PHYSICS Courses

PHYS 101N. Conceptual Physics. 4 Credits.
An introductory descriptive course which develops and illustrates the concepts of physics in terms of phenomena encountered in daily life. Topics include mechanics, electricity and magnetism. (offered fall, summer).

PHYS 102N. Conceptual Physics. 4 Credits.
An introductory descriptive course which develops and illustrates the concepts of physics in terms of phenomena encountered in daily life. Topics include sound, light, fluids and heat. (offered spring) Prerequisites: PHYS 101N.

PHYS 103N, Introductory Astronomy of the Solar System. 4 Credits.
A study of the physical principles and scientific investigation of objects in our solar system. Emphasis on how we acquire knowledge of celestial objects to develop models of our universe.

PHYS 104N, Introductory Astronomy of Galaxies and Cosmology. 4 Credits.
Emphasizes the study of stars, star systems, cosmology and relativity. Emphasis on how we acquire knowledge of celestial objects to develop models of our universe.

PHYS 109. Introductory Astronomy Laboratory. 1 Credit.
An introductory laboratory course in astronomy dealing with experiments about the laws of nature that apply to objects in our solar system. Prerequisite: written permission of the chief departmental advisor of the Physics Department.

PHYS 111N. Introductory General Physics. 4 Credits.
Emphasizes mechanics, wave motion and heat and will also cover the needed elements of trigonometry and vectors. Students receiving credit for PHYS 111N cannot receive credit for PHYS 102N either simultaneously or subsequently. (offered fall, spring, summer) Prerequisite: MATH 102M or MATH 103M or MATH 162M or MATH 166.

PHYS 112N. Introductory General Physics. 4 Credits.
Emphasizes electricity, light, and introduction to modern physics. Prerequisites: PHYS 111N and MATH 102M (or MATH 103M) or MATH 162M or MATH 166. (offered fall, spring, summer).

PHYS 113. Physics Laboratory. 1 Credit.
Available for pass/fail grading only. An introductory laboratory covering experiments from mechanics, wave motion, heat and sound. Prerequisites: written permission of the chief departmental advisor of the Physics Department.

PHYS 114. Physics Laboratory. 1 Credit.
Available for pass/fail grading only. An introductory laboratory covering experiments from electricity, magnetism, and optics. Prerequisites: written permission of the chief departmental advisor of the Physics Department.

PHYS 120. Physics in the 21st Century. 1 Credit.
This seminar will provide students with a broad introduction to the cutting edge of physics research and its applications in diverse areas of contemporary physics. Recommended for incoming students interested in physics and the natural sciences.

PHYS 126N. Honors: Introductory Astronomy. 4 Credits.
Open only to students in the Honors College. A special honors version of PHYS 103N.

PHYS 127N. Honors: Introductory Astronomy. 4 Credits.
Open only to students in the Honors College. A special honors version of PHYS 104N.

PHYS 226N. Honors: University Physics I. 4 Credits.
Open only to students in the Honors College. A special honors version of PHYS 231N. This course also includes a Recitation Section for more in-depth discussion of advanced problems. Prerequisites: MATH 211 with a grade of C or better. Pre- or corequisite: MATH 212.

PHYS 232N, Honors: University Physics II. 4 Credits.
Open only to students in the Honors College. A special honors version of PHYS 232N, including a recitation section for discussion of advanced problems. Prerequisites: PHYS 231N or PHYS 226N or PHYS 261N with a grade of C or better, and both MATH 211 and MATH 212 each with a grade of C or better.

PHYS 231N, University Physics I. 4 Credits.
A general introduction to physics in which the principles of classical and modern physics are applied to the solution of physical problems. The reasoning through which solutions are obtained is stressed. Topics include mechanics, fluids, and thermodynamics. This course is designed for majors in the physical sciences, engineering, mathematics, and computational sciences. Students receiving credit for PHYS 231N and PHYS 232N cannot simultaneously or subsequently receive credit for PHYS 101N and PHYS 102N or PHYS 111N and PHYS 112N. (offered fall, spring, summer) Prerequisites: MATH 211 with a grade of C or better. Pre- or corequisites: MATH 212 or permission of instructor.

PHYS 232N, University Physics II. 4 Credits.
A general introduction to physics in which the principles of classical and modern physics are applied to the solution of physical problems. The reasoning through which solutions are obtained is stressed. This course is designed for majors in the physical sciences, engineering, mathematics, and computational sciences. Topics include electricity and magnetism, and optics. Students receiving credit for PHYS 231N and PHYS 232N cannot simultaneously or subsequently receive credit for PHYS 101N and PHYS 102N or PHYS 111N and PHYS 112N. (offered fall, spring, summer) Prerequisites: PHYS 231N or PHYS 226N or PHYS 261N with a grade of C or better, and both MATH 211 and MATH 212 with each a grade of C or better.

PHYS 261N. Advanced University Physics I. 4 Credits.
This calculus-based course is the required introductory course for Physics majors. In addition to the physics curriculum of PHYS 231N, this course has a recitation section for advanced problems and additional mathematical preparation for advanced courses in physics. Prerequisites: MATH 211, with a grade of C or better. Pre- or corequisite: MATH 212.

PHYS 262N. Advanced University Physics II. 4 Credits.
This calculus-based course is the required introductory course for Physics majors. In addition to the physics curriculum of PHYS 232N, this course has a recitation section for advanced problems and additional mathematical preparation for advanced courses in physics. Prerequisites: PHYS 261N with a grade of C or better; MATH 211 and MATH 212, each with a grade of C or better.

PHYS 303. Intermediate Experimental Physics. 3 Credits.
A laboratory-oriented course designed to provide students with a broad introduction to instrumentation and techniques used in modern physics laboratories. Topics to be covered include: basic electronics with an introduction to diode, transistor and op-amp circuitry, and an introduction to physical computing using LabView and Arduino micro controllers. Prerequisites: PHYS 232N or PHYS 227N or PHYS 262N.

PHYS 304. Intermediate Experimental Physics. 3 Credits.
A laboratory oriented course designed to provide students with a broad introduction to instrumentation and techniques used in modern physics laboratories. This course is a continuation of PHYS 303. Prerequisite: PHYS 232N and PHYS 303.

PHYS 309. Physics on the Back of an Envelope. 1 Credit.
Physicists should be able to estimate the order-of-magnitude of anything. How many atoms of Julius Caesar do you eat every day? How much waste does a nuclear power plant generate? Will develop concepts, relations and numbers useful for estimation. Will cover little new material, emphasizing already acquired knowledge. Will help students apply physics to real-life questions and understand which physical effects are appropriate on which scales. Seminar course. Prerequisites: PHYS 102N or PHYS 112N or PHYS 232N or PHYS 227N or PHYS 262N.
PHYS 311. Color in Nature and Art. 3 Credits.
Explores the relationship between light as stimulus and color perceived by us. Develops underlying concept of technology of art and applied art. Describes basis for optical phenomena involved in many facets of daily life. Topics include: the interaction of light and the visual perception it produces; the basic concept of spectra; wave, ray, and quantum optics; polarized light; photography; paintings; pigments; rainbows and mirages; color theory systems; formation of images; optical instruments. There is no physics prerequisite for this course. Prerequisite: MATH 102M (or MATH 103M).

PHYS 313. Elements of Astrophysics. 3 Credits.
A one-semester course covering the important topics of modern astrophysics. The physical basis of stellar evolution and chemical element formation is derived from first principles. Observational details of white dwarfs, neutron stars, pulsars, and black holes are developed. Prerequisites: PHYS 232N or PHYS 227N or PHYS 262N.

PHYS 319. Analytical Mechanics. 3 Credits.
Fundamentals of Newtonian mechanics. Topics include kinematics, dynamics, energy and momentum, central forces and planetary motion, and resonance phenomena. (Offered Spring) Prerequisites: PHYS 232N or PHYS 227N or PHYS 262N. Pre- or corequisite: MATH 307 or MATH 280.

PHYS 323. Modern Physics. 3 Credits.
Introduction to the wave nature of matter, with applications in materials science, atomic, and nuclear physics. Introduction to relativity, including applications in mechanics and electrodynamics. (Offered Fall) Prerequisites: PHYS 232N or PHYS 227N or PHYS 262N and MATH 212.

PHYS 332. Physics of Music and Musical Reproduction. 3 Credits.
This course explores the topics of: the nature of sound, vibrations, resonance, the human ear, loudness, pitch, timbre, musical scales, dissonance and consonance, musical instruments, sound recording and reproduction, electronic music, noise, and acoustics. Prerequisite: MATH 102M.

PHYS 350. Light and Lasers. 3 Credits.
An analysis of those concepts of geometrical physical optics needed for the understanding of laser resonators, optical propagation, and radiation detection. A study of laser diodes, molecular, neutral and ion gas lasers, tunable dye and excimer lasers. Laser applications in medicine, communications, information processing, holography, pollution detection, and material testing and fabrication are stressed. Prerequisite: PHYS 102N or PHYS 112N or PHYS 232N.

PHYS 355. Mathematical Methods of Physics. 3 Credits.
This course will provide a strong foundation in the mathematical methods and applications necessary for undergraduate study of physics beyond the introductory level. (Offered Fall) Prerequisites: PHYS 232N or PHYS 227N or PHYS 262N and MATH 212. Pre- or corequisite: MATH 312 or MATH 285.

PHYS 367. Cooperative Education. 1-3 Credits.
May be repeated for credit. Available for pass/fail grading only. Student participation for credit based on the academic relevance of the work experience, criteria, and evaluative procedures as formally determined by the department and Career Development Services prior to the semester in which the work experience is to take place. (qualifies as a CAP experience) Prerequisites: approval of the chief departmental advisor and Career Development Services in accordance with the policy for granting credit for Cooperative Education programs.

PHYS 368. Internship. 1-3 Credits.
Available for pass/fail grading only. Academic requirements will be established by the department and will vary with the amount of credit desired. Allows students to gain short duration career-related experience. (Qualifies as a CAP experience) Prerequisites: approval of the chief departmental advisor and Career Development Services.

PHYS 406/506. Observational Astronomy. 3 Credits.
Observational techniques in astronomy with emphasis on constellation identification, celestial movements, and telescopic observation. Individualized night observations are required. Prerequisite: junior standing.

PHYS 408/508. Astronomy for Teachers. 3 Credits.
A course in astronomy dealing with stars and stellar systems. Topics will include observational astronomy, the electromagnetic spectrum, relativity, stellar and galactic structures, cosmology, and the search for extraterrestrial intelligence. Prerequisite: junior standing.

PHYS 411. Introduction to Atomic Physics. 3 Credits.
The hydrogen atom, radiative transitions, two-electron systems, many-electron atoms, interaction with external fields, theory of atomic spectra. Prerequisites: PHYS 452 and MATH 307.

PHYS 413/513. Methods of Experimental Physics. 3 Credits.
Experiments in classical and modern physics, designed to develop skills in the collection, analysis, and interpretation of experimental data. (Offered Spring) Corequisite: CS 150. Prerequisites: PHYS 303 or ECE 287, and PHYS 323.

PHYS 415/515. Introduction to Nuclear and Particle Physics. 3 Credits.
An introduction to the structure of the atomic nucleus, natural and artificial radioactivity, nuclear decay processes and stability of nuclei, nuclear reactions, properties of nuclear forces, and nuclear models. Also, particle phenomenology, experimental techniques and the standard model. Topics include the spectra of leptons, mesons, and baryons; strong, weak, and electromagnetic interactions. Corequisite: MATH 307. Prerequisite: PHYS 452.

PHYS 416/516. Introduction to Solid State Physics. 3 Credits.
Introduction to solid state physics and materials science, with emphasis placed on the applications of each topic to experimental and analytical techniques. Topics include crystallography, thermal and vibrational properties of crystals and semiconductors, metals and the band theory of solids, superconductivity and the magnetic properties of materials. Prerequisites: PHYS 452 and MATH 307.

PHYS 417/517. Introduction to Particle Accelerator Physics. 3 Credits.
Introduction to the historical development and applications of particle accelerators. Fundamentals of relativistic particle dynamics including particle acceleration; linear beam optics and particle transfers stability; weak and strong focusing; introduction to the statistical descriptions of particle beams; linear and non-linear synchrotron motion; and radiation production by accelerated relativistic particles. Examples relevant to betatrons, cyclotrons, synchrotrons, and linear accelerators will be given. Prerequisites: PHYS 319 or MAE 205, and PHYS 425 or ECE 323.

PHYS 420/520. Introductory Computational Physics. 3 Credits.
Introduction of computational methods and visualization techniques for problem solving in physics. Prerequisites: PHYS 319, PHYS 323, CS 150, and MATH 212.

PHYS 425/525. Electromagnetism I. 3 Credits.
A study of the classical theory and phenomena of electricity and magnetism. Topics include the calculation of electric and magnetic fields, magnetic and dielectric properties of matter, and an introduction to Maxwell's equations. Pre- or corequisite: PHYS 355. Prerequisites: PHYS 232N or PHYS 227N or PHYS 262N and MATH 312.

PHYS 451/551. Theoretical Mechanics. 3 Credits.
A mathematical study of the concepts of mechanics. Vector calculus methods are used. Topics include mechanics of a system of particles, Lagrangian mechanics, Hamilton's canonical equations, and motion of a rigid body. Prerequisites: PHYS 319, PHYS 355 and MATH 312.

PHYS 452/552. Introduction to Quantum Mechanics. 3 Credits.
Introduction to the physical and mathematical structure of quantum theory, including the historical and experimental origins of the subject. The subject matter includes techniques for solving the Schrodinger equation in one, two, and three dimensions. Both coordinate and momentum space representations are used. The harmonic oscillator and the Hydrogen atom receive particular attention. Prerequisites: PHYS 319, PHYS 323, and PHYS 355.

PHYS 453/553. Electromagnetism II. 3 Credits.
A course in electrodynamics developed from Maxwell's Equations. Topics include Maxwell's Equations, Conservation Laws, Electromagnetic Waves, Potentials and Fields, Radiation, and the interplay of electrodynamics and special relativity. Prerequisites: PHYS 425 or ECE 323 and MATH 312.
PHYS 454/554. Thermal and Statistical Physics. 3 Credits.
A study of the fundamental concepts of thermodynamics, kinetic theory, and statistical mechanics. Topics include the thermodynamics of simple systems, kinetic theory of gases, statistical mechanics of gases and an introduction to quantum statistics. Prerequisites: PHYS 319 and PHYS 323.

PHYS 456/556. Intermediate Quantum Mechanics, 3 Credits.
This course follows directly from PHYS 452. It includes a more detailed study of simple systems, an introduction to abstract quantum mechanics and Dirac notation, and applications to operator methods. Particular attention is paid to electron spin, angular momentum theory, operator treatment of the harmonic oscillator, the Pauli exclusion principle, perturbation theory, and scattering. Prerequisites: PHYS 323 and PHYS 452 or permission of the instructor.

PHYS 460/560. Fundamentals of Accelerator Physics and Technology with Simulations and Measurements Lab. 3 Credits.
Explores the historical development of accelerators and their past and present applications. Principles of acceleration, including the physics of linear accelerators, synchrotrons, and storage rings. Magnet design; machine lattice design and particle beam optics. Longitudinal and transverse beam dynamics, including synchrotron and betatron particle motion. Special topics will be reviewed, including synchrotron radiation, injection techniques, and collective effects and beam instabilities. Prerequisites: PHYS 319 and PHYS 425.

PHYS 467. Preparing for the Physics GRE. 1 Credit.
This course will review the style and scope of problems likely to be found on the Physics Graduate Record Exam (GRE). Emphasis is on quick solving of problems based on foundational knowledge and intuition. This course is particularly intended for students preparing to apply for graduate school, but may be of interest to all students. Prerequisites: PHYS 323 and PHYS 319.

PHYS 468W. Research Methods in Mathematics and Sciences. 3 Credits.
Emphasizes the tools and techniques used to solve scientific problems. Topics include use and design of experiments, use of statistics to interpret experimental results, mathematical modeling of scientific phenomena, and oral and written presentation of scientific results. Students will perform four independent inquiries, combining skills from mathematics and science to solve research problems. Required for Physics teaching licensure track; not available as upper-division elective in content area. This is a writing intensive course. Prerequisites: Admission to the Monarch Teach Program; PHYS 232N or MATH 212; and a grade of C or better in ENGL 211C or ENGL 221C or ENGL 231C.

PHYS 490W. Senior Thesis I. 1 Credit.
Part one of a two-semester option for completing the Senior Thesis. PHYS 490W plus PHYS 490W is equivalent to PHYS 499W. Prerequisite: permission of the instructor and a grade of C or better in PHYS 311 or MATH 212 or PHYS 323 or PHYS 319. PHYS 492W is a writing intensive course. Prerequisite: PHYS 490W.

PHYS 497/597. Special Problems and Research. 1-3 Credits.
These courses afford the student an opportunity to pursue individual study and research. Prerequisite: senior standing or permission of the instructor.

PHYS 499W. Senior Thesis. 3 Credits.
Each student will undertake a research experience under the supervision of a department faculty member. The experience can be of an experimental, theoretical, or calculation type. A final oral and written report are required. The research may be completed on campus or at one of the department affiliated research organizations. (offered fall, spring, summer) (This is a writing intensive course.) Prerequisite: grade of C or better in ENGL 211C or ENGL 221C or ENGL 231C and permission of the instructor.

PHYS 503. Electronic Instrumentation. 3 Credits.

PHYS 506. Observational Astronomy. 3 Credits.
Observational techniques in astronomy with emphasis on constellation identification, celestial movements, and telescopic observation. Individualized night observations are required.

PHYS 508. Astronomy for Teachers. 3 Credits.
A course in astronomy dealing with stars and stellar systems. Topics will include observational astronomy, the electromagnetic spectrum, relativity, stellar and galactic structures, cosmology, and the search for extraterrestrial intelligence.

PHYS 513. Methods of Experimental Physics. 3 Credits.
Experiments in classical and modern physics, designed to develop skills in the collection, analysis, and interpretation of experimental data.

PHYS 515. Introduction to Nuclear Particle Physics. 3 Credits.
An introduction to the structure of the atomic nucleus, natural and artificial radioactivity, nuclear decay processes and stability of nuclei, nuclear reactions, properties of nuclear forces, and nuclear models. Also, particle phenomenology, experimental techniques and the standard model. Topics include the spectra of leptons, mesons, and baryons; strong, weak, and electromagnetic interactions.

PHYS 516. Introduction to Solid State Physics. 3 Credits.
Introduction to solid state physics and materials science, with emphasis placed on the applications of each topic to experimental and analytical techniques. Topics include crystallography, thermal and vibrational properties of crystals and semiconductors, metals and the band theory of solids, superconductivity and the magnetic properties of materials.

PHYS 517. Introduction to Particle Accelerator Physics. 3 Credits.
Introduction to the historical development and applications of particle accelerators. Fundamentals of relativistic particle dynamics including particle acceleration; linear beam optics and particle transfers stability; weak and strong focusing; introduction to the statistical descriptions of particle beams; linear and non-linear synchrotron motion; and radiation production by accelerated relativistic particles. Examples relevant to betatrons, cyclotrons, synchrotrons, and linear accelerators will be given. Prerequisites: PHYS 319 or MAE 205, and PHYS 425 or ECE 323.

PHYS 520. Introductory Computational Physics. 3 Credits.
Introduction of computational methods and visualization techniques for problem solving in physics.

PHYS 525. Electromagnetism I. 3 Credits.
A study of the classical theory and phenomena of electricity and magnetism. Topics include the calculation of electric and magnetic fields, magnetic and dielectric properties of matter, and an introduction to Maxwell's equations.

PHYS 551. Theoretical Mechanics. 3 Credits.
A mathematical study of the concepts of mechanics. Vector calculus methods are used. Topics include mechanics of a system of particles, Lagrangian mechanics, Hamilton’s canonical equations, and motion of a rigid body.

PHYS 552. Introduction to Quantum Mechanics. 3 Credits.
Introduction to the physical and mathematical structure of quantum theory, including the historical and experimental origins of the subject. The curriculum includes techniques for solving the Schrodinger wave equation, particularly for the harmonic oscillator and the hydrogen atom. Prerequisites: PHYS 319 and PHYS 323.

PHYS 553. Electromagnetism II. 3 Credits.
A course in electromodynamics developed from Maxwell’s Equations. Topics include Maxwell’s Equations, Conservation Laws, Electromagnetic Waves, Potentials and Fields, Radiation, and the interplay of electromodynamics and special relativity.

PHYS 554. Thermal and Statistical Physics. 3 Credits.
A study of the fundamental concepts of thermodynamics, kinetic theory, and statistical mechanics. Topics include the thermodynamics of simple systems, kinetic theory of gases, statistical mechanics of gases and an introduction to quantum statistics.

PHYS 556. Intermediate Quantum Mechanics. 3 Credits.
This course follows directly from PHYS 552. It includes a more detailed study of simple systems, an introduction to abstract quantum mechanics and Dirac notation, and applications to operator methods. Particular attention is paid to electron spin, angular momentum theory, operator treatment of the harmonic oscillator, the Pauli exclusion principle, perturbation theory, and scattering.
PHYS 560. Fundamentals of Accelerator Physics and Technology with Simulations and Measurements Lab. 3 Credits.
Historical development of accelerators and their past and present applications. Principles of acceleration, including the physics of linear accelerators, synchrotrons, and storage rings. Magnet design; machine lattice design and particle beam optics. Longitudinal and transverse beam dynamics, including synchrotron and betatron particle motion. Special topics will be reviewed, including synchrotron radiation, injection techniques, and collective effects and beam instabilities.

PHYS 597. Special Problems and Research. 1-3 Credits.
These courses afford the student an opportunity to pursue individual study and research. Prerequisites: permission of the instructor.

PHYS 601. Mathematical Methods of Physics I. 3 Credits.
Basic mathematical methods with applications: vector analysis, linear algebra, series and series of functions, Hilbert spaces, complex variable theory.

PHYS 602. Mathematical Methods of Physics II. 1 Credit.

PHYS 603. Classical Mechanics. 3 Credits.

PHYS 604. Classical Electrodynamics I. 3 Credits.

PHYS 621. Quantum Mechanics I. 3 Credits.

PHYS 658. MICROWAVE MEAS & BEAM INST LAB. 3 Credits.
Introduction to RF and microwave technology and laboratory methods for its characterization. Topics include microwave measurements in the time and frequency domains, basics of spectrum analyzers, vector signal analyzers, and time domain reflectometers; transmission lines, complex impedance, reflection coefficients; microwave measurements with a Vector Network Analyzer, basics of vector network analyzers; stripline pickups and kickers; beam signals for Circular Accelerators, beam spectrums, power spectral density, betatron and synchrotron signals; beam impedance and methods for measuring it; impedance matching, basics of matching devices; and RF cavity and linac structure measurements, cavity and coupled cavity structure basics, beam pull, coupling, cavity bandwidth.

PHYS 659. Microwave Sources. 3 Credits.
Introduction to principles of common standing wave (klystron) and traveling-wave (TWT and FEL) microwave devices, particularly how electron beams exchange energy with rf fields. Students will be able to predict device gain and efficiency, and will understand basic beam dynamics, microwave tubes focusing, and space charge effects. Beam physics material includes magnetic focusing, Busch's Theorem, solenoidal and PPM focusing, diamagnetic effects, potential depression, and balanced, confined, and Brillouin flow. Prerequisites: PHYS 425, PHYS 453, MATH 211, and MATH 212.

PHYS 695. Selected Topics in Pure and Applied Physics. 1-3 Credits.
These courses afford the student an opportunity to pursue individual study. Prerequisites: permission of the instructor.

PHYS 696. Special Topics in Accelerator Physics. 3 Credits.
Special topics related to particle accelerators and their applications. Departmental approval required.

PHYS 698. Research. 1-9 Credits.
M.S. level research supervised by the student's thesis advisor.

PHYS 699. Thesis. 1-9 Credits.
M.S. level research supervised by the student's thesis advisor.

PHYS 701. Advanced Mathematical Methods of Physics. 3 Credits.
Group theory, Lie groups and Lie algebras, differential geometry, tensor fields on manifolds, integral calculus of differential forms. Prerequisites: PHYS 601.

PHYS 704. Classical Electrodynamics II. 3 Credits.
Electrodynamics: Maxwell equations, plane electromagnetic waves and wave propagation, waveguides, radiating systems, special theory of relativity, including the dynamics of relativistic particles and electromagnetic fields. Prerequisites: PHYS 604.

PHYS 707. Statistical Mechanics. 3 Credits.

PHYS 711. Computational Physics. 3 Credits.
Studies of high level computer languages. Computational techniques used in physics. Numerical techniques for differential and integral problems. Algebraic processing languages. Introduction to scientific visualization techniques.

PHYS 721. Quantum Mechanics II. 3 Credits.

PHYS 722. Nuclear and Particle Physics I. 3 Credits.
Nuclear forces, models of nuclear structure and reactions, hadron and lepton scattering, introduction to constituent quark model and hadron spectroscopy. Prerequisites: PHYS 621.

PHYS 723. Nuclear and Particle Physics II. 3 Credits.
Discrete and continuous symmetries and application to particle physics, SU(2) and SU(3) symmetries and static properties of hadrons. Klein-Gordon and Dirac equations, quantum electrodynamics and Feynman rules, strong and weak interactions, Standard Model and physics beyond the Standard Model. Prerequisites: PHYS 722 or PHYS 822.

PHYS 724. Condensed Matter Physics I. 3 Credits.
Electronic and lattice properties of solids, band structures of metals, semiconductors and insulators, dynamics of electron and phonons, electromagnetic and optical properties of metals and doped semiconductors, phenomenology of superconductivity and magnetism, and selected experimental methods of solid state physics. Prerequisites: PHYS 621, and PHYS 721 or PHYS 821.

PHYS 727. Atomic Physics. 3 Credits.
Irreducible tensor methods. Radiative excitation and ionization processes. Atom-atom scattering. Time-evolution of atomic observables in external fields. Multiple channel quantum defect theory and complex atomic and molecular spectra. Prerequisites: permission of the instructor.

PHYS 750. Quantum Electronics. 3 Credits.
Interaction of quantized electromagnetic field with matter, including photon coherence, theory of laser, nonlinear optics and selected applications. Prerequisites: PHYS 604.
PHYS 751. Simulation of Beam and Plasma Systems. 3 Credits.
Provides a comprehensive introduction to numerical modeling techniques used to analyze beam and plasma systems in the context of accelerator technology. Emphasis on self-consistent modeling of systems where self-fields cannot be neglected, collective effects are important, and in "plasma accelerators" where particles are accelerated in the ionized gas using resonant plasma waves. More advanced refinements of the PIC method are also surveyed including mesh refinement, advanced movers, and optimal Lorentz frame simulations. Prerequisites: PHYS 425, PHYS 451, PHYS 453, and PHYS 460 or PHYS 560.

PHYS 752. Control Theory with Applications to Accelerators and RF Systems. 3 Credits.
Focuses on control theory applied to dynamic systems, in particular to systems found in accelerator/light source facilities. Fundamental concepts of control theory and feedback design techniques are explored to then introduce the student to robust design and optimized design of controllers Prerequisites: PHYS 417 or PHYS 517, and PHYS 601.

PHYS 754. Accelerator Physics. 3 Credits.
Overview of the underlying physics of modern particle accelerators. Acceleration, beam transport, nonlinear dynamics, coherent synchrotron radiation, wakefields and impedances, collective effects, phase space cooling, free-electron lasers, novel methods of acceleration, accelerator systems. Prerequisites: PHYS 859.

PHYS 756. Beam Physics with Intense Space Charge. 3 Credits.
This course is intended to give the student a broad overview of the dynamics of beams with strong space charge. The emphasis is on theoretical and analytical methods of describing the acceleration and transport of beams. Some aspects of numerical and experimental methods will also be covered. Students will become familiar with standard methods employed to understand the transverse and longitudinal evolution of beams with strong space charge. The material covered will provide a foundation to design practical architectures. Prerequisites: Undergraduate level Electricity and Magnetism and Classical Mechanics is required; some familiarity with plasma physics, special relativity, and basic accelerator physics is strongly recommended.

PHYS 758. SRF Technology: Practices and Hands-on Measurements. 3 Credits.
The purpose of the course is to introduce students to the SRF technology and the procedures and techniques used in the production and testing of SRF cavities. It will focus on multi-cell elliptical structures. The course is intended to be mainly hands-on work with cavities using the processing, test and measurement systems available at the Jefferson Lab SRF Institute. The course is intended for graduate-level students with a background in SRF technology, individuals working in the field, and individuals intending on working in the field. Students will be required to take several basic online safety training classes in advance of the course. Prerequisites: Students should have an undergraduate degree in physics or engineering with a basic knowledge of the use of radio frequency test equipment such as vector network analyzers, spectrum analyzers, and power measurement equipment; completion of PHYS 658 and PHYS 460/PHYS 560 is desirable.

PHYS 760. Low Temperature Physics. 3 Credits.
Properties and behavior of materials and systems at low temperature with emphasis on particle accelerator and microwave applications. Macroscopic quantum phenomena in condensates. Superfluidity, electrodynamic properties of superconductors. Prerequisites: PHYS 825.

PHYS 765. Linear Accelerators. 3 Credits.
This course will cover design and general operating principles for linear accelerators, including acceleration methods for particles and beams. Topics will include the evolution and descriptions of particle beams under acceleration, the physics of accelerated particle beams, as well as the effects of space charge, high-order modes (HOMs), and other collective effects. Aspects of both normal conducting (RF) and superconducting (SRF) linear accelerators will be covered. Prerequisites: PHYS 603, PHYS 604, and PHYS 754 or PHYS 854.

PHYS 790. Introduction to the Processes of Quantum Chromodynamics. 3 Credits.
An introduction to basic Quantum Chromodynamics (QCD) methods in hadron-scattering experiments. Focus will be placed on perturbative methods and partonic interpretations of specific processes. The course will begin with a general overview of QCD, and specific processes will be studied in detail to illustrate the general features of partonic physics and their QCD interpretations. The course will close with a summary of questions of current research interest. Prerequisites: PHYS 871.

PHYS 791. Seminar I. 1 Credit.
This seminar is designed to enhance both written and oral communication skills as applied to physics. Topics include effective display of data, preparation of scientific reports and preparation and delivery of scientific talks.

PHYS 792. Seminar II. 1 Credit.
A continuation of PHYS 791 at an advanced level. This seminar is designed to enhance both written and oral communication skills as applied to physics. Topics include effective display of data, preparation of scientific reports and preparation and delivery of scientific talks.

PHYS 800. Advanced Mathematical Methods of Physics. 3 Credits.
Group theory, Lie groups and Lie algebras, differential geometry, tensor fields on manifolds, integral calculus of differential forms. Prerequisites: PHYS 601.

PHYS 804. Classical Electrodynamics II. 3 Credits.
Electrodynamics: Maxwell equations, plane electromagnetic waves and wave propagation, waveguides, radiating systems, special theory of relativity, including the dynamics of relativistic particles and electromagnetic fields. Prerequisites: PHYS 604.

PHYS 807. Statistical Mechanics. 3 Credits.

PHYS 811. Computational Physics. 3 Credits.
Studies of high level computer languages. Computational techniques used in physics. Numerical techniques for differential and integral problems. Algebraic processing languages. Introduction to scientific visualization techniques.

PHYS 821. Quantum Mechanics II. 3 Credits.

PHYS 822. Nuclear and Particle Physics I. 3 Credits.
Nuclear forces, models of nuclear structure and reactions, hadron and lepton scattering, introduction to constituent quark model and hadron spectroscopy. Prerequisites: PHYS 621.

PHYS 823. Nuclear and Particle Physics II. 3 Credits.
Discrete and continuous symmetries and application to particle physics, SU(2) and SU(3) symmetries and static properties of hadrons. Klein-Gordon and Dirac equations, quantum electrodynamics and Feynman rules, strong and weak interactions. Standard Model and physics beyond the Standard Model. Prerequisites: PHYS 722 or PHYS 822.

PHYS 824. Condensed Matter Physics I. 3 Credits.
Electronic and lattice properties of solids, band structures of metals, semiconductors and insulators, dynamics of electron and phonons, electromagnetic and optical properties of metals and doped semiconductors, phenomenology of superconductivity and magnetism, and selected experimental methods of solid state physics. Prerequisites: PHYS 621, and PHYS 721 or PHYS 821.
PHYS 825. Condensed Matter Physics II. 3 Credits.
Many body and collective effects in condensed matter, including phase transitions, Bose and Fermi quantum liquids, superfluidity, superconductivity and magnetism, and properties of mesoscopic and low-dimensional systems. Prerequisites: PHYS 707 or PHYS 807, and PHYS 724 or PHYS 824.

PHYS 827. Atomic Physics. 3 Credits.
Irreducible tensor methods. Radiative excitation and ionization processes. Atom-atom scattering. Time-evolution of atomic observables in external fields. Multiple channel quantum defect theory and complex atomic and molecular spectra. Prerequisites: permission of the instructor.

PHYS 842. Advanced Quantum Mechanics. 3 Credits.
Introduction to relativistic quantum mechanics; symmetries in relativistic wave equations; solutions to relativistic wave equations for bound states and scattering processes; classical field theory and role of symmetries in construction of conserved currents; introduction to second quantization of fields. Prerequisites: PHYS 704 or PHYS 804, PHYS 721 or PHYS 821.

PHYS 850. Quantum Electronics. 3 Credits.
Interaction of quantized electromagnetic field with matter, including photon coherence, theory of laser, nonlinear optics and selected applications. Prerequisites: PHYS 604.

PHYS 851. Simulation of Beam and Plasma Systems. 3 Credits.
Provides a comprehensive introduction to numerical modeling techniques used to analyze beam and plasma systems in the context of accelerator technology. Emphasis on self-consistent modeling of systems where self-fields cannot be neglected, collective effects are important, and in "plasma accelerators" where particles are accelerated in the ionized gas using resonant plasma waves. More advanced refinements of the PIC method are also surveyed including mesh refinement, advanced movers, and optimal Lorentz frame simulations. Prerequisites: PHYS 425, PHYS 451, PHYS 453, and PHYS 460 or PHYS 560.

PHYS 852. Control Theory with Applications to Accelerators and RF Systems. 3 Credits.
Focuses on control theory applied to dynamic systems, in particular to systems found in accelerator/light source facilities. Fundamental concepts of control theory and feedback design techniques are explored to then introduce the student to robust design and optimized design of controllers. Prerequisites: PHYS 417 or PHYS 517, and PHYS 601.

PHYS 853. Atomic & Molecular Physics. 3 Credits.
Theory of atomic and diatomic molecular structure, including coupling of angular momenta and tensor operators. Influence of external static fields and interaction of atomic and molecular systems with both classical and quantized radiation fields. Contemporary topics such as degenerate Fermion and Boson gases, quantum sensors, mesoscopic quantum physics, squeezed light, resonance fluorescence, cold atoms and atom interferometry are also included. Prerequisites: PHYS 621 and either PHYS 721 or PHYS 821 or permission of the instructor.

PHYS 854. Accelerator Physics. 3 Credits.
Overview of the underlying physics of modern particle accelerators. Acceleration, beam transport, nonlinear dynamics, coherent synchrotron radiation, wakefields and impedances, collective effects, phase space cooling, free-electron lasers, novel methods of acceleration, accelerator systems. Prerequisites: PHYS 859.

PHYS 856. Beam Physics with Intense Space Charge. 3 Credits.
This course is intended to give the student a broad overview of the dynamics of beams with strong space charge. The emphasis is on theoretical and analytical methods of describing the acceleration and transport of beams. Some aspects of numerical and experimental methods will also be covered. Students will become familiar with standard methods employed to understand the transverse and longitudinal evolution of beams with strong space charge. The material covered will provide a foundation to design practical architectures. This course will be the same as PHYS 756, except that it will be augmented with additional assignments at the appropriate level. Prerequisites: Undergraduate level Electricity and Magnetism and Classical Mechanics is required; some familiarity with plasma physics, special relativity, and basic accelerator physics is strongly recommended.

PHYS 857. Plasma Physics. 3 Credits.
Motion of charged particles in electromagnetic fields. Coulomb collisions and transport processes. Collisional Boltzmann equation. Generation of various forms of plasma in the laboratory. Basic plasma diagnostic methods including plasma and laser spectroscopy, measurements of electron and ion density and energy distribution. Prerequisites: PHYS 603, PHYS 604, PHYS 704/PHYS 804, PHYS 727/PHYS 827 or permission of the instructor.

PHYS 858. SRF Technology: Practices and Hands-on Measurements. 3 Credits.
The purpose of the course is to introduce students to the SRF technology and the procedures and techniques used in the production and testing of SRF cavities. It will focus on multi-cell elliptical structures. The course is intended to be mainly hands-on work with cavities using the processing, test and measurement systems available at the Jefferson Lab SRF Institute. The course is intended for graduate-level students with a background in SRF technology, individuals working in the field, and individuals intending on working in the field. Students will be required to take several basic online safety training classes in advance of the course. This course will be the same as PHYS 758, except that it will be augmented with additional assignments at the appropriate level. Prerequisites: Students should have an undergraduate degree in physics or engineering with a basic knowledge of the use of radio frequency test equipment such as vector network analyzers, spectrum analyzers, and power measurement equipment, completion of PHYS 658 and PHYS 460/PHYS 560 is desirable.

PHYS 859. Classical Mechanics and Electromagnetism in Accelerator Physics. 3 Credits.
Further development of classical mechanics and electromagnetism and their application to accelerator physics: Lagrangian and Hamiltonian formulation of equations of motion, canonical transformations, adiabatic invariants, linear and nonlinear resonances. Louisvielle's theorem, solutions of Maxwell's equation in cavities and waveguides, wakefields, radiation and retarded potentials, synchrotron radiation. Prerequisites: PHYS 601, PHYS 603, and PHYS 704 or PHYS 804.

PHYS 860. Low Temperature Physics. 3 Credits.
Properties and behavior of materials and systems at low temperature with emphasis on particle accelerator and microwave applications. Macroscopic quantum phenomena in condensates. Superfluidity, electrodynamic properties of superconductors. Prerequisites: PHYS 825.

PHYS 861. Nuclear Physics. 3 Credits.

PHYS 865. Linear Accelerators. 3 Credits.
This course will cover design and general operating principles for linear accelerators, including acceleration methods for particles and beams. Topics will include the evolution and descriptions of particle beams under acceleration, physics of accelerated particle beams, as well as the effects of space charge, high-order modes (HOMs), and other collective effects. Aspects of both normal conducting (RF) and superconducting (SRF) linear accelerators will be covered. Prerequisites: PHYS 603, PHYS 604, and PHYS 754 or PHYS 854.

PHYS 871. Introduction to Quantum Field Theory. 3 Credits.
Quantization of the Klein-Gordon field, interactions in quantum field theory and Feynman diagrams, quantization of the Dirac field, quantization of the electromagnetic field, quantum electrodynamics, renormalization, quantum chromodynamics and asymptotic freedom. Prerequisites: PHYS 842.
PHYS 890. Introduction to the Processes of Quantum Chromodynamics. 3 Credits.
An introduction to basic Quantum Chromodynamics (QCD) methods in hadron-scattering experiments. Focus will be placed on perturbative methods and partonic interpretations of specific processes. The course will begin with a general overview of QCD, and specific processes will be studied in detail to illustrate the general features of partonic physics and their QCD interpretations. The course will close with a summary of questions of current research interest. Pre- or corequisite: PHYS 871.

PHYS 891. Seminar I. 1 Credit.
This seminar is designed to enhance both written and oral communication skills as applied to physics. Topics include effective display of data, preparation of scientific reports and preparation and delivery of scientific talks.

PHYS 892. Seminar II. 1 Credit.
A continuation of PHYS 891 at an advanced level. This seminar is designed to enhance both written and oral communication skills as applied to physics. Topics include effective display of data, preparation of scientific reports and preparation and delivery of scientific talks.

PHYS 898. Doctoral Research. 1-12 Credits.

PHYS 899. Dissertation. 1-9 Credits.