statistics and properties of electrons in crystals. This course is intended primarily for non-physics majors who have not taken 33-211.
Prerequisites: 33-142 or 33-152 or 33-107 or 33-122 or 33-112 or 33-132

33-226 Physics of Energy

Spring: 9 units
This course will apply basic science, in particular introductory physics concepts, to a wide variety of topics related to energy. The course will closely follow a widely praised textbook The Physics of Energy, so be divided into 3 parts: basic energy science; energy sources; and climate. This course fills the breadth requirement for Physics Majors or can be used as one of the 4 electives required for the Applied Physics Track.
Prerequisites: 33-152 or 33-122 or 33-142

33-228 Electronics I

Spring: 10 units
An introductory laboratory and lecture course with emphasis on elementary circuit analysis, design, and testing. We start by introducing basic circuit elements and study the responses of combinations to DC and AC excitations. We then take up transistors and learn about biasing and the behavior of amplifier circuits. The many uses of operational amplifiers are examined and analyzed; general features of feedback systems are introduced in this context. Complex functions are used to analyze all of the above linear systems. Finally, we examine and build some simple digital integrated circuits.
Prerequisites: 33-112 or 33-132 or 33-107 or 33-142 or 33-152 or 33-122

33-231 Physical Analysis

Fall: 10 units
This course aims to develop analytical skills and mathematical modeling skills across a broad spectrum of physical phenomena, stressing analogies in behavior of a wide variety of systems. Specific topics include dimensional analysis and scaling in physical phenomena, exponential growth and decay, the harmonic oscillator with damping and driving forces, linear approximations of nonlinear systems, coupled oscillators, and wave motion. Necessary mathematical techniques, including differential equations, complex exponential functions, matrix algebra, and Taylor series, are introduced as needed.
Prerequisites: 21-122 and (33-142 or 33-122 or 33-152)

33-232 Mathematical Methods of Physics

Spring: 10 units
This course introduces, in the context of physical systems, a variety of mathematical tools and techniques that will be needed for later courses in the physics curriculum. Topics will include linear algebra, Fourier series and transforms, vector calculus with physical applications, and a first look at partial differential equations. The techniques taught here are useful in more advanced courses such as Physical Mechanics, Electricity and Magnetism, and Advanced Quantum Physics.
Prerequisite: 33-231

33-234 Quantum Physics

Spring: 10 units
An introduction to the fundamental principles and applications of quantum physics. A brief review of the experimental basis for quantization motivates the development of the Schrodinger wave equation. Several unbound and bound problems are treated in one dimension. The properties of angular momentum are developed and applied to central potentials in three dimensions. The one electron atom is then treated. Matrix description of quantum physics and the notion of spin are introduced. Properties of collections of indistinguishable particles are developed allowing an understanding of the structure of the Periodic Table of elements. A variety of mathematical tools are considered as needed.
Prerequisite: 33-211

33-241 Introduction to Computational Physics

Fall: 9 units
This undergraduate course will provide an introduction to the numerical methods and computational algorithms used to solve a variety of problems in physics. In introductory physics courses, you are able to derive analytical solutions for simpler problems and often with simplifying assumptions. Have you wondered if a numerical solution can be obtained for a more complex problem that has no closed-form analytical solution? Computational physics provides a modern and powerful approach to compliment classical approaches to problem solving. Today's and tomorrow's scientists must be computationally fluent to be competitive and successful. In this course, you will learn to formulate problems by applying physical principles, select and apply numerical methods, develop and apply computational algorithms, solve physical problems analytically and numerically, and visualize quantitative results using plotting software.
Prerequisites: 15-112 and 21-122 and 33-104 and (33-152 or 33-142 or 33-107 or 33-112 or 33-132 or 33-122)

33-301 Physics Upperclass Colloquium I

Fall: 1 unit
Junior and senior Physics majors meet together for 1 hour a week to hear discussions on current physics research from faculty, undergraduate and graduate students, and outside speakers. Other topics of interest such as application to graduate school, areas of industrial research and job opportunities will also be presented.

33-302 Physics Upperclass Colloquium II

Spring: 1 unit
Continuation of 33-301: Junior and senior Physics majors meet together for 1 hour a week to hear discussions on current physics research from faculty, undergraduate and graduate students, and outside speakers. Other topics of interest such as application to graduate school, areas of industrial research and job opportunities will also be presented.

33-331 Physical Mechanics I

Fall: 10 units
Fundamental concepts of classical mechanics. Conservation laws, momentum, energy, angular momentum, Lagrange's and Hamilton's equations, motion under a central force, scattering, cross section, and systems of particles.
Prerequisites: 33-231 and 33-232 and 21-259

33-332 Physical Mechanics II

Spring: 10 units
This is the second semester of a two-semester course on classical mechanics. The course will use the tools developed in 33-331 to examine motion in non-inertial reference frames; in particular, rotating frames. This then leads to the development of general rigid body motion, Euler's Equations. Finally, the course will cover coupled oscillations with particular emphasis on normal modes.
Prerequisite: 33-331

33-338 Intermediate Electricity and Magnetism I

Fall: 10 units
This course includes the basic concepts of electro- and magnetostatics. In electrostatics, topics include the electric field and potential for typical configurations, work and energy considerations, the method of images and solutions of Laplace's Equation, multipole expansions, and electrostatics in the presence of matter. In magnetostatics, the magnetic field and vector potential, magnetostatics in the presence of matter, properties of dia-, para- and ferromagnetic materials are developed.
Prerequisites: 33-231 and 21-259 and 33-232

33-339 Intermediate Electricity and Magnetism II

Spring: 10 units
This course focuses on electro- and magnetodynamics. Topics include Faraday's Law of induction, electromagnetic field momentum and energy, Maxwell's equations and electromagnetic waves including plane waves, waves in non-conducting and conducting media, reflection and refraction of waves, and guided waves. Electromagnetic radiation theory includes generation and characteristics of electric and magnetic dipole radiation. The Special Theory of Relativity is applied to electrodynamics: electric and magnetic fields in different reference frames, Lorentz transformations, four-vectors, invariants, and applications to particle mechanics.
Prerequisite: 33-338

33-340 Modern Physics Laboratory

Spring: 10 units
Emphasis is on hands-on experience observing important physical phenomena in the lab, advancing the student's experimental skills, developing sophisticated data analysis techniques, writing thorough reports, and improving verbal communication through several oral progress reports given during the semester and a comprehensive oral report on one experiment. Students perform three experiments which are drawn from the areas of atomic, condensed matter, classical, and nuclear and particle physics. Those currently available are the following: Zeeman effect, light scattering, optical pumping, thermal lensing, Raman scattering, chaos, magnetic susceptibility, nuclear magnetic resonance, electron spin resonance, X-ray diffraction, M and #246;ssbauer effect, neutron activation of radioactive nuclides, Compton scattering, and cosmic ray muons.
Prerequisites: 33-234 and (33-338 or 33-341 or 33-331)

33-341 Thermal Physics I

Fall: 10 units
The three laws of classical thermodynamics, which deal with the existence of state functions for energy and entropy and the entropy at the absolute zero of temperature, are developed along phenomenological lines. Elementary statistical mechanics is then introduced via the canonical ensemble to understand the interpretation of entropy in terms of probability and to calculate some thermodynamic quantities from simple models. These laws are applied to deduce relationships among heat capacities and other measureable quantities and then are generalized to open systems and their various auxiliary thermodynamic potentials; transformations between potentials are developed. Criteria for equilibrium of multicomponent systems are developed and applied to phase transformations and chemical reactions. Models of solutions are obtained by using statistical mechanics and are applied to deduce simple phase diagrams for ideal and regular solutions. The concept of thermodynamic stability is then introduced and illustrated in the context of phase transformations.
Prerequisites: 33-232 and 33-234 and 33-231

33-342 Thermal Physics II

Spring: 10 units
This course begins with a more systematic development of formal probability theory, with emphasis on generating functions, probability density functions and asymptotic approximations. Examples are taken from games of chance, geometric probabilities and radioactive decay. The connections between the ensembles of statistical mechanics (microcanonical, canonical and grand canonical) with the various thermodynamic potentials is developed for single component and multicomponent systems. Fermi-Dirac and Bose-Einstein statistics are reviewed. These principles are then applied to applications such as electronic specific heats, Einstein condensation, chemical reactions, phase transformations, mean field theories, binary phase diagrams, paramagnetism, ferromagnetism, defects, semiconductors and fluctuation phenomena.
Prerequisite: 33-341

33-350 Undergraduate Research

Fall and Spring
Open to sophomore, junior, and senior physics majors. The student undertakes a project of interest under the supervision of a faculty member for 3 to 9 units of credit. May include research done in a research lab, extending the capabilities of a teaching lab, or a theoretical or computational physics project. The student experiences the less structured atmosphere of a research program where there is much room for independent initiative. Student should contact faculty directly to inquire about opportunities. Registration requires approval of the Director of Undergraduate Affairs.

33-353 Intermediate Optics

Fall: 12 units
Offered alternative years. Geometrical optics: reflection and refraction, mirrors, prisms, lenses, apertures and stops, simple optical instruments, fiber optics. Scalar wave optics: wave properties of light, interference, coherence, interferometry, Huygens-Fresnel principle, Fraunhofer diffraction, resolution of optical instruments, Fourier optics, Fresnel diffraction. Laser beam optics: Gaussian beams. Vector wave optics: electromagnetic waves at dielectric interfaces, polarized light. The course will use complex exponential representations of electromagnetic waves.
Prerequisites: 33-122 or 33-142 or 33-112 or 33-132 or 33-107 or 33-152

33-355 Nanoscience and Nanotechnology

Fall: 9 units
This course will explore the underlying science behind nanotechnology, the tools used to create and characterize nanostructures, and potential applications of such devices. Material will be presented on a level intended for upper-level science and engineering students. The course will start with a survey of physics at different length scales, and introduce the application of elementary quantum mechanics and solid-state physics to nanoscience and nanotechnology. Characterization using electron microscopy, scanning probe methods, and spectroscopic techniques will then be described in detail. Fabrication using top-down and bottom-up methods will be discussed, contrasting these approaches and providing examples of each. Nanotechnology methods will be compared with those used in the modern microelectronics industry. Finally, examples of nanoscale components and systems will be described, which may include semiconductor heterostructures; nanotubes and graphene; single-electron transistors; nanoscale magnetic devices; photonic devices; nanofluidic devices; nano electrical-mechanical systems (NEMS); and superconducting devices. There will be time allocated to other topics, with the mutual agreement of the instructor and the class. Stand-alone laboratory exercises will be included as an important element of the course. These will focus on the use of scanning probe methods to study the nm-scale structure and atomic forces involved in various nanostructures as well as micro-scale patterning using photolithography. In addition to the prerequisites, students should have taken a prior laboratory course in a science or engineering department and should have some familiarity with differential equations at an elementary level.
Prerequisites: 33-234 or 33-225

33-398 Special Topics

Fall: 9 units
The description of most all physical systems relies on the concept of a manifold. In addition to the space-time manifold, which plays the role of the stage upon which the dynamics plays out, many systems involve target spaces which are manifolds. These target spaces are typically Lie Groups. A classic example of such a system is the rigid rotator, where every configuration of the system is a point on the manifold which defines the group of rotations. The purpose of this class will be to learn the basics of differential geometry and apply these ideas to physical systems. Topics will include Hamiltonian dynamics, fluid mechanics as well as gauge theories. Requirements: Knowledge of Linear Algebra. No prior knowledge of group theory will be expected.
Prerequisites: (21-260 or 33-231) and 21-341

33-441 Introduction to Biophysics

Fall: 10 units
Biological physics, or the physics of living systems, is an exciting interdisciplinary frontier of physics that aims to understand the phenomenon of life using concepts and tools from Physics. This intermediate level course will introduce the general concepts and principles underpinning the physical behavior of living systems, from the dynamics of proteins and molecules to collective behavior of living cells and organisms. The course will develop key physics concepts that are most vital to biological processes, including energy conversion, information transfer, mechanics of movement, statistical phenomena, and fluid flow. We will apply these physics concepts to demonstrate how biological systems function, build simplified mathematical models to predict behavior, and use experimental data to inform and test models. The integration of biological phenomena, physical concepts, mathematical modeling, and analysis of experimental data represents an entirely new mode of learning, based on strategies adopted in research. These strategies will break traditional disciplinary barriers between physics and biology. The students will be expected to gain an intuitive grasp of ways to: frame the physical problem, identify appropriate theoretical frameworks, analyze experimental data, and ways to generalize and to understand the dependence of biophysical phenomenon on time and length scales. No prior knowledge of biology is expected. This class is offered in Fall of even years (e.g. Fall '24, 26, etc.)
Prerequisites: 33-142 or 33-112 or 33-152 or 33-107 or 33-132 or 33-122

33-444 Introduction to Nuclear and Particle Physics

Spring: 9 units
Description of our understanding of nuclei, elementary particles, and quarks, with equal emphasis on the nuclear and particle aspects of sub-atomic matter. We discuss the physics of accelerators, and how particle interactions with matter lead to various kinds of detector instrumentation. Then we discuss methods for measuring sub-atomic structure, symmetries and conservation laws, and the electromagnetic, weak, and strong interactions. We examine the quark model of the mesons and baryons, as well as several models of the atomic nucleus. This class is offered in Spring of even years (e.g. Spring '24, '26, etc.)
Prerequisites: 33-234 and 33-338

33-445 Advanced Quantum Physics I

Fall: 9 units
Mathematics of quantum theory, linear algebra and Hilbert spaces; review of classical mechanics; problems with classical mechanics; postulates of quantum theory; one dimensional applications; the harmonic oscillator; uncertainty relations; systems with N degrees of freedom, multi-particle states, identical particles; approximation methods. This course has a co-requisite of 33-331.
Prerequisite: 33-234

33-446 Advanced Quantum Physics II

Spring: 9 units
Classical symmetries; quantum symmetries; rotations and angular momentum; spin; addition of angular momentum; the hydrogen atom; quantum "paradoxes" and Bell's theorem; applications.
Prerequisite: 33-445

33-448 Introduction to Solid State Physics

Spring: 9 units
This course gives a quantitative description of crystal lattices, common crystal structures obtained by adding a basis of atoms to the lattice, and the definition and properties of the reciprocal lattice. Diffraction measurements are studied as tools to quantify crystal lattices, including Bragg's law and structure factors. Diffraction from amorphous substances and liquids is also introduced. The various types of atomic bonding, e.g., Van der Waals, metallic, ionic, covalent and hydrogen are surveyed. Binding energies of some crystalline structures are calculated. Models of crystal binding are generalized to include dynamics, first for classical lattice vibrations and then for quantized lattice vibrations known as phonons. These concepts are used to calculate the heat capacities of insulating crystals, to introduce the concept of density of states, and to discuss phonon scattering.
The band theory of solids is developed, starting with the free electron model of a metal and culminating with the properties of conductors and semiconductors. Magnetic phenomena such as paramagnetism and the mean field theory of ferromagnetism are covered to the extent that time permits.
Prerequisites: 33-341 and (33-225 or 33-234)

33-451 Senior Research

Fall and Spring
Open to all senior physics majors. May include research done in a research lab, extending the capabilities of a teaching lab, or a theoretical or computational physics project for 3 to 9 units of credit. The student experiences the less structured atmosphere of a research program where there is much room for independent initiative. Modern Physics Laboratory, 33-340, should precede this course, though it is not required. Student should contact faculty directly to inquire about opportunities. Registration requires approval of the Director of Undergraduate Affairs.

33-456 Advanced Computational Physics

Spring: 9 units
This course uses techniques covered in Introduction to Computational Physics as a foundation. Major topics in the course will be Data Science, Parallel Computing and Machine Learning with applications from astrophysics, thermodynamics, orbital mechanics and other domains.
The course will introduce professional practices such as compiling and optimizing code, using software development environments and software engineering. Students will gain a practical knowledge of current computing hardware design, the C computer language, the TensorFlow deep learning framework and the Spark big data platform, while using a Linux supercomputing environment.
Prerequisite: 33-241

33-466 Extragalactic Astrophysics and Cosmology

Spring: 9 units
Starting from the expanding universe of galaxies, this course lays out the structure of the universe from the Local Group of galaxies to the largest structures observed. The observational pinnacle of the Big Bang theory, the microwave background radiation, is shown to provide us with many clues to conditions in the early universe and to the parameters which control the expansion and fate of the universe. Current theories for the development of galaxies and clusters of galaxies are outlined in terms of our current understanding of dark matter. Observational cosmology continues to enjoy a golden era of discovery and the latest observational results will be interpreted in terms of the basic cosmological parameters.
Prerequisites: 33-224 and 33-234

33-467 Astrophysics of Stars and the Galaxy

Fall: 9 units
The physics of stars is introduced from first principles, leading from star formation to nuclear fusion to late stellar evolution and the end points of stars: white dwarfs, neutron stars and black holes. The theory of stellar structure and evolution is elegant and impressively powerful, bringing together all branches of physics to predict the life cycles of the stars. The basic physical processes in the interstellar medium will also be described, and the role of multi-wavelength astronomy will be used to illustrate our understanding of the structure of the Milky Way Galaxy, from the massive black hole at the center to the halo of dark matter which emcompasses it. This class is offered in Fall of odd years (e.g. Fall '23, 25, etc.)
Prerequisites: 33-224 and 33-234

33-499 Supervised Reading

Fall and Spring
Physics majors may explore a certain area of advanced physics under the direct supervision of a faculty member for up to 9 units of credit. Special permission is required from the Director for Undergraduate Affairs to register. The student must contact a faculty member directly to inquire about opportunities, and to develop a written plan that includes a list of topics to be covered, expectations of student time and/or work, as well as a description of how student learning will be evaluated. The Director of Undergraduate Affairs will review this plan and students will be registered only if the plan is approved.

33-650 General Relativity

Fall: 9 units
General Relativity is the classical theory of gravity. It is widely recognized as a beautiful theory - equating gravity and the geometry of spacetime leads to a profound conceptual change in the way we regard the universe. The predictions of the theory are relevant to systems as varied as high precision measurements of the earth's gravitational field or the strongly curved space-times around black holes. In this course, we will gradually develop an understanding of the geometries which are the solutions of the Einstein equation, with an emphasis on their relevance to physical situations. We will motivate the theory step by step and eventually introduce the Einstein equation itself.
Prerequisites: 33-211 and 33-339

33-658 Quantum Computation and Quantum Information Theory

Fall: 10 units
This course provides an overview of recent developments in quantum computation and quantum information theory. The topics include: a review of relevant concepts in quantum mechanics and in information theory. It will then cover quantum channels, both ideal and noisy, quantum cryptography, an introduction to computational complexity, Shors factorization algorithm, Grovers search algorithm, and proposals for the physical realization of quantum devices, such as correlated photons, ions in traps, and nuclear magnetic resonance. It will also include hands-on experience running programs on cloud quantum computers.
Prerequisite: 33-234 Min. grade B

33-659 Quantum Hall Effect and Topological Insulators

Intermittent: 12 units
This course will introduce students to the topic of topological insulators and related phenomena using the Berry phase a unifying concept. In the first half of the semester, we will cover basic concepts such as Berry phase, Dirac fermions, Hall conductance and its link to topology, and the Hofstadter problem of lattice electrons in a magnetic field. Linear response theory will be discussed in relation to the Hall conductance. In the second half, we will move on to explain topological phases of matter such as Chern insulators and two- and three-dimensional topological insulators. Various techniques to calculate the topological indices will be introduced and connection to real materials will be discussed. Numerical studies of various tight-binding models provide intuitive understandings and will be an essential part of this course.
Prerequisite: 33-448

33-755 Quantum Mechanics I

Fall: 12 units
This course introduces fundamental concepts of quantum mechanics. Applications are made to quantum computing, the harmonic oscillator, the hydrogen atom, electron spin and addition of angular momentum.
Prerequisite: 33-446

33-756 Quantum Mechanics II

Spring: 12 units
This course focuses on qualitative and approximation methods in quantum mechanics, including time-independent and time-dependent perturbation theory, scattering and semiclassical methods. Applications are made to atomic, molecular and solid matter. Systems of identical particles are treated including many electron atoms and the Fermi gas. Prerequisite: 33-755, Quantum Mechanics I; 33-759 Theoretical Physics. 3 hrs. lecture. Typical Text: Cohen-Tannoudji Quantum Mechanics, volume 2.
Prerequisites: 33-755 and 33-759

33-758 Quantum Computation and Quantum Information Theory

Spring: 12 units
This course, taught in collaboration with the Computer Science Department, provides an overview of recent developments in quantum computation and quantum information theory. The topics include: an introduction to quantum mechanics, quantum channels, both ideal and noisy, quantum cryptography, an introduction to computational complexity, Shor's factorization algorithm, Grover's search algorithm, and proposals for the physical realization of quantum devices, such as correlated photons, ions in traps, and nuclear magnetic resonance. The textbook is Nielsen and Chuang, Quantum Computation and Quantum Information. 3 hrs. lecture plus weekly seminar. A 10 unit version of the course, 33-658, does not include the seminar.

33-759 Introduction to Mathematical Physics I

Fall: 12 units
This course is an introduction to methods of mathematical analysis used in solving physical problems. Emphasis is placed both upon the generality of the methods, through a variety of sample problems, and upon their underlying principles. Topics normally covered include matrix algebra (normal modes, diagonalization, symmetry properties), complex variables and analytic functions, differential equations (Laplace's equation and separation of variables, special functions and their analytic properties), orthogonal systems of functions.
Prerequisite: 33-232

33-761 Classical Electrodynamics I

Fall: 12 units
This course deals with the static and dynamic properties of the electromagnetic field as described by Maxwell's equations. Among the topics emphasized are solutions of Laplace's, Poisson's and wave equations, effects of boundaries, Green's functions, multipole expansions, emission and propagation of electromagnetic radiation and the response of dielectrics, metals, magnetizable bodies to fields.
Prerequisite: 33-339

33-762 Classical Electrodynamics II

Spring: 12 units
The applications of electromagnetic theory to various physical systems is the main emphasis of this course. The topics discussed include the theory of wave guides, scattering of electromagnetic waves, index of refraction, special relativity and foundation of optics. 3 hrs. lecture. Typical Text: Jackson, Classical Electrodynamics. 2nd Ed.

33-765 Statistical Mechanics

Spring: 12 units
This course develops the methods of statistical mechanics and uses them to calculate observable properties of systems in thermodynamic equilibrium. Topics treated include the principles of classical thermodynamics, canonical and grand canonical ensembles for classical and quantum mechanical systems, partition functions and statistical thermodynamics, fluctuations, ideal gases of quanta, atoms and polyatomic molecules, degeneracy of Fermi and Bose gases, chemical equilibrium, ideal paramagnetics and introduction to simple interacting systems. 3 hrs. lecture, 1 hr. recitation. Typical Texts: Swendsen, An Introduction to Statistical Mechanics and Thermodynamics; Kardar, Statistical Physics of Particles; McQuarrie, Statistical Mechanics

33-767 Biophysics: From Basic Concepts to Current Research

Spring: 12 units
This course mixes lectures and student presentations on advanced topics in Biological Physics. In the course, students will gain a deep appreciation of the fact that very basic physical and chemical principles underlie many central life processes. Life is not only compatible with the laws of physics and chemistry, rather, it exploits them in ingenious ways. After taking the course, students should be able to name examples of such situations for which they can provide a coherent line of reasoning that outlines these connections. They will be able to explain key experiments by which these connections either have been found or are nowadays routinely established, and outline simple back-of-the-envelope estimates by which one can convince oneself of either the validity or inapplicability of certain popular models and ideas. They should also have become sufficiently familiar with the key terminology frequently encountered in biology, such that they can start to further educate themselves by consulting biological and biophysical literature. The course uses Physical Biology of the Cell by Rob Phillips et al. (Garland Science, New York, NY, 2013, ISBN 978-0-8153-4450-6).

33-769 Quantum Mechanics III: Many Body and Relativistic Systems

Fall: 12 units
The first main theme of this course is quantum mechanics applied to selected many-body problems in atomic, nuclear and condensed matter physics. The second main theme is relativistic quantum mechanics. Creation and annihilation operators are introduced and used to discuss Hartree-Fock theory as well as electromagnetic radiation. The Dirac equation is introduced and applied to the hydrogen atom. Prerequisite: 33-756, 33-76l. 3 hrs. lecture
Prerequisites: 33-761 and 33-756

33-770 Field Theory I

Fall: 12 units
This course gives systematic studies of the relativistic field theories. Topics included are canonical quantization of fields, LSZ reduction formula, Feynman diagram techniques, application to quantum electrodynamics and the discussion of the methods of renormalization.
Prerequisite: 33-756

33-771 Field Theory II

All Semesters: 12 units
Missing Course Description - please contact the teaching department.

33-775 Introduction to Research 1

Fall: 12 units
Both semesters are designed to give the student opportunity to gain experience in modern experimental techniques either through participation in research laboratories or through formal instruction, depending on the student's background. In the first semester, the student will also learn of the research of the department through lectures by the faculty on their work. All students are required to take the first semester, but those with post-graduate or unusual laboratory experience may not be required to take the second. However, it should be noted that for the M.S. degree, 12 units of laboratory are required.

33-777 Introductory Astrophysics

Fall: 12 units
Introductory Astrophysics is survey course with a mix of observational and theoretical investigations into astrophysical systems across a range of scales, covering planetary physics (solar system and extrasolar planets), stellar structure/evolution, Milky Way, extragalactic astrophysics, and cosmology.

33-778 Introduction to Cosmology

Fall: 12 units
An introduction to modern cosmology that includes detailed description of the smooth expanding universe (e.g., nucleosynthesis, the cosmic microwave background, and dark matter) and the perturbations that translate into the large scale structure of the universe.
Prerequisites: 33-331 and 33-341

33-779 Introduction to Nuclear and Particle Physics

Fall: 12 units
An introduction to the physics of atomic nuclei and elementary particles. This course is suitable as a one-semester course for students not specializing in this area and also provides an introduction to further work in 33-780, 33-78l. Topics included are symmetry principles of strong and weak interactions, quark model, classification of particles and nuclear forces.

33-780 Nuclear and Particle Physics II

Spring: 12 units
This course covers the phenomenology of weak interactions, parton model for the deep inelastic scattering, and introduction to gauge theories of weak and electromagnetic interactions. Various topics of current interest in particle physics will also be included. Prerequisite: 33-779, 33-770 (or concurrently). 3 hrs. lecture.
Prerequisites: 33-779 and 33-770

33-783 Solid State Physics

Fall: 12 units
This course is designed to give advanced graduate students a fundamental knowledge of the microscopic properties of solids in terms of molecular and atomic theory, crystal structures, x-ray diffraction of crystals and crystal defects, lattice vibration and thermal properties of crystals; free-electron model, energy bands, electrical conduction and magnetism.
Prerequisite: 33-756 Min. grade B