PHYSICS and ASTRONOMY

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Professors

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Giovanni Bonvicini, Sean Gavin, Robert Harr, Peter M. Hoffmann, Gavin Lawes, Ashis Mukhopadhyay, Boris E. Nadgorny, Karur R. Padmanabhan, Alexey A. Petrov

Assistant Professors
Zhi-Feng Huang, Steven Rehse, Takeshi Sakamoto, Zhixian Zhou

Senior Lecturers
Jeffery Conn, Punya Talagala

Adjunct Faculty
Gregory W. Auner, Ivan Avrutsky, Elizabeth Buc, Xiaoyan Han, Vaman Naik, Prem Vaishnava

GRADUATE DEGREES

MASTER OF ARTS with a major in Physics
MASTER OF SCIENCE with a major in Physics
DOCTOR OF PHILOSOPHY with a major in Physics

Physics is the science that describes the behavior of the physical world. It is the most basic of all sciences and as such is responsible for the interpretation of fundamental physical processes which support many other scientific disciplines.

The degree programs of this department are designed to provide students with the broad-based knowledge and problem-solving skills that are needed in order to be productive physicists in an academic, government, or industrial environment. The programs can accommo-
date students with varying undergraduate backgrounds and are designed to provide maximum flexibility for individual students. At the doctoral level, specializations are offered in the areas of: elementary particle physics, nuclear physics, condensed matter physics, atomic physics, materials science, optics, mathematical physics, quantum field theory, and applied physics. Faculty members are committed to excellence in research and teaching, and work in an open and informal atmosphere which allows effective communication between students and advisers. The faculty hold national and international reputations in their areas of specialization. They organize and participate in conferences, publish extensively, and receive numerous outside grants, contracts and fellowships. In addition, they engage in many collaborations with scientists in both foreign and American universities and national laboratories. The department is housed in a modern physics building containing well-equipped research laboratories.

**MASTER’S DEGREE WITH A MAJOR IN PHYSICS**

For some students, the master’s degree will be used as part of a continuing Ph.D. program; for others, it will be a terminal degree leading to employment in government laboratories, industrial programs, hospitals, teaching positions, and other occupations. The Master of Science with a Major in Physics is offered under Plan A, and the Master of Arts with a Major in Physics is offered under Plan B, as described below.

**Admission** to this program is contingent upon admission to the Graduate School. (See Graduate School Admissions for requirements). In addition, applicants must satisfy the following criteria:

Prerequisite preparation should include a minimum of general college physics with laboratory (equivalent to Physics 2170, 2180, and 3300), fifteen credits in the intermediate physics courses (for example, those equivalent to Physics 5200, 5210, 5340, 5500, 6400, 6410, 6600, 6610, 6850); mathematics through Mathematics 5070; and Chemistry 1220/1230 or equivalent courses.

The Graduate Record Examination, both the General section and the Physics subject test, is strongly recommended as a counseling aid in preparing the student’s plan of study.

**Scholarship:** All course work must be completed in accordance with the academic procedures of the College of Liberal Arts and Sciences and the Graduate School governing graduate scholarship and degrees.

**MASTER OF SCIENCE REQUIREMENTS**

The Master of Science degree is offered by this Department only under the following option:

**Plan A:** Twenty-four credits in course work plus an eight-credit thesis.

Specific requirements include the following:

1. At either the graduate or undergraduate level, Physics 5210, 5500 6400, 6410, 6600, 6610 , or equivalent courses, and mathematics through MAT 5070 or an equivalent course.
2. At least nine credits of coursework in physics at the 7000 level or above (exclusive of Physics 7990, 7996, 7999, 8995, 8999).

3. A departmental final oral examination is required of all candidates.

MASTER OF ARTS REQUIREMENTS
The Master of Arts degree is offered by this Department only under the following option:

**Plan B:** Twenty-nine credits in course work plus a three-credit essay.

*Course requirements are the same as requirements (1) through (3) in the Master of Science program above.*

DOCTOR OF PHILOSOPHY WITH A MAJOR IN PHYSICS
**Admission Requirements:** see above, under ‘Master’s Degree With a Major in Physics.’

**DEGREE REQUIREMENTS:** Candidates for the doctoral degree must complete ninety credits beyond the baccalaureate, including thirty credits of dissertation research. The thirty credit dissertation registration requirement is fulfilled by registering for the courses 9991, 9992, 9993, and 9994 (Doctoral Dissertation Research and Direction I, II, III, and IV, respectively), in consecutive academic year semesters. Students must demonstrate proficiency in the fields of:

(a) Mechanics
(b) Electromagnetic Theory
(c) Quantum Physics
(d) Thermodynamics and Statistical Mechanics

The following courses or their equivalent will be required of all candidates: Physics 7110, 7200, 7400, 7410, 7500, 7600.

In general, it is recommended that students take all the advanced courses in their specialty. Students specializing in any branch of theoretical physics are encouraged to take the quantum theory of fields, or a related directed study. Finally, the student must submit an approved dissertation.

On petition of the student and his/her thesis adviser, the Departmental Graduate Committee may waive any of the above course requirements.

**Ph.D. Qualifying Examination:** This will normally be taken after the student has completed approximately one year of graduate course work. Its purpose is to investigate the student’s knowledge of physics and capacity for creative thought. This is a written examination. The student must submit a *Plan of Work* prior to taking this examination.

**Scholarship:** All course work must be completed in accordance with the regulations of the Graduate School and the College governing graduate scholarship and degrees.

**Physics Colloquium (PHY 8995):** It is required that all full-time graduate students register for and attend the Departmental Physics Colloquium each semester they are in residence.
Financial Aid

*General sources of financial aid for graduate students may be found in the section on Graduate Financial Assistance.*

Graduate teaching assistant appointments are available to qualified entering and continuing graduate students. A graduate course load of approximately eight credits per semester is usual with such an appointment. Normally about eight to ten contact hours of quiz (recitation) sections or laboratory instruction sessions per week are arranged. Graduate teaching assistants also spend time at the Physics Resource Center assisting undergraduate students.

Graduate research assistant appointments, involving no teaching duties, are also available to qualified students. Stipends for these appointments are comparable to the teaching appointment stipends. Research undertaken while holding such an appointment may form the basis of the master’s or doctoral thesis.

In addition, various government fellowships, University fellowships, and Knoller Physics Fellowships are available within the Department. Students applying for either teaching or research appointments are automatically considered for these grants. Application blanks and specific information concerning the above appointments may be obtained by writing the Chairperson.

**COURSES OF INSTRUCTION**

The following courses, numbered 5000-9999, are offered for graduate credit. Courses numbered 5000-6999 which are also offered for undergraduate credit may be found in the undergraduate bulletin, along with all other undergraduate courses (numbered 0900-4999). Courses in the following list numbered 5000-6999 may be taken for undergraduate credit unless specifically restricted to graduate students as indicated by individual course limitations.

*All courses with a laboratory have a non-refundable materials fee and are so indicated in the Schedule of Classes.*

**ASTRONOMY (AST)**

**5010 (AST 5010) Astrophysics and Stellar Astronomy. (PHY 5010)** Cr. 3 (LCT: 3)
Prereq: PHY 2140 or PHY 2180, MAT 2010, or consent of instructor. Electromagnetic radiation and matter; solar characteristics; stellar distances; magnitudes; spectral classification; celestial mechanics; binary stars; stellar motions, structure and evolution; compact and variable stars; Milky Way Galaxy and interstellar medium; galaxies and clusters of galaxies; quasars; Hubble's Law; cosmology. (B:W)

**6180 (PHY 6180) Astronomy and Planetary Geology for Secondary-School Educators.** Cr. 3-4
Open only to middle- or high school teachers. Prereq: PHY 2130, 2140. Material fee applies when taken for four credits (optional laboratory). Quantitative description of constituents of solar system. Required math: algebra and trigonometry. Material Fee As Indicated In The Schedule of Classes (B:F)
5010 (AST 5010) Astrophysics and Stellar Astronomy. Cr. 3
Prereq: PHY 2140 or 2180, MAT 2010 or consent of instructor. Electromagnetic radiation and matter; solar characteristics; stellar distances; magnitudes; spectral classification; celestial mechanics; binary stars; stellar motions, structure and evolution; compact and variable stars; Milky Way Galaxy and interstellar medium; galaxies and clusters of galaxies; quasars; Hubble's Law; cosmology. (B:W)

5030 Plasma Physics. Cr. 3
Prereq: PHY 6600, or 2180 and consent of instructor and MAT 2020. Introduction to plasma physics for students in science and engineering. Motion of charged particles in electromagnetic fields; magnetoionic theory including electron conductivity and mobility; wave propagation in a plasma; plasma kinetic theory with emphasis on Boltzmann, Vlasov and Fokker-Planck equations; plasma sheaths. (B:W)

5100 Methods of Theoretical Physics I. Cr. 3
Prereq: PHY 2180, MAT 2030. Introduction to mathematical tools used in advanced courses in physics. (F)

5200 (WI) Classical Mechanics I. Cr. 3
Prereq: PHY 2180, PHY 5100. Introduction to fundamental ideas: Newton's laws, notions of momentum, angular momentum, kinetic and potential energy, mechanical energy, conservation laws, motion in 1- and 3-D, friction and retardation forces, oscillations, resonances, and gravitation. (F)

5210 Classical Mechanics II. Cr. 3
Prereq: PHY 5200 and MAT 2350. Accelerated reference frames, centrifugal and Coriolis forces, rigid body dynamics, motion of tops and gyroscopes, Lagrange's equations, constraints, Lagrange multipliers, general central force problem, stability of orbits, relativistic mechanics. (W)

5340 Optics. Cr. 3
Prereq: PHY 2140 or PHY 2180, MAT 2030; coreq. for PHY majors: PHY 5341. Electromagnetic radiation; geometrical, physical, and modern optics. (F)

5341 Optics Laboratory. Cr. 2
Prereq. or coreq: PHY 5340 or ECE 5760. Experiments involving geometrical, physical, and quantum optics. Material Fee As Indicated In The Schedule of Classes (F)

5500 Thermal Physics. Cr. 4
Prereq: PHY 3300, PHY 5100. Notions of temperature, equation of state, internal energy, the three Laws of Thermodynamics, Carnot's theory, entropy, thermodynamic potentials, kinetic theory, partition function, heat capacity of solids, thermodynamics of radiation, Fermi-Dirac gases. (F)
5620  Electronics and Electrical Measurements.  Cr. 5
Prereq: PHY 2180 or 2140 or consent of instructor. Amplifier circuits, operational amplifiers, oscillators, digital electronics, analog and digital measurements. Material Fee As Indicated In The Schedule of Classes (W)

5990  Directed Study.  Cr. 1-3
Prereq: junior standing and consent of adviser and instructor. Primarily for students who wish to continue in a field beyond material covered in regular courses, or who wish to study material not covered in regular courses, including certain research participation.  (T)

6050  Special Topics in Physics for Secondary-School Educators.  Cr. 3
Prereq: introductory physics courses in mechanics, and in electricity and magnetism; or consent of instructor. Open only to pre-college or community college teachers. Special topics in physics designed for secondary teachers. Topics offered as needed; may include: astronomy and cosmology, meteorology, relativity, quantum theory, atomic and nuclear physics, optics.  (Y)

6100  Classical Physics for Secondary School Educators.  Cr. 3
Open only to middle- or high school teachers. Prereq: PHY 2130, 2140. Mechanics, electricity, magnetism: fundamentals. Applications to problem solving. Selected special topics. Required math: algebra and trigonometry.  (B:F)

6120  Energy Generation and Consumption for Secondary-School Educators.  Cr. 3-4
Open only to middle- or high school teachers. Prereq: PHY 2130, 2140. Material fee applies when elected for four credits (optional laboratory). Different sources of energy and how their use impacts the environment. Required math: algebra and trigonometry. Material Fee As Indicated In The Schedule of Classes  (B:W)

6160  Meteorology for Secondary-School Educators.  Cr. 3-4
Open only to middle- or high school teachers. Prereq: PHY 2130, 2140. Material fee applies when elected for four credits (optional laboratory). Earth’s atmosphere and various weather processes. Required math: algebra and trigonometry. Material Fee As Indicated In The Schedule of Classes  (S)

6180 (PHY 6180) Astronomy and Planetary Geology for Secondary-School Educators. (AST 6180) Cr. 3-4
Open only to middle- or high school teachers. Prereq: PHY 2130, 2140. Material fee applies when taken for four credits (optional laboratory). Quantitative description of constituents of solar system. Required math: algebra and trigonometry. Material Fee As Indicated In The Schedule of Classes  (B:F)

6350  Applied Modern Optics.  Cr. 3
Prereq: PHY 5340. Coherent radiation, laser physics and optical devices, optical techniques in experimental science, topics in modern optics.  (B:W)
6400 Quantum Physics I. Cr. 3
Prereq: PHY 3300, PHY 5100, MAT 2150. Operators and their eigenfunctions, quantization rules, solution of Schroedinger equation in 1- and 3-D, the hydrogen atom, angular momentum, spin, boson, fermions, Time-independent perturbation theory. (W)

6410 Quantum Physics II. Cr. 3
Prereq: PHY 6400 or consent of instructor. Applications of quantum mechanics: atoms in electric and magnetic fields, multielectron atoms, molecules, quantum statistics, solids (band structure, magnetic properties), nuclei, fundamental forces and standard model. (F)

6450 Introduction to Material and Device Characterizations. Cr. 4
Coreq: PHY 7050 or ECE 5500 or ECE 5550 or equiv. Lecture/laboratory; introduction to analytic and measurement techniques for characterizing and evaluating materials, especially for potential applicability in sensor and integrated devices. Techniques include diffraction and microscopy methods, electron spectroscopies, and electrical, optical and magnetic measurements. (W)

6570 (ECE 6570) Smart Sensor Technology I: Design. (BME 6470) Cr. 4
Prereq: B.S. degree in engineering or science. Introduction to various types of sensors and the design of basic analog VLSI circuit building blocks. (F)

6600 Electromagnetic Fields I. Cr. 3
Prereq: PHY 5100, PHY 5200, MAT 2150, or consent of instructor. Topics include electrostatics, solution of Laplace equation, dielectric media, electric current, magnetic field of steady currents, magnetic properties of matter, electromagnetic induction. (W)

6610 Electromagnetic Fields II. Cr. 3
Prereq: PHY 6600 or consent of instructor. Continuation of PHY 6600: Maxwell equations, electromagnetism and relativity, optics, wave guides and transmission lines, radiation of EM waves. (W)

6850 (WI) Modern Physics Laboratory. Cr. 2
Prereq: PHY 3300 or consent of instructor. Techniques and experiments in physics of atoms, atomic nuclei, molecules, the solid state and other areas that have advanced our modern understanding of physics. Material Fee As Indicated In The Schedule of Classes (W)

6860 Computational Physics. Cr. 3
Introduction to computational languages and local computational environment; description of techniques in numerical analysis including linear algebra, integration, algebraic and differential equations, data analysis and symbolic algebra; optimization and parallel computing. (B:W)

6991 Special Topics. Cr. 1-4 (Max. 4)
Prereq: consent of instructor. Offered for S and U grades only. Topics and prerequisites for each section to be announced in Schedule of Classes. More than one section may be elected in a semester. (Y)

6992 Physics Graduate Teaching Assistant Training. Cr. 1
Prereq: graduate standing or consent of instructor. Offered for S and U grades only. Students solve and discuss problems from calculus-based general physics courses in front of their peers
and instructor, enhancing their ability to analyze, interpret and present the material in a clear, informative way. (F)

**7010 (PHY 5015) Modern Physics for Secondary-School Educators. Cr. 3-4**
Open only to middle- or high school teachers. Prereq: PHY 2130, 2140. Material fee applies when elected for four credits (optional laboratory). Development of relativity and quantum mechanics. Emphasis on nuclear physics and elementary particles. Required math: algebra and trigonometry. Material Fee As Indicated In The Schedule of Classes (F,S)

**7050 Elementary Solid State Physics. Cr. 3**
Prereq: PHY 6400 or equiv. Contemporary solid state physics dealing primarily with experiments in this area and with modern descriptive models of solids. (F)

**7060 Survey of Elementary Particle Physics. Cr. 3**
Prereq: PHY 6400 or equiv. Fundamental interactions and the basic particles; introduction to quantum mechanical treatment of decay, scattering, spin, internal symmetries; introduction to quantum field theory; gauge theories; the standard model and proposed modifications; experimental evidence; survey of experimental methods, detector, accelerators and colliders. (W)

**7070 Survey of Nuclear Physics. Cr. 3**
Prereq: PHY 6400 or equiv. Survey of nuclear decay, nuclear structures, nuclear interactions and reactions, nuclear models, conservative laws and subnuclear particles. (F)

**7110 Methods of Theoretical Physics II. Cr. 3**
Prereq: PHY 5100 or equiv. Continuation of PHY 5100. (W)

**7200 Advanced Mechanics. Cr. 4**
Prereq: PHY 5210 or consent of instructor. Variational principles, central forces, transformation theory, Hamilton-Jacobi theory. (W)

**7215 (PSL 7215) Nanobioscience. (CHE 7215) (CHM 7215) Cr. 3**
Prereq: first year calculus, general chemistry. Introduction to interdisciplinary research field of nanobioscience, at the interphase of biology, chemistry, and physics; specific properties of nanoscale objects. (F)

**7400 Quantum Mechanics I. Cr. 3**
Prereq: PHY 7200 or consent of instructor; coreq: PHY 5100 or equiv. Schrodinger wave equation, its meaning and solutions as applied to simple physical and chemical problems. Perturbation theory. Theory of atomic collisions, matrix mechanics, transformation theory, angular momentum and spin, theory of measurement. (F)

**7410 Quantum Mechanics II. Cr. 3**
Prereq: PHY 7400. Continuation of PHY 7400. (W)

**7500 Statistical Mechanics. Cr. 4**
Prereq: PHY 5500, 7400 or consent of instructor. Classical and quantum statistical mechanics and applications. (B:F)
7550 Solid State Physics I. Cr. 3
Prereq: PHY 7400 or consent of instructor. Crystal structure, elastic constants, introduction to
band theory, semiconductors, magnetic properties of materials, optical properties of solids. (B:F)

7560 Solid State Physics II. Cr. 3
Prereq: PHY 7550. Continuation of PHY 7550. (B:W)

7580 (ECE 7570) Smart Sensor Technology II: Characterization and Fabrication. (BME 7470) Cr. 4
Prereq: PHY 6570 or ECE 6570. The fabrication process; characterization of sensors; design of
associated analog VLSI circuit. (W)

7600 Electromagnetic Theory I. Cr. 3
Prereq: PHY 6610 or consent of instructor. Microscopic and macroscopic Maxwell's equations,
special relativity, Lagrangian and Hamiltonian formulation of EM theory, energy-momentum
tensor, conservation laws, radiation, scattering, applications. (B:F)

7610 Electromagnetic Theory II. Cr. 3
Prereq: PHY 7600. Continuation of PHY 7600. (B:W)

7990 Directed Study. Cr. 1-3 (Max. 6)
Prereq: consent of adviser, instructor, chairperson of graduate studies committee and graduate
officer must be obtained prior to registration. Application forms available in department office.
Primarily for graduate students in physics who wish to study material not covered in regular
courses. (T)

7996 Research in Physics. Cr. 1-4 (Max. 12)
Prereq: consent of adviser and chairperson of graduate studies committee. (T)

7999 Master's Essay Direction. Cr. 1-3 (3 req.)
Prereq: consent of adviser. (T)

8570 (ECE 8570) Smart Sensor Technology Seminar. (BME 8470) Cr. 1
Prereq: ECE 6570, 7570. Technological advances. Interaction of research experience in smart
sensors and integrated devices. (W)

8800 Nuclear Physics. Cr. 3
Prereq: PHY 7070, 7110, and 7410. Research topics in nuclear physics such as: relativistic heavy
ion physics, nuclear/nucleon models, and many body theory. Covers both theory and
experimental methods. (B:W)

8810 Particle Physics. Cr. 3
Prereq: PHY 7060, 7110, and 7410. Advanced elementary particle physics including weak,
electromagnetic, and strong interactions. Rudiments of experimental devices and techniques
at level appropriate to both experimentally- and theoretically-oriented students. (B:F)

8850 Quantum Theory of Fields I. Cr. 3
Prereq: PHY 7110, 7410. Introduction to quantum field theory with quantum electrodynamics.
Renormalization, regularization, Feynman diagrams, applications to scattering processes and
bound states. Suitable for both students of theory and experiment in the fields of nuclear, particle, and solid state physics. (B:F)

8860 Quantum Theory of Fields II. Cr. 3
Prereq: PHY 8850. Continuation of quantum field theory. Advanced topics; development of strong, electroweak, and gravitational interactions; other topics. Appropriate for students in fields of nuclear, particle, or solid state physics. (B:W)

8991 Special Topics. Cr. 1-3 (Max. 12)
Prereq: consent of instructor, adviser and chairperson of graduate studies committee. Offered for S and U grades only. Topics and prerequisites for each section to be announced in Schedule of Classes. More than one topic may be elected in a semester. (F,W)

8995 Colloquium. Cr. 1
Offered for S and U grades only. Must be elected every semester by all graduate physics students. Lectures given by visitors, graduate staff and advanced graduate students. (F,W)

8999 Master's Thesis Research and Direction. Cr. 1-8 (8 req.)
Prereq: consent of adviser. (T)

9990 Pre-Doctoral Candidacy Research. Cr. 1-8 (Max. 10)
Prereq: consent of department. For Ph.D. program applicants. Offered for S and U grades only. Research in preparation for doctoral dissertation. (T)

9991 Doctoral Candidate Status I: Dissertation Research and Direction. Cr. 7.5
Prereq: consent of dissertation adviser; Ph.D. candidate in department. Required in academic-year semester following advancement to Ph.D. candidacy. Offered for S and U grades only. (T)

9992 Doctoral Candidate Status II: Dissertation Research and Direction. Cr. 7.5
Prereq: consent of dissertation adviser; PHY 9991. Required in academic-year semester following 9991. Offered for S and U grades only. (T)

9993 Doctoral Candidate Status III: Dissertation Research and Direction. Cr. 7.5
Prereq: consent of dissertation adviser; PHY 9992. Required in academic-year semester following 9992. Offered for S and U grades only. (T)

9994 Doctoral Candidate Status IV: Dissertation Research and Direction. Cr. 7.5
Prereq: consent of dissertation adviser; PHY 9993. Required in academic-year semester following 9993. Offered for S and U grades only. (T)

9995 Candidate Maintenance Status: Doctoral Dissertation Research and Direction.
Cr. 0
Prereq: consent of dissertation adviser; completion of 30 credits in PHY 9999, or 9991-9994. Offered for S and U grades only. (T)

9999 Doctoral Dissertation Research and Direction. Cr. 1-16
Prereq: consent of doctoral adviser. Offered for S and U grades only. (T)
**Course Symbols and Abbreviations:**

(B) – Offered every other year
(F) – Offered Fall Term
(I) – Offered irregularly
(S) – Offered Spring/Summer Term
(T) – Offered every term
(W) – Offered Winter Term
(Y) – Offered at least once every academic year (Fall or Winter, not Spring/Summer)