**PHYSICS DEPARTMENT**

**COURSE DESCRIPTIONS FOR GRADUATE STUDENTS**

# FALL 2016 and Spring 2017

**COMPILED BY CORBIN COVAULT**

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**DIRECTOR, GRADUATE PROGRAM, PHYSICS**

**VERSION 1.2**

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***KEY:***

- **@ Course typically taken by most first-year graduate students**
- **# Combined Graduate/Undergraduate Course listing**
- **<A> Counts toward requirement of two "A"-list courses**
- **<B> Counts toward requirement of one "B"-list course**
- **! Course part of STEP/PEP masters degree program**
- *** Status of course uncertain for Spring 2017. Check back later.**

**ALL COURSES COUNT FOR 3 CREDIT HOURS EACH, LETTER-GRADED UNLESS OTHERWISE INDICATED.**

**QUICK SUMARY OF CONTENTS:**

**GRADUATE PHYSICS COURSES OFFERED FALL 2016:**

**@ PHYS 413. Classical and Statistical Mechanics I.** An integrated approach to classical and statistical mechanics. Lagrangian and Hamiltonian formulations, conservation laws, kinematics and dynamics, Poisson brackets, continuous media, derivation of laws of thermodynamics, the development of the partition function. To be followed by PHYS 414. Standard First Year Course. Offered every year, Fall semester. Fall 2016: Instructor: Craig Copi: MWF 2:15PM – 3:05PM Rock 303.

**# PHYS 415. Introduction to Solid State Physics.** Characterization and properties of solids; crystal structure, thermal properties of lattices, quantum statistics, electronic structure of metals and semiconductors. Grad/Undergrad course with PHYS 315, but with extra work required. Offered most years. Fall 2016: Instructor: Jesse Berezovsky: MWF 10:35AM – 11:25AM Rock 306.

**# PHYS 420. Introduction to Biological Physics.** This course explores the intersection of physics and biology: how do fundamental physical laws constrain life processes inside the cell, shaping biological organization and dynamics? We will start at the molecular level, introducing the basic ideas of non-equilibrium statistical physics and thermodynamics required to describe the fluctuating environment of the cell. This allows us to build up a theoretical framework for a variety of elaborate cellular machines: the molecular motors driving cell movement, the chaperones that assist protein folding, the information-processing circuitry of genetic regulatory networks. The emphasis throughout will be on simple, quantitative models that can tackle the inherent randomness and variability of cellular phenomena. We will also examine how to verify these models through the rich toolbox of biophysical experimental and computational technologies. The course should be accessible to students from diverse backgrounds in the physical and life sciences: we will explain both the biological details and develop the necessary mathematical/physical ideas in a self-contained manner. Grad/Undergrad course with PHYS 320, but with extra work required. Offered most years. Fall 2016: Instructor: Michael Hinczewski: MWF 3:20PM – 4:10PM Rock 303.

**GRADUATE PHYSICS COURSES OFFERED FALL 2016 (CONT.)**

**@ PHYS 423. Classical Electromagnetism.** Review of vector calculus, delta function, splitting a second rank tensor in a symmetric and antisymmetric part and its relation to cross-product. Overview of Maxwell equations and boundary conditions. Electrostatics: from Gauss law to Coulomb's law and back, Poisson equation. Uniqueness theorem, Dirichlet and Neumann boundary conditions. Boundary value problems: 2D polar, 3D spherical, 3D cylindrical and rectangular coordinates. Image charges with conducting surfaces and relation to Green's function. Multipole expansions. Electrostatics in continuous media: polarization. Boundary problems with dielectrics. Electrostatic energy and free energy. Magnetostatics: From Ampere to Biot-Savart and back. Vector potential, magnetic dipole moment. Magnetostatics in continuous media. Scalar magnetic potential. Faraday's law. Energy and free energy in magnetostatics. Quasi static fields: combining magnetostatics with Ohm's law, diffusion equation. Full set of Maxwell equations: Maxwell's term. Gauge transformations, general solutions in terms of Green's function, Feynman-Heavyside formulation of fields for a moving point charge. Conservation theorems for energy, momentum and angular momentum, Maxwell stress tensor. Relation between microscopic and macroscopic Maxwell equations. Electromagnetic waves in vacuum. Reflection and refraction. Kramers-Kronig relations. Waves in confined geometry. Waveguide basics Electromagnetic radiation: asymptotic expansion, electric dipole, magnetic dipole and quadrupole radiation. Radiation by a moving point charge. Review of special relativity. Lorentz invariance of Maxwell equations. Lienard-Wiechert potentials and fields for a point charge. Non-relativistic limit. Examples of radiation by rrelativistic moving charges. Standard First-year course. Offered every year, Fall semester. Fall 2016: Instructor: Walter Lambrecht: MWF 10:35AM to 11:25 AM. Rock 304.

**<A> PHYS 428. Cosmology and Structure.** Distances to galaxies. The content of the distant universe. Large scale structure and galaxy clusters. Physical cosmology. Structure and galaxy formation and evolution. Testing cosmological models. Grad/Undergrad course with ASTR 328, but with extra work required. Usually offered every other year. Note that only one of these three courses: PHYS 428, PHYS 436, or PHYS 465 can count toward meeting the requirement of taking two "A"-list classes. Note: This is a graduate course that is administered by the Department of Astronomy. Physics grad students must receive physics departmental approval before enrolling in this course. Fall 2016: Instructor: James Mihos. TuTh 11:30 to 12:45. Sears 552. Contact Astronomy Department for more information.

**<A> PHYS 431. Physics of Nuclear Magnetic Resonance Imaging.** Description of physical principles underlying the spin behavior in MRI and the Bloch equations of spin magnetization. The important topics of imaging reconstruction are introduced, such as Fourier imaging in multi-dimensions,conventional, fast, and chemical-shift imaging techniques, spin echo, gradient echo, and variable flip-angle methods, back-projection and sampling theorems, filtering, T1 and T2 relaxation times, rf penetration, diffusion (with its tensor description) and perfusion. Applications for flow imaging, MR angiography, and functional brain imaging, and methods of sequence design and coil design, especially for parallel imaging, are also discussed. Offered Fall, most years. Fall 2016: Instructor: Bob Brown and Timothy Eagan: Tu 4:00PM to 6:30PM. Rock 306.

**# PHYS 449. Methods of Mathematical Physics I.** Analysis of complex functions: singularities, residues, contour integration; evaluation and approximation of sums and integrals; exact and approximate solution of ordinary differential equations; transform calculus; Sturm-Liouville theory; calculus of variations. Grad/Undergrad course with PHYS 349, but with extra work required. Offered most years in the Fall. Fall 2016: Instructor: Rolfe Petschek and Cladia deRahm: TuTh 10:00AM to 11:15AM. Rock 306.

**<A> PHYS 451. Empirical Foundations of the Standard Model I.** (***Unofficial course title: "Standard Model I")*** In this course we discuss the Standard Model of Particle Physics from the theoretical and experimental perspectives. The gauge theories of the electroweak and strong interactions and their experimental tests are discussed in detail. The properties of quarks, leptons and gauge bosons are discussed together with their experimental discoveries. We discuss the properties of the Higgs mechanism needed to understand the electroweak symmetry breaking and the generation of masses of all elementary particles in nature. ***Prerequisite***: *Eithe*r PHYS 482 (Quantum Mechanics II) *or* PHYS 581 (Quantum Mechanics III) *or* PHYS 591 (Guage Field Theory) *or* permission of the instructor. Some familiarity with quantum field theory and group theory not needed, but could be useful. For more details see https://fileviez.com/ss2016/ **Usually taught alternate years in the Fall.** Fall 2016: Instructor: Pavel Fileviez Perez: TuTh 1:00PM to 2:20PM. Rock 306.

**@ PHYS 481. Quantum Mechanics I.** Basic principles of quantum mechanics; measurement principle and its application; bound and scattering states of one and three dimensional potentials in non-relativistic quantum mechanics; harmonic oscillator; quantum dynamics of free particles, scattering states and two level problems; Feynman path integral; particle in a magnetic field; angular momentum and vector operators; symmetry, conservation laws and degeneracies; approximation methods (time-dependent and time-independent perturbation theory, WKB method, variational principle, adiabatic and abrupt approximation for quantum dynamics); relativistic quantum mechanics (solutions to the Dirac equation and its interpretation); lattice quantum mechanics. Standard First Year Course. Offered during Fall, every year. Fall 2016: Instructor: Kurt Hinterbichler and Andrew Tolley: MWF 11:40AM to 12:30PM. Rock 306.

***STEP/PEP MASTER'S PROGRAM COURSES:***

**! PHYS 491. Modern Physics for Innovation I.** The first half of a two-semester sequence providing an understanding of physics as a basis for successfully launching new high-tech ventures. The course will examine physical limitations to present technologies, and the use of physics to identify potential opportunities for new venture creation. The course will provide experience in using physics for both identification of incremental improvements, and as the basis for alternative technologies. Case studies will be used to illustrate recent commercially successful (and unsuccessful) physics-based venture creation, and will illustrate characteristics for success. Admission to this course requires consent of the instructor. STEP/PEP program course. Offered during Fall, every year. Fall 2017: Instructor: Edward Caner: Thursdays, 6:00PM to 9:00PM. Rock 306.

**! PHYS 493. Feasibility and Technology Analysis.** This course provides the tools scientists need to determine whether a technology is ready for commercialization. These tools include (but are not limited to): financial analysis, market analysis, industry analysis, technology analysis, intellectual property protection, the entrepreneurial process and culture, an introduction to entrepreneurial strategy and new venture financing. Deliverables will include a technology feasibility analysis on a possible application in the student's scientific area. Admission to this course requires consent of the instructor. STEP/PEP program course. Offered during Fall, every year. Fall 2015: Instructor: TBD: Mondays, 6:00PM to 9:00PM.

**GRADUATE PHYSICS COURSES OFFERED SPRING 2017:**

**@ PHYS 414. Classical and Statistical Mechanics II.** A continuation of PHYS 413. Noninteracting systems, statistical mechanics of solids, liquids, gases, fluctuations, irreversible processes, phase transformations. Standard First Year Course. Offered during Spring, every year. Spring 2017: Instructor: Michael Hinczewski: Tentatively MWF 11:40 to 12:30.

**# <A> PHYS 427. Laser Physics.** (formerly "Quantum Electronics"). An introduction to theoretical and practical quantum electronics covering topics in quantum optics, laser physics, and nonlinear optics. Topics to be addressed include the physics of two-level quantum systems including the density matrix formalism, rate equations and semiclassical radiation theory; laser operation including oscillation, gain, resonator optics, transverse and longitudinal modes, Q-switching, mode-locking, and coherence; and nonlinear optics including the nonlinear susceptibility, parametric interactions, stimulated processes and self-action. Offered approximately every other year, usually in the Spring. Grad/Undergrad course with PHYS 327, but with extra work required. Spring 2017: Instructor: Ken Singer. Tentatively TuTh: 10:00 to 11:15.

***#<A> PHYS 436. Modern Cosmology:** An introduction to modern cosmology, and an explanation of current topics in the field. The first half of the course will cover the mathematical and physical basis of cosmology, while the second will delve into current questions and the observations that constrain them. Grad/Undergrad course with PHYS 336, but with extra work required. Note that only one of these three courses: PHYS 428, PHYS 436, or PHYS 465 can count toward meeting the requirement of taking two "A"-list classes. **The status of this course for Spring 2017 is not settled.** Spring 2017: Tentative: Craig Copi, Tentatively TuTh: 10:00 to 11:15

***# PHYS 450. Methods of Mathematical Physics II.** (Continuation of PHYS 449.) Special functions, orthogonal polynomials, partial differential equations, linear operators, group theory, tensors, selected special topics. Prereq: PHYS 449. Grad/Undergrad course with PHYS 350, but with extra work required. Usually offered every other year during Spring semester. Taught occasionally. Last offered Spring 2012. **The status of this course for Spring 2017 is not settled. Either PHYS 450 or PHYS 465 will be taught but probably not both. Please check later in the Fall for final details.** Spring 2017: Tentative instructor for Spring 2017: Either Perez or Mathur.

**<B> PHYS 460. Advanced Topics in Nuclear Magnetic Resonance Imaging (3).** The second semester for the imaging track addresses more advanced levels of the topics in 431. These topics include electromagnetic coil and hardware design, parallel imaging, spectroscopy topics, sequence design and debugging, artifacts, fast imaging, diffusion imaging, blood flow and functional MRI (brain function), rf heating issues, chemical shift studies, and rf pulse design. More discussion of translational and clinical applications of medical imaging. Various spin Hamiltonians relevant to MRI are introduced and studied as time permits. Generally offered in the Spring of most years, instructor provided by EBME department. Spring 2017, Instructor: Xin Yu (EBME) (tentative), W 4:30 PM to 6:30 PM.

**GRADUATE PHYSICS COURSES OFFERED SPRING 2017 (continued):**

***<A> PHYS 465. General Relativity.** This is a first course in general relativity. The techniques of tensor analysis will be developed and used to describe the effects of gravity and Einstein's theory. Consequences of the theory as well as its experimental tests will be discussed. An introduction to cosmology will be given. Prerequisite: consent of the instructor. Grad/undergrad course with PHYS 365. Extra work required. Usually offered most years, Spring semester. Note that only one of these three courses: PHYS 428, PHYS 436, or PHYS 465 can count toward meeting the requirement of taking two “A”-list classes. **The status of this course for Spring 2017 is not settled. Either PHYS 450 or PHYS 465 will be taught but probably not both. Please check later in the Fall for final details.** Spring 2017, Instructor: Tentative: Either Perez or Mathur, Tentatively: MF 3:20PM to 4:35 PM.

**@ PHYS 472. Graduate Physics Laboratory.** A series of projects designed to introduce the student to modern research techniques such as automated data acquisition. Students will be assessed as to their individual needs and a sequence of projects will be established for each individual. Topics may include low temperature phenomena, nuclear gamma ray detection and measurement and optics. Standard First Year Course. Offered during Spring, every year. Note that this is generally a ***required*** course for all graduate students. Students with extensive experimental experience in undergraduate research may petition to have the requirement for PHYS 472 waived. Spring 2017: Instructor: Jesse Berezovsky. MWF 8:30 AM to 11:20 AM.

**@ PHYS 482. Quantum Mechanics II.** Continuation of PHYS 481. Many particle wave-functions for interacting bosons and fermions (with applications to Bose condensates, ground and excited state wave-functions for superfluid helium, Hartree-Fock analysis of the ground state of the electron liquid, the Laughlin 1/3 fractional quantum Hall state, the Kohn-Hohenberg variational principle); creation and annihilation operators for bosons and fermion (applications to the use of canonical transformations in the BCS theory of superconductivity and spin-waves, bosonization of one-dimensional fermions); quantum theory of the scalar field and the electromagnetic field (vacuum fluctuations, spontaneous emission, Casimir effect); dissipative quantum mechanics (density matrices and Bloch equations, Caldeira-Leggett model). Prerequisite: PHYS 481 or consent of instructor. Standard First Year Course. Offered during Spring, every year. Spring 2017: Instructor: Hinterbichler, Tentatively: MWF 2:15 PM to 3:05 PM.

**GRADUATE PHYSICS COURSES OFFERED SPRING 2017 (continued):**

***<B> PHYS 566. Advanced Cosmology.** Advanced topics in General Relativity and Cosmology. We explore the homogeneity and isotropy of the Universe, nucleosynthesis and the cosmic microwave background. We will also establish some of the problems with the standard Hot Big Bang model and check how inflation resolves them. We will then look at predictions of inflation and explore in particular the quantization of fields on curved space-time, which will allow us to understand not only how quantum fluctuations during inflation evolved to become the large scale of the Universe today but also the information loss paradox for Black Holes and the Unruh effect. Prerequisite: PHYS 365 and consent of instructor. Usually offered every two or three years in the Spring. Not offered 2015-2016 academic year. Last taught: Spring 2014: **The status of this course for Spring 2017 is not settled. Either PHYS 566 or PHYS 581 will be taught but probably not both. Please check later in the Fall for final details.** Spring 2017, Instructor: Tentative: Either Perez or Mathur,

*** <B> PHYS 581. Quantum Mechanics III.** (Continuation of PHYS 482). The methods of quantum field theory applied to the nonrelativistic many-body problem, radiation theory, and relativistic particle physics. Second quantization using canonical and path-integration techniques. Constrained systems and gauge theories. Graphical perturbative methods and graph summation approaches. Topological aspects of field theories. Prerequisite: PHYS 482 and consent of instructor. Last taught Fall 2011. **The status of this course for Spring 2017 is not settled. Either PHYS 566 or PHYS 581 will be taught but probably not both. Please check later in the Fall for final details.** Spring 2017, Instructor: Tentative: Either Perez or Mathur,

**GRADUATE PHYSICS COURSES OFFERED SPRING 2017 (continued):**

***STEP/PEP MASTER'S PROGRAM COURSES:***

**! PHYS 492. Modern Physics for Innovation II** Continuation of PHYS 491, with an emphasis on current and prospective opportunities for Physics Entrepreneurship. Longer term opportunities for Physics Entrepreneurship in emerging areas, including (but not be limited to) nanoscale physics and nanotechnology; biophysics and applications to biotechnology; physics-based opportunities in the context of information technology. Prerequisite: PHYS 491. Admission to this course requires consent of the instructor. STEP/PEP program course. Offered during Spring, every year. Spring 2017: Instructor: Edward Caner, Tentative: Tu 6:30 PM to 9:30 PM

**! PHYS 494. Technology-Based Venture Creation.** The primary goal of this course is to provide the tools needed to develop a business plan based on an innovation that has been determined commercially feasible. Additional topics include: advanced entrepreneurial strategy, sales and negotiation, entrepreneurial finance, and leadership in an entrepreneurial environment. Admission to this course requires consent of the instructor. STEP/PEP program course. Offered during Spring, every year. Spring 2017: Instructor: TBD Tentative: M 6:00 PM to 9:00 PM.

**SPECIAL COURSES OFFERED EVERY SEMESTER:**

**PHYS 539. Special Topics Seminar.** "Physics Reading Course". Individual or small group instruction on topics of current interest. Topics include, but are not limited to, particle physics, astrophysics, optics, condensed matter physics, biophysics, imaging. Several such courses may be offered concurrently. Reading courses are offered at the discretion of individual faculty who should submit a topical course outline, reading assignment overview, and grading criteria prior to the start of the semester. Course may be assigned between 1 and 3 credits at the discretion of the instructor. Letter-graded, counts toward university requirement for 24 credits of letter-graded coursework (12 credits if student already has a masters). See important information on PHYS 539 on PSGA web site: http://www.phys.cwru.edu/~pgsa/guide/pgsafiles/phys_539_reading_course_guidelines.pdf

**PHYS 601. Research in Physics.** -- Supervised independent study and research in physics. Counts towards 36 credits of non-dissertation credit required for PhD (18 hours if student already has a masters) . Does not count toward university requirement for 24 credits of letter-graded coursework (12 credits if student already has a masters). Students may take between 1 and 9 credits per semester of PHYS 601, although 3 credits per semester is typical. Students must make arrangements and receive prior approval from their research advisor before signing up for PHYS 601. Students should sign up for Physics 601 only in the case that they do not plan to meet their non-dissertation course requirements with regular letter-graded courses and/or with one or more Reading Courses (PHYS 539). PHYS 601 is Non-letter graded. Grade of P (pass) or NP (no pass) only.

**PHYS 651. Thesis (M.S.).** Supervised independent research conducted toward completion of master's degree thesis. Note that this course is for ***master's degree program students only***, not PhD students. Prior approval from your research advisor is required before signing up for PHYS 651.

**PHYS 666. Department Colloquium Seminar.** Zero Credit course. Pass/Fall based on attendence of weekly department colloquia. All physics department graduate students in residence at CWRU are required to register for PHYS 666. **Thursdays: 4:00 PM to 5:15 PM, Rock 301.**

**PHYS 701. Dissertation (Ph.D.).** Supervised independent research conducted toward completion of PhD dissertation. Students may take between 1 and 9 credits per semester of PHYS 701. Students must make arrangements and receive prior approval from their research advisor before signing up for PHYS 701. Only students who have advanced to PhD Candidacy should sign up for PHYS 701. Total 36 credit hours minimum required for PhD. Non-letter graded. Grade of S (satisfactory) or U (unsatisfactory) only. ***Important: Once you start taking PHYS 701 you must register for at least one credit of PHYS 701 for each subsequent Fall and Spring semester until you graduate with your PhD.***

**COURSES NOT TAUGHT 2016-2017 BUT LIKELY TO BE OFFERED IN FUTURE YEARS:**

**# PHYS 426.** Contemporary Physical Optics. Geometrical optics and ray tracing, wave propagation, interaction of electromagnetic radiation with matter, interference, diffraction, and coherence. Supplementary current topics from modern optics such as nonlinear optics, holography, optical trapping and optical computing. Grad/Undergrad course with PHYS 326, but with extra work required. Usually offered every year during the Spring semester. Last offered: Spring 2016: Instructor: Cory Christenson. Likely offered Spring 2018.

**<A> PHYS 441. Physics of Condensed Matter I.** *Structure of condensed matter:* Crystal structure, diffraction techniques, scattering from a periodic structure, reciprocal lattice, non-crystalline structures, various forms of disorder (alloys, quasicrystals, liquid crystals, glasses and liquids), description of symmetry using pointgroups and spacegroups. Structure of surfaces. Grain boundaries. Crystal growth. *Electronic states in crystals:* Free electrons statistical mechanics: Sommerfeld theory. Bloch's theorem, periodic boundary conditions, density of states. Nearly free electron approximation. Tight-binding and linear combination of atomic orbitals approximation. Application to real solids: Si, graphene, simple metals. Band structure methods: pseudo potentials, multiple scattering, linear methods. *Group theory:* irreducible representations, symmetry labeling of energy bands and energy levels in molecules Measuring energy bands using photoemission and optical interband transitions. *Justification of the independent electron approximation:* Hartree-Fock and density functional theory, electron-electron interactions in the electron gas, Fermi-liquid theory, quasiparticles, GW approximation. *Mechanical properties:* Cohesive energy, bulk modulus, elastic constants, dislocations and plasticity of metals. Types of bonding and relation to crystal structures. Ionic bonding, Ewald summation technique, metallic bonding, vander Waals bonding, covalent bonding. Interpreting band structure and density functional theory in relation to bonding. Lattice dynamics. Normal modes in crystals, quantum mechanical treatment of phonons, statistical properties related to phonons, continuum theory of acoustic waves, inelastic scattering, calculating force constants via density functional perturbation theory, phonons in ionic materials, longitudinal transverse splittings. Measuring phonons via infrared and Raman spectroscopy. *Electronic structure of defects in solids:* effective mass approximation, Green function method. Experimental approaches to measure defects. Surface electronic structure, work function. Usually offered every other year. Last Offered: Fall 2015: Instructor: Walter Lambrecht. Not offered 2016-2017. Likely offered Fall 2017.

**COURSES NOT TAUGHT 2016-2017 BUT LIKELY TO BE OFFERED IN FUTURE YEARS (Continued):**

**<B> PHYS 442. Physics of Condensed Matter II.** (Continuation of PHYS 441.) *Electron dynamics.* Derivation of the Semiclassical equations including Berry phase terms, motion in electric and magnetic fields. Landau diamagnetism, Shubnikov de Haas oscillations and Fermi surfaces, cyclotron resonance, Hall effect, anomalous Hall effect, spin Hall effect, quantized Hall effect. Transport theory: charge and heat transport, thermoelectric effects, Onsager relations, magneto transport properties, spin injection. Drude theory, Boltzmann equation. Various scattering processes in semiconductors and metals: electron-phonon coupling, impurity scattering. Transport in nanoscale systems: Landauer-Buttiker theory, quantum point contacts. Semiconductor carrier statistics, diffusion equation, pn-nunction, heterojunctions. *Optical properties:* general features: Kramers-Kronig relations, Kubo-Greenwood formulation of dielectric function, dielectric screening and the electron-electron interaction, Lindhard dielectric function, plasmons, excitons. Dielectric properties: The modern theory of polarization in terms of Berry phases, piezo, pyro and ferroelectricity. Multiferroics. Magnetism. Continuum theory: free energy of magnetization. *Origin of magnetic moments in atoms:* Hund's rules, diamagnetism, paramagnetism. Magnetic ordering: ferromagnetism and antiferromagnetism. Mean field approximation, Landau theory. Ising model and critical phenomena. Magnetic domains. *Magnetic exchange interactions:* origin of magnetic coupling in electron-electron interaction, Heitler-London, Heisenberg model, Stoner theory, Hubbard model, band structure and (non-collinear) spin-density functional theory point of view. *Superconductivity:* basic phenomenology, Landau-Ginzburg equations, Josephson effect, electron-phonon coupling, Cooper pairs, BCS theory. Usually offered every other year. Last Offered: Spring 2016: Instructor: Walter Lambrecht. Not offered 2016-2017. Likely offered Spring 2018.

**<B> PHYS 591. Gauge Field Theory I.** Noether's Theorem, symmetries and conserved currents, path integral techniques, quantization, Feynman rules, anomalies, QED, electroweak interactions, QCD, standard model, renormalization, renormalization group, asymptotic freedom, conformal field theories, effective field theories. Prerequisite: consent of instructor. Offered occasionally, every other year or so. Last Offered: Fall 2015: Instructor: Crescimanno. Last Offered: Not offered 2016-2017. May be offered Fall 2017 or Spring of 2018.

**COURSES WHICH HAVE NOT BEEN TAUGHT IN RECENT YEARS AND/OR COURSE WITH UNCLEAR FUTURE STATUS WITHIN THE DEPARTMENT.**

*These courses have not been taught in the recent past. Although they are still "on the books" there are no immediate plans to teach these courses in the near future. Some of these courses are under review and make be replaced with other course listings in the future. Please contact your advisor and/or the graduate program director if you are interested in taking/offering any of these courses.*

**PHYS 438. Introduction to Surface Science.** Geometric, chemical, and electronic structure of surfaces and interfaces between solid, liquid, and gas, contrasting surface properties with those of the bulk. Surface and interface thermodynamics, surface energy and surface tension in liquid and solid systems, surface shape effects, two-dimensional lattice, adsorption phenomena, the interactions of electrons, ions, and photons with a surface, and experimental techniques in surface science. Prerequisite: PHYS 315, CHEM 335, or consent of instructor. **This course has not been taught in recent history.**

**PHYS 447. Physics of Liquid Crystals.** **This course has not been taught in recent history, but may be taught in future years.**

**<B> PHYS 452.** Empirical Foundations of the Standard Model II. (Continuation of PHYS 451). Tests of the predictions of the broken SU(2) x U(1) gauge-symmetric model of the electroweak interactions and the color-SU(3) model of the strong interactions. Structure of the weak currents, the quark mixing matrix, and the gauge-boson couplings. Exploration of the Higgs sector and the coupling of the Higgs to quarks and leptons. Heavy-quark physics. Calculation of hadronic processes using partonic distribution functions. CP violation, neutrino masses, fermion nonconservation, and possible extensions of the Standard Model. Prerequisite: PHYS 451 or consent of instructor. **This course has not been taught in recent history. The physics department is considering the future status of this course.**

**<B> PHYS 522. Nonlinear Optics.** Classical phenomenology and Maxwell's equations in media; Maxwell-Bloch equations. Theory of nonlinear wave interactions and propagation. Properties of optical fibers and nonlinear materials. Theory of nonlinear propagation, solitons, inverse scattering transforms, optical chaos. Applications to lasers, optical bistability, self-induced transparency, and stimulated light scattering. Prerequisites: PHYS 423 and PHYS 481. **This course has not been taught in recent history.**

**<B> PHYS 541. Quantum Theory of the Solid State.** Elementary excitations in solids, including lattice vibrations, spin waves, helicons, and polarons. Quasiparticles and collective coordinates. BCS theory of superconductivity. Quasicrystals. Transport properties. Conduction electrons in magnetic fields and the quantum Hall effect. Green function methods of many-body systems. Prerequisite: PHYS 482 and consent of instructor. **This course has not been taught in recent history.**

**PHYS 542. Quantum Theory of the Solid State II.** Continuation of PHYS 541. Prerequisite: PHYS 541 and consent of instructor. **This course has not been taught in recent history.**

**<B> PHYS 544. Advanced Theory of Materials.** Density functional theory: successes and limitations. Electronic structure and total energy calculation methods. Simulations of structure of solids, molecular dynamics. Experimental probes: particle-solid interactions. Applications to various classes of materials: metals and their alloys, semiconductors, narrow band systems. Defective solids: point defects, surfaces and interfaces; and artificially structured materials: Prerequisite: PHYS 442 or consent of instructor. **This course has not been taught in recent history.**

**COURSES NOT TAUGHT IN RECENT HISTORY (Continued):**

**PHYS 545. Advanced Topics in the Physics of Many Particle Systems I.** The matter field; Hartree-Fock approximation; equations of motion for elementary excitations. Ground-state Green functions; spectral representation; perturbation expansion for Green functions; Dyson equation; density-fluctuation propagators and linear response functions. Applications to plasmas, normal Fermi liquids, spin systems, superfluid Bose systems, and superconductors. Prerequisite: PHYS 482 and consent of instructor. **This course has not been taught in recent history.**

**PHYS 546. Advanced Topics in the Physics of Many Particle Systems II.** See PHYS 545. Prerequisite: PHYS 545 and consent of instructor. **This course has not been taught in recent history.**

**PHYS 551. Theoretical Nuclear Physics I.** Physical properties of the nucleus, nuclear structure and nuclear models, nuclear scattering, and nuclear transformations from a theoretical viewpoint. Prerequisite: PHYS 482 and consent of instructor. **This course has not been taught in recent history.**

**PHYS 552. Theoretical Nuclear Physics II.** See PHYS 551. Prerequisite: PHYS 551 and consent of instructor. **This course has not been taught in recent history.**

**PHYS 565. Advanced General Theory of Relativity.** Review of special relativity, principle of equivalence, tensor analysis. Einstein field equations, tests of general relativity, post-Newtonian method, gravitational radiation, relativistic astrophysics, symmetries of space-time. Prerequisite: Consent of instructor. **This course has not been taught in recent history.**

**PHYS 579. Special Topics Seminar.** In-depth examination of a cutting-edge topic of current interest. New topic is selected each semester. **This course has not been taught in recent history.**

**<B> PHYS 592. Gauge Field Theory II.** Electroweak theory; spontaneous symmetry breaking; renormalization group. Strong interactions; grand unified theories and theories beyond the Standard Model. PHYS 592 will explore in depth the field theoretic basis of the Standard Model of particle physics and some of its most important extensions. Prerequisite: consent of instructor. No immediate plans to offer this course since many of these topics are now included in Quantum Mechanics III (PHYS 581). **This course has not been taught in recent history. The physics department is considering the future status of this course.**