Department of Physics

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Charles Sukenik, Chair
Balsa Terzic, Graduate Program Director

The Department of Physics offers programs of study leading to both the M.S. degree in physics and the Ph.D. degree in physics. Primary focus is placed on the Ph.D. program, and most students enrolled for graduate study are enrolled in that program. Students have the opportunity to perform research in state-of-the-art facilities under faculty direction. Graduates are prepared for research at the highest levels in academia, government laboratories, and corporate laboratories.

Admission

Applicants for admission to graduate study must have an earned bachelor's degree in physics or a closely related discipline from an accredited institution or an equivalent degree from a foreign institution. The applicant is normally required to have a minimum cumulative grade point average of 3.0 on a 4.0 scale. In addition, the general portion of the Graduate Record Examination (GRE) is required for application to either the master's or the doctoral program; applicants to the doctoral program are strongly encouraged to take the GRE specialized physics test as well. The Test of English as a Second Language (TOEFL) is required of all nonnative speakers of English who have resided in the U.S. for less than ten years.

It is normally expected that most incoming graduate students will be supported as teaching assistants. Old Dominion University requires that all graduate teaching assistants who do not speak English as a first language pass a test of spoken English.

Admission decisions are based on undergraduate achievement, GRE scores, and personal reference letters. Graduate study may commence at the beginning of any academic term. Decisions regarding financial support for students entering in the fall term are normally made by April 15, so a student's completed application must be received by January 15. Anyone who applies after January 15 should communicate directly with the Department of Physics concerning the availability of support.

Master of Science - Physics

Requirements

A student may select either the thesis or non-thesis option. For either option, each student's course of study must have the advance approval of the graduate program director.

Non-Thesis Option

Thirty graduate credits that must include the following courses:

PHYS 556	Intermediate Quantum Mechanics	3
or PHYS 621	Quantum Mechanics I	
PHYS 603	Classical Mechanics	3
PHYS 604	Classical Electrodynamics I	3
PHYS 791	Seminar I	1

No more than 12 credits numbered at the 500 level may be used to meet this requirement.

Up to 12 credits from other University departments may be used to meet this requirement if approved by the graduate program director.

Written Examination

In addition to these course requirements, the candidate must pass a written comprehensive examination. It is usually taken just before the student's third semester of study. If a student fails this examination, he or she is allowed a second attempt, which must be at the time when the Written Examination is next given. In all but the most extraordinary circumstances, a student will not be allowed any additional attempts to pass this examination. Normally,

this written examination is the same as the written portion of the Ph.D. Candidacy Examination, graded at the master's level.

Thesis Option

Thirty graduate credits that must include the following courses:

PHYS 556	Intermediate Quantum Mechanics	3
or PHYS 621	Quantum Mechanics I	
PHYS 603	Classical Mechanics	3
PHYS 604	Classical Electrodynamics I	3
PHYS 698	Research	3
PHYS 699	Thesis	3
PHYS 791	Seminar I	1

No more than 12 credits numbered at the 500 level may be used to meet this requirement.

Up to 12 credits from other university departments may be used to meet this requirement if approved by the graduate program director.

Thesis Research

A student's research is supervised by his or her MS thesis committee. The committee is composed of three faculty members from the Physics Department (thesis advisor plus two additional faculty).

The format of the thesis is specified by the Guide for Preparation of Theses and Dissertations. The thesis defense is the final examination that a student must pass to receive a master's degree. This is a public presentation of the results contained in his or her thesis.

Doctor of Philosophy - Physics

Requirements

The broad requirements for the Ph.D. degree are

1. satisfactory performance in a designated core of graduate courses,
2. successful completion of the Ph.D. Candidacy Examination, which has both written and oral parts,
3. successful completion of a teaching requirement, and
4. satisfactory completion of a dissertation.

Each student's course of study must have the advance approval of the graduate program director.

Course Requirements

Seventy-eight graduate credits beyond the undergraduate degree or 48 graduate credits beyond the master's degree must be taken and must include the following courses:

PHYS 601	Mathematical Methods of Physics I	3
PHYS 602	Mathematical Methods of Physics II	1
PHYS 603	Classical Mechanics	3
PHYS 604	Classical Electrodynamics I	3
PHYS 621	Quantum Mechanics I	3
PHYS 804	Classical Electrodynamics II	3
PHYS 807	Statistical Mechanics	3
PHYS 811	Computational Physics	3
PHYS 821	Quantum Mechanics II	3
PHYS 891	Seminar I	1
PHYS 892	Seminar II	1

A minimum of six additional credits for specialized full-semester courses at the 800 level must be taken. A student may waive or substitute for any of these courses with the approval of the graduate program director.

Up to 12 credits from other university departments may be used to meet this requirement if approved by the graduate program director. A student may waive PHYS 892, with the approval of the Graduate Program Committee, if he or she presents a paper at a scientific meeting. Before formation of his or

her dissertation committee, a student is formally advised about these courses and other academic matters by graduate faculty advisors.

Ph.D. Candidacy Examination

A student admitted to the Ph.D. program in physics becomes a bona fide candidate for the Ph.D. degree by passing the Ph.D. Candidacy Examination. The purpose of this comprehensive examination is to determine if a student has the foundation and maturity to begin research in physics. A student who does not pass the Ph.D. Candidacy Examination within the allowed number of attempts explained below will be dismissed from the Ph.D. program. However, that student would still have the opportunity to satisfy the requirements for the M.S. degree in physics.

The Ph.D. Candidacy Examination consists of two parts—the Written Examination and the Oral Examination. Each part must be passed independently in order to pass the Ph.D. Candidacy Examination.

After passing the Written Examination, a student has to form a dissertation committee. Details of the committee are stated in the Dissertation section below.

Written Examination

The written examination is given two times each year—in late August and early January. A student admitted to the Ph.D. program must take this examination by the beginning of his or her third semester of graduate study. In circumstances such that the student has not had the appropriate courses to meet this deadline, he or she may petition the Graduate Program Committee for an extension. If a student fails this examination, he or she is allowed a second attempt, which must be at the time when the Written Examination is next given. In all but the most extraordinary circumstances, a student is dismissed from the Ph.D. program after failing the written examination twice.

Oral Examination

The Oral Examination is a one-hour presentation given by a student to an oral examination committee (normally consisting of his or her dissertation committee, minus the external member), meeting in closed session, normally on a topic relevant to the student's dissertation research. This presentation must be made within one year after a student passes the written examination. A request for extension of the deadline must be made in writing to the Graduate Program Committee.

A student's dissertation advisor, in consultation with the student, may choose from two possible formats for this presentation:

1. a presentation by the student directly on his or her dissertation research or
2. a presentation on a specific topic that the student has been assigned to investigate for several months.

For either option, the student must write a short paper of 10 or fewer pages on his or her presentation topic and give it to all members of the oral examining committee at least two weeks before the scheduled date of the examination. The committee will determine whether the student passes or fails the oral examination. More than one negative vote from the examining committee will result in failure. A student who fails the oral examination will be allowed a second attempt. The student's dissertation advisor will decide the format and timing of such a second attempt, with the provision that the second attempt must be completed within six months of the first attempt. Extensions of the deadline for completing this requirement must be requested in writing to the Graduate Program Committee.

Dissertation

The dissertation is the final and most important requirement that must be completed by a candidate for the Ph.D. degree in physics. It must be based on original research in physics that makes a contribution to existing knowledge and be of sufficient quality and interest to merit publication in a refereed physics journal. Research that is classified by the U. S. Government (in a way that restricts its distribution) is not a suitable basis for a dissertation, as one essential characteristic of a dissertation is that its contents must be disseminated freely.

The candidate's dissertation research is supervised generally by his or her dissertation committee. Close supervision is provided by the candidate's research advisor, who is a member of the dissertation committee and may be a tenured, tenure-track, research, or adjunct member of the graduate-certified faculty of the Department of Physics. If the research advisor is a tenured or tenure-track member of the faculty, he or she is the chair of the candidate's dissertation committee. If the research advisor is an adjunct or research faculty member, a tenured or tenure-track graduate-certified faculty member must serve as co-advisor and also serve as chair of the dissertation committee. The dissertation committee is composed of five members, a majority of whom must be tenured or tenure-track members of the graduate-certified faculty of the Department of Physics and one of whom must be a tenured or tenure-track faculty member of the graduate-certified faculty in a department of Old Dominion University other than the Department of Physics. It is the responsibility of the research advisor and the candidate to nominate prospective members for the dissertation committee to the graduate program director, who must formally approve the membership of the dissertation committee.

The format of the dissertation is specified by the Guide for Preparation of Theses and Dissertations, and variations allowed within the Department of Physics are specified by the graduate program director.

Dissertation Defense

The final examination that a candidate must pass in order to receive the Ph.D. is an oral examination by the dissertation committee based on the candidate's public presentation of the results contained in his or her dissertation. This defense is conducted in two phases:

1. a public presentation in front of the dissertation committee that is open to any person who may wish to attend and direct relevant questions to the candidate and
2. a closed session between the candidate and the dissertation committee in which the candidate is questioned further by that committee.

The dissertation committee determines by majority vote whether the candidate passes or fails this final oral defense. If the candidate fails, he or she is allowed only one additional attempt to pass at a later time.

Teaching Requirement

Each candidate for the Ph.D. degree must earn a minimum of four teaching credits, which are defined in the following way:

- One such credit is awarded for teaching a one-hour recitation for one semester in the Department of Physics, and
- Two such credits are awarded for teaching a one-semester laboratory course in the Department of Physics.

The graduate program director may approve the substitution of an equivalent amount of teaching experience for this requirement.

PHYSICS Courses

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.
Fundamentals of relativistic particle dynamics including particle acceleration; weak and strong focusing; linear beam optics and particle transfer matrices; linear and non-linear synchrotron motion; introduction to the statistical descriptions of particle beams; 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. The course contains a mandatory recitation section.

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. The course contains a mandatory recitation section. Prerequisites: PHYS 319 and PHYS 323.

PHYS 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. The course contains a mandatory recitation section.

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. The course contains a mandatory recitation section.

PHYS 595. Special Topics in Physics. 1-3 Credits.
In-depth study of a selected topic in physics at the graduate level. May include a laboratory or computational component. Prerequisite: Permission of the instructor.

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.
Continuation of PHYS 601. Basic mathematical methods with applications: integral transforms, ordinary differential equations and partial differential equations. Prerequisite: PHYS 601.

PHYS 603. Classical Mechanics. 3 Credits.
Particle in a central-force field. Dynamics in a rotating reference frame. Lagrangian and Hamiltonian formulations. Small oscillations. Kinematics and dynamics of a rigid body. Canonical transformation, Hamilton-Jacobi theory.

PHYS 604. Classical Electrodynamics I. 3 Credits.
Electrostatics: Gauss' Law and Poisson and Laplace equations. Methods for the solution of boundary-value problems with rectangular, cylindrical, and spherical symmetry. Expansion in multipoles. Dielectrics. Magnetostatics and Faraday's law.

PHYS 621. Quantum Mechanics I. 3 Credits.
Mathematical foundations of Hilbert spaces. Background on Hamiltonian mechanics and electro-magnetism. Postulates of Quantum Mechanics, measurements and Schroedinger equation. Simple systems. Schroedinger Equation in 1-3 dimensions and solutions for specific systems. Symmetries and angular momentum. Time-independent perturbation theory.

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 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.
Review of thermodynamics. Classical statistical mechanics and applications. The virial expansion. Quantum statistical mechanics and the micro-canonical, canonical, and grand-canonical ensembles. The Fermi and Bose gases, and applications. Special topics in statistical mechanics. Prerequisites: PHYS 603.

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.
Further development of quantum mechanics. Multi-particle states, bosons and fermions. Classical Limit. Variational principle, time-dependent perturbation theory and scattering. Path integral formulation. Symmetry and groups, addition of angular moments. Examples from solid state, atomic, nuclear, and particle physics. Prerequisites: PHYS 621.

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 754. Accelerator Physics. 3 Credits.
Overview of the underlying physics of modern particle accelerators. Beam acceleration, coupled and uncoupled beam transport, nonlinear dynamics, collective effects, phase space cooling, and free-electron lasers will be covered. Depending on the instructor, additional topics of current interest such as coherent synchrotron radiation, wakefields and impedances, and novel methods of acceleration will be discussed.

PHYS 759. Classical Mechanics and Electromagnetism in Accelerator Physics. 3 Credits.
Further developments in 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. Louisville's theorem, solutions of Maxwell's equation in cavities and waveguides, wakefields, radiation and retarded potentials, and synchrotron radiation. Prerequisites: PHYS 601, PHYS 603, and PHYS 704 or PHYS 804.

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. Design and Operating Principles of Particle Accelerators. 3 Credits.
This course will introduce design and general operating principles for particle 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) particle beam acceleration 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 patronic 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 795. Special Topics in Physics. 1-3 Credits.
Thorough coverage of areas selected to meet special needs and interests. Prerequisites: Permission of the instructor.

PHYS 797. Research. 1-6 Credits.

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.
Review of thermodynamics. Classical statistical mechanics and applications. The virial expansion. Quantum statistical mechanics and the micro-canonical, canonical, and grand-canonical ensembles. The Fermi and Bose gases, and applications. Special topics in statistical mechanics. Prerequisites: PHYS 603.

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.
Further development of quantum mechanics. Multi-particle states, bosons and fermions. Classical Limit. Variational principle, time-dependent perturbation theory and scattering. Path integral formulation. Symmetry and groups, addition of angular moments. Examples from solid state, atomic, nuclear and particle physics. Prerequisites: PHYS 621.

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 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. Beam acceleration, coupled and uncoupled beam transport, nonlinear dynamics, collective effects, phase space cooling, and free-electron lasers will be covered. Depending on the instructor, additional topics of current interest such as coherent synchrotron radiation, wakefields and impedances, and novel methods of acceleration will be discussed.

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 859. Classical Mechanics and Electromagnetism in Accelerator Physics. 3 Credits.

Further development in 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. Louisville's theorem, solutions of Maxwell's equation in cavities and waveguides, wakefields, radiation and retarded potentials, and 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.

The Yukawa potential in classical and quantum mechanics. One- and two-meson exchange amplitudes. Pion-exchange interactions: one- and two-pion exchange two-nucleon potentials, and two-pion exchange three-nucleon potentials. Electromagnetic interactions. Nucleon-nucleon scattering. Realistic models of two- and three-nucleon potentials. Relativistic corrections to the nuclear Hamiltonian. Electro-weak currents of nucleons and nuclei. Prerequisites: PHYS 621 and either PHYS 721 or PHYS 821.

PHYS 865. Design and Operating Principles of Particle Accelerators. 3 Credits.

This course will introduce design and general operating principles for particle 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) particle beam acceleration 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 patronic 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.