

Department of Physics Courses

Note on Course Numbers

Each Carnegie Mellon course number begins with a two-digit prefix which designates the department offering the course (76-xxx courses are offered by the Department of English, etc.). 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. xx-6xx courses may be either undergraduate senior-level or graduate-level, depending on the department. xx-7xx courses and higher are graduate-level. Please 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 First Year Seminar

Fall: 3 units

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.

33-106 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, temperature, heat, equations of state, thermodynamic processes, heat engines, refrigerators, first and second laws of thermodynamics, and the kinetic theory of gases.

33-107 Physics II for Engineering Students

Fall and Spring: 12 units

This is the second half of a two-semester calculus-based introductory physics sequence for engineering students. The course covers waves, including standing and travelling waves, superposition, beats, reflection, interference, electricity, including electrostatics and electric fields, Gauss' law, electric potential, and simple circuits, magnetism, including magnetic forces, magnetic fields, induction and electromagnetic radiation. Prerequisites: 21-120 and 33-106

33-111 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, angular momentum, statistical physics, and the laws of thermodynamics. No computer experience is needed.

33-112 Physics II for Science Students

Fall and Spring: 12 units

This is the second semester course that follows 33-111. Electricity and magnetism is developed, including the following topics: Coulomb's law, polarization, electric field, electric potential, DC circuits, magnetic field and force, magnetic induction, and the origins of electromagnetic waves. Prerequisites: 21-120 and 33-111

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 an ability to read music and having some previous musical experience will be very 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. No calculus or algebra will be required. The course is open for all students at CMU.

33-120 Science and Science Fiction

Summer: 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. Success of this course will depend upon class participation. Students will be expected to contribute to discussion of assigned readings and problems, and to give brief presentations in class on assigned films.

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.

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. Prerequisites: (33-121 and 21-120) or 33-151 or 33-141 or (33-111 and 21-120) or 33-131 or 33-106

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.

33-126 Astronomy Lab

Fall: 3 units

This course is the laboratory source in science and astronomy. It overviews the scientific method, teaches how to obtain knowledge from data and to develop physics-based models of natural phenomena, trains how to use astronomical instruments (telescope) to make observations and to explain these observations qualitatively, and explains how to apply of the state-of-the-art professional software to study our universe. Astronomy is one of the oldest fields of science with at least 3000 years of recorded history. On the astronomy side, major topics of this laboratory course include an overview of the Solar system and the Universe. The goals of the laboratory course are to expand the student's understanding of the motions of objects through the sky, to use astronomical techniques, such as telescope and simulated observations, and to obtain, analyze, and interpret data.

33-131 Matter and Interaction I

Fall: 12 units

A more challenging alternative to 33-111, Physics for Science Students I. Students with particularly strong physics backgrounds may volunteer for this course. Modeling of physical systems, including 3D computer modeling, with emphasis on atomic-level description and analysis of matter and its interactions. Momentum, numerical integration of Newton's laws, ball-and-spring model of solids, harmonic oscillator, energy, energy quantization, mass-energy equivalence, multiparticle systems, collisions, angular momentum including quantized angular momentum, kinetic theory of gases, statistical mechanics (temperature, entropy, and specific heat of the Einstein solid, Boltzmann factor).

33-132 Matter and Interactions II

Spring: 12 units

A more challenging alternative to 33-112, Physics for Science Students II. Emphasis on atomic-level description and analysis of matter and its electric and magnetic interactions. 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. Computer modeling and visualization; desktop experiments.

Prerequisites: 21-120 and 33-131

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.

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).

Prerequisites: 33-106 or 33-141 or (21-120 and 33-111) or 33-131 or 33-151 or (33-121 and 21-120)

33-151 Matter and Interactions I

Fall: 12 units

A more challenging alternative to 33-111, Physics for Science Students I. Students with particularly strong physics backgrounds may volunteer for this course. Modeling of physical systems, including 3D computer modeling, with emphasis on atomic-level description and analysis of matter and its interactions. Momentum, numerical integration of Newton's laws, ball-and-spring model of solids, harmonic oscillator, energy, energy quantization, mass-energy equivalence, multiparticle systems, collisions, angular momentum including quantized angular momentum, kinetic theory of gases, statistical mechanics (temperature, entropy, and specific heat of the Einstein solid, Boltzmann factor).

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: (21-122 and 33-151) 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 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.

33-202 Physics Sophomore Colloquium II

Spring: 2 units

Continuation of 33-201.

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: 33-122 or 33-132 or 33-152 or 33-112 or 33-107 or 33-142

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. 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&M (33-338/33-339).

Prerequisites: 33-107 or 33-112 or 33-142 or 33-152 or 33-122 or 33-132

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: 33-151 or 33-141 or 33-111 or 33-131 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: 33-107 or 33-132 or 33-112 or 33-142 or 33-122 or 33-152

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: 33-107 or 33-132 or 33-112 or 33-152 or 33-142 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 elementary Fourier series, are introduced as needed. Prerequisites: 21-122 and (33-132 or 33-107 or 33-122 or 33-152 or 33-142 or 33-112)

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, vector calculus with physical application, Fourier series and integrals, partial differential equations and boundary value problems. 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. 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 introduced as needed. Prerequisite: 33-211

33-241 Introduction to Computational Physics

Fall: 9 units

This course, together with 33-456, is designed to introduce the student to the computational tools needed for study and research in science, engineering and other disciplines. Topics covered include: types of computers and computing systems; programming languages and environments, applications and application areas with their appropriate algorithms; issues of correctness. Coursework includes: lectures, presentations by students, and a large number of programming assignments involving the most commonly used examples of these topics applied to simple physical problems. Prerequisites: 15-112 and 21-122 and 33-104 and (33-152 or 33-122 or 33-132 or 33-112 or 33-107 or 33-142)

33-301 Physics Upperclass Colloquium I

Fall: 1 unit

Upperclass 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 are also be presented.

33-302 Physics Upperclass Colloquium II

Spring: 1 unit

Continuation of 33-301.

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: 21-259 and 33-232

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: 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, Mössbauer effect, neutron activation of radioactive nuclides, Compton scattering, and cosmic ray muons.

Prerequisites: 33-234 and (33-341 or 33-331 or 33-338)

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 measurable 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: 33-234 and 33-232

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

The student undertakes a project of interest under the supervision of a faculty member. 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. A list of research projects is available. The student must contact the Assistant Head for the Undergraduate Affairs before registering so that student project pairings can be set. Reports on results are required at end of semester.

33-353 Intermediate Optics

Fall: 12 units

Offer 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 33-152 or 33-142 or 33-132 or 33-107 or 33-112

33-355 Nanoscience and Nanotechnology

Fall: 9 units

Offered alternative years. 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 brief review of the physical principles of electric fields and forces, the nature of chemical bonds, the interaction of light with matter, and elastic deformation of solids. 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 micro-electronics industry. Finally, examples of nanoscale components and systems will be described, including quantum dots, self-assembled monolayers, molecular computing, and others. 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. Students will sign up for these laboratory sessions and perform the exercises under the supervision of a teaching assistant. 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: 33-122 or 33-152 or 33-142 or 33-112 or 33-132 or 33-107

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: (33-231 or 21-260) and 21-341

33-441 Introduction to BioPhysics

Fall: 10 units

This intermediate level course is primarily offered to Physics and Biology undergrads (junior/senior) and provides a modern view of molecular and cellular biology as seen from the perspective of physics, and quantified through the analytical tools of physics. This course will not review experimental biophysical techniques (which are covered, e.g., in 03-871). Rather, physicists will learn what sets "bio" apart from the remainder of the Physics world and how the apparent dilemma that the existence of life represents to classical thermodynamics is reconciled. They also will learn the nomenclature used in molecular biology. In turn, biologists will obtain (a glimpse of) what quantitative tools can achieve beyond the mere collecting and archiving of facts in a universe of observations: By devising models, non-obvious quantitative predictions are derived which can be experimentally tested and may lead to threads that connect vastly different, apparently unrelated phenomena. One major goal is then to merge the two areas, physics and biology, in a unified perspective.

Prerequisites: 03-121 and (33-122 or 33-107 or 33-132 or 33-142 or 33-112 or 33-152)

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.

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.

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. 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. A list of research projects is available. The student must contact a faculty member and/or the Assistant Head for the Undergraduate Affairs before registering so that student project pairings can be set. Reports on results are required at end of semester.

33-456 Advanced Computational Physics

Spring: 9 units

This course extends the study of the topics of 33-241 emphasizing practical numerical, symbolic and data-driven computational techniques as applied to a selection of currently active research areas. It is taught by faculty and staff actively engaged in a variety of areas of computational science. Numerical methods may include SVD decomposition, chi-squared minimization, and Fast Fourier Transforms and Monte Carlo simulation of experiments. Applications may include data analysis, eigenvalue problems and others depending on the research activities of the instructors. The students will be expected to become proficient in a specific programming language and to gain the ability to move to other languages and algorithms as their future computationally intensive efforts may require.

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: 33-234 and 33-224

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 encompasses it.

Prerequisites: 33-234 and 33-224

33-499 Supervised Reading

Fall and Spring

The student explores a certain area of advanced physics under the supervision of a faculty member. The student must contact a faculty member and the Assistant Head for Undergraduate Affairs before registering.

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. Typical Textbook(s): "Gravity, An Introduction to Einstein's General Relativity" by James Hartle.

Prerequisites: 33-339 and 33-211

33-658 Quantum Computation and Quantum Information Theory

Spring: 10 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 course includes a weekly seminar. Typical Textbook(s): "Quantum Computation and Quantum Information" by Nielsen and Chuang.

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. 3hrs. lecture. Typical Text: Cohen-Tannoudji Quantum Mechanics, volume 1.

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.

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. 3 hrs. lecture and recitation. Typical Text: G. Arfken, Mathematical Methods for Physicists.

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. 3 hrs. lecture. Typical Text: Jackson, Classical Electrodynamics, 2nd Ed.

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: Reif, Statistical and Thermal Physics; Pathria, Statistical Mechanics.

33-767 Biophysics: From Basic Concepts to Current Research

Spring: 12 units

Biological Physics aims to apply the principles of physics and the methods of mathematical analysis and computer modeling to understand how biological systems work. This course serves as an introduction into this discipline, suitable as a one-semester course for students not necessarily specializing in this area. It will both provide the necessary general concepts, as well as follow some selected topics up to the current frontier of research. Prerequisite: 33-765 or permission of instructor. Typical text: P. Nelson, Biological Physics, as well as selected original papers.

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, 33-76I. 3 hrs. lecture

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: 33-769. 3 hrs. lecture.

33-771 Field Theory II

All Semesters: 12 units

Missing Course Description - please contact the teaching department.

33-777 Introductory Astrophysics

Fall: 12 units

Introductory Astrophysics will explore the applications of physics to the following areas: (i) celestial mechanics and dynamics, (ii) the physics of solar system objects, (iii) the structure, formation and evolution of stars and galaxies, (iv) the large scale structure of the universe of galaxies, (v) cosmology: the origin, evolution and fate of the universe.

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, 33-78I. Topics included are symmetry principles of strong and weak interactions, quark model, classification of particles and nuclear forces. Prerequisite: 33-769 (or concurrently). 3 hrs. lecture. Typical Text: Perkins, Introduction to High Energy Physics, plus notes and reading.

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.

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. 3 hrs. lecture. Typical Text: Ashcroft and Mermin, Solid State Physics.

Prerequisite: 33-756 Min. grade B