# Physics

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## COLLEGE OF SCIENCE

### Graduate Faculty:

**Ali, Naushad,** Professor and *Chair,* Ph.D., University of Alberta, Canada, 1984; 1986.
**Byrd, Mark,** Professor, Ph.D., University of Texas at Austin, 1999; 2003.
**Chitambar, Eric,** Assistant Professor, Ph.D., University of Michigan, Ann Arbor, 2010; 2012.
**Cutnell, John D.,** Professor, *Emeritus,* Ph.D., University of Wisconsin, 1967; 1968.
**Gruber, Bruno J.,** Professor, *Emeritus,* Ph.D., University of Vienna, Austria, 1961; 1972.
**Henneberger, Walter C.,** Professor, *Emeritus,* Ph.D., Gottingen University, Germany, 1959; 1963.
**Jayasekera, Thushari,** Assistant Professor, Ph.D., University of Oklahoma,. 2005; 2011.
**Johnson, Kenneth W.,** Professor, *Emeritus,* Ph.D., Ohio State University, 1967; 1970.
**Malhotra, Vivak,** Professor, *Emeritus,* Ph.D., Kanpur University, India, 1978; 1984.
**Masden, J. Thomas,** Associate Professor, *Emeritus,* Ph.D., Purdue University, 1983; 1984.
**Mazumdar, Dipanjan,** Assistant Professor, Ph.D., Brown University, 2008; 2014.
**Migone, Aldo D.,** Professor, Ph.D., Pennsylvania State University, 1984; 1986.
**Poopalasingam Sivakumar,** Assistant Professor, Ph.D., University of Oklahoma, 2009; 2015.
**Sanders, Frank C., Jr.,** Associate Professor, *Emeritus,* Ph.D., University of Texas, 1968; 1969.
**Saporoschenko, Mykola,** Professor, *Emeritus,* Ph.D., Washington University, 1958; 1965.
**Silbert, Leonardo,** Associate Professor, Ph.D., University of Cambridge, 1998; 2006.
**Talapatra, Saikat,** Professor, Ph.D., Southern Illinois University, Carbondale. 2002; 2007.

The Department of Physics offers graduate programs leading to the Master of Science degree with a major in physics and to the Doctor of Philosophy degree in Applied Physics.

This program requires a $65 application fee that must be submitted with the application for Admissions to Graduate Study in Physics. Applicants must pay this fee by credit card.

## Master of Science

In order to be considered for admission into the Master of Science program, students must have a baccalaureate degree in Physics, or equivalent. Applicants for admission to the Master's degree program are strongly encouraged to submit GRE scores together with other application materials.

In addition to the general requirements of the Graduate School for the Master of Science degree, the student must complete PHYS 500A (or mathematics equivalent), 510, 520A, B, and 530A,B.

Other specific requirements for the Master's degree are as follows:

A thesis is required, based upon not more than six nor less than three semester hours of 599-level credit. The 599 credit requirement is in addition to the minimum 15-hour requirement at the 500 level as stated in this catalog and should be distributed preferably over several terms of enrollment.

Each candidate for an M. S. degree is required to pass an examination, written or oral or both, covering graduate work including the thesis; the examination is administered by the student's thesis committee.

Each candidate for an M.S. degree is required to earn one credit in PHYS 581 by lecturing in the graduate seminar. An oral thesis defense satisfies this requirement.

## Master of Science (Non-Thesis/Research Paper Option)

In order to be considered for admission into the Master of Science Non-Thesis Option (MSNT) program, students must have a baccalaureate degree in Physics, or equivalent.

In addition to the general requirements of the Graduate School for the Master of Science degree, the student must complete PHYS 425, 450, 500A (or mathematics equivalent), 510, 520A,B and 530A. Those students enrolled in the MS non-thesis option who have taken PHYS 425 and/or PHYS 450 as part of their undergraduate curriculum may replace those courses with any other 500-level course and/or 400-level course (after consulting with their respective advisory committee).

An advanced experimental or computational, or theoretical project resulting in a research paper is required, based upon not less than four semester hours of PHYS 598. The research paper has to be completed by the end of the second year in the program. It should be written as a standard scientific text (i.e., with appropriate referencing), and it should be between 15 and 20 pages in length. The research paper should explain in detail the project undertaken by the student enrolled in the MS non-thesis option and must contain background and motivation (with proper literature review), and problem statement and goals of the project, results, a discussion related to the work undertaken in accomplishing the goals and objectives, conclusions and plans for future work. The style that should be used is that appropriate for a manuscript submitted to Phys. Rev.

Further, it is also noted that the outcome of the project (in the form of the research paper) has to be approved by the student's advisory committee. Once the research paper is approved, an electronic version of the research paper must be filed in the Graduate School by submission at Open SIUC.

Other specific requirements for the MSNT are as follows:

Each candidate for an MSNT degree is required to have a CGPA of 3.0 (in 4.0 scale) throughout the program.

## Doctor of Philosophy in Applied Physics

### Program Description and Objectives:

The Department of Physics offers a graduate program at the doctoral level leading to the Ph.D. degree in Applied Physics. The Applied Physics doctoral program is designed to provide advanced studies both in the application of the concepts and methods of physics to various research areas, including: materials, nanoscience and nanotechnology, quantum computing, computational physics, condensed matter physics, magnetism, thin films, and in the application of the methods and techniques of physics to the study of industrial processes and products. The Applied Physics Ph.D. provides students with broad, in-depth knowledge of the fundamentals of those areas of physics relevant to applications, as well as with advanced specialized knowledge in applied areas. The ultimate goal of this program is to produce graduates that are competent scientific researchers in Applied Physics, i.e., researchers that are capable of initiating and completing an independent investigation in a specific sub-field of Applied Physics. The graduates of this program will be able to fill the needs of academia, industry and government in the area of Applied Physics.

## Admissions

Applicants will be admitted into the Applied Physics Ph.D. following one of three routes:

1. Direct admission: this option requires the applicant to have completed a Bachelor's degree in Physics (or its equivalent) with a grade point average of at least 3.25 (in exceptional cases the Department may solicit the Graduate School to waive this requirement).
2. Accelerated admission: students are admitted into the Master's degree program and after one semester they can be considered for admission into the doctoral program if they show exceptional research potential and have accumulated a GPA of 3.25.
3. Regular admission: for students who have completed a Master's degree in Physics or equivalent and have accumulated a GPA of 3.25 in graduate level courses (in exceptional cases the Department may solicit the Graduate School to waive this requirement). The students obtaining their Master's degree at SIU will have satisfied most of the core course requirements for the Applied Physics Ph.D.

All applicants for admission to the doctoral program in Applied Physics must submit Graduate Record Examination (GRE) scores together with other required application materials.

## Course Requirements

In addition to the general requirements of the Graduate School, the student must complete a sequence of Required Basic Core Courses, and Elective Courses that includes:

Required Basic Core Courses:

| | |
|---|---|
| Physics 500A | Mathematical Methods in Physics (3 credits) |
| Physics 510 | Classical Mechanics (3 credits) |
| Physics 520A,B | Electromagnetic Theory (6 credits) |
| Physics 530A,B | Quantum Mechanics II (6 credits) |

In addition, students are required to complete one additional course (3 credits only) from those in the following list:

Elective Courses:

| | |
|---|---|
| Physics 550 | Computational Physics |
| Physics 545A | Statistcal Mechanics II (3 credits only) |
| Physics 565A | Solid State Physics II (3 credits only) |
| SCI 501A,B | Research Transmission Electron Microscopy |
| SCI 502A,B | Research Scanning Electron Microscopy |
| Physics 575 | Special Topics in Physics: Magnetism and Magnetic Materials |
| Physics 575 | Special Topics in Physics |
| Physics 575 | Special Topics in Physics: Spectroscopy of Materials |
| Physics 575 | Special Topics in Physics: Surface Science |
| Physics 575 | Special Topics in Physics: Quantum Computing |
| Physics 575 | Special Topics in Physics: Hybrid Materials |
| Physics 575 | Special Topics in Physics: Advanced Optics |

The following courses are not allowed to count as electives: Physics 599 (Thesis), 600 (Dissertation), and 601 (Continuing Enrollment).

Starting no later than the beginning of the third semester in the program, students will be required to enroll for two consecutive semesters in Physics 570, a 3-credit hour per semester Special Project course.

In addition to the above-described coursework, while working on their dissertation, the students must complete 24 credit hours of Physics 600 (Dissertation) in no less than two academic years of full-time work.

## Admission to Candidacy

To be admitted to candidacy, the prospective doctoral candidate must satisfactorily complete the Qualifying Procedure.

The Qualifying Procedure includes:

1. Three written examinations
2. A research proposal
3. The student's performance in Required Basic Core courses
4. The recommendation of the research advisor (if the student has a research advisor).

1. **Three written examinations –** The students will take three written exams. The exams are chosen by the student from the following five possible topics: Quantum Mechanics, Classical Mechanics, Statistical Mechanics, Electromagnetic Theory and Solid State Physics.

   The students will have to select three out of the five exams to take (i.e., they will not be allowed to pick the best three out of four or five).

   The students will have to pass the three exams, as evaluated and determined by the Graduate Committee.

   These written exams will be prepared at the undergraduate level. That is, at a level that is consistent with the corresponding courses at the 200-, 300-, 400- level at SIU.

   The level will be specified by the corresponding textbooks used in these courses at SIU.

   For Classical Mechanics Halliday and Resnick (or equivalent) specifies the 200- level and Symon or Thornton and Marion specifies the 300- and 400- level;

   For E+M Theory, Halliday and Resnick (or equivalent) specifies the 200- level and Lorrain and Corson, or Griffiths or equivalent specifies the 300- and 400- level;

   For Statistical Mechanics, at the 400-level only, "Thermal Physics" by Kittel and Kroemer specifies the level;

   For Quantum Mechanics at the 300-level "Modern Physics" by Serway, Moser, and Moyer or equivalent, specifies the level, and "Introduction to Quantum Mechanics" (Second Edition), by David J. Griffiths specifies the 400-level;

For Solid State Physics, at the 400-level only "Introduction to Solid State Physics" by Kittel specifies the level

The written exams will consist of a set of questions from which the students will get to choose a subset that they will answer. Where it is applicable (i.e. for Classical Mechanics, E+M and Quantum), some of the questions will be at the 200- level and others at the 300- and 400- level.

The written exams will be held one per day over the course of a week.

2. **A written research proposal –** The research proposal has to be completed by the end of the second year in the program.

   It should be written as standard scientific text (i.e., with appropriate referencing), and it should be between 10 and 15 pages in length.

   The style that should be used is that appropriate for a manuscript submitted to Phys. Rev.

3. **The course performance** of the student in the required classes for the program. (Must have a grade point average of 3.25 (out of 4) in the basic core curriculum in Applied Physics).

4. **If the student is engaged in research** by the end of the first year in the program, the recommendation of the research advisor.

## General Considerations

Students are expected to have completed the Qualifying Procedure by the end of the fourth semester in the doctoral program.

Students are required to take the exam at the end of their first Spring semester in the program.

The written exam portion of the Qualifying Procedure will be prepared and administered by an examination committee appointed by the Chair.

The written exam portion of the Qualifying Procedure will be held on a yearly basis, generally in early August.

Students will be allowed to participate in the exam portion of the qualifying procedure twice. The one exception to the above rule is that students who so desire can have a "free try" at the Qualifying Examination by taking it at the beginning of their first semester in the program without this instance counting as one of the two allowed opportunities to take the exam. Students are encouraged to attempt the written exam portion of the Qualifying Procedure as early as the beginning of their first semester in the program in order to make use of the free option.

Students will be allowed to change one exam area (of the three) per each time they take the exams. This adds up to a maximum total of two changes, if the student takes the exams in the free try. Note that what is limited to two times (or to three times, if the student takes advantage of the free try) is the number of times the student can participate in the qualifying exam procedure; i.e. it is not that the student can repeat two times each individual exam. The students can participate in the exam process twice (or three times with the free try) and must pass three exams at the end of their tries.

Those students who start at SIU in the Spring semester will have their free try at the beginning of the following Fall; they will be required to take this free try.

Students who complete the Master's degree at SIU and then proceed to the Ph.D. will be considered as incoming doctoral students for the purpose of the free try exam. They will, however, be required to take this free try.

Those students who begin at SIU in the Fall can have their free try only in the Fall in which they start.

The Graduate Committee will evaluate all four points of the Qualifying Procedure for each student applicant and will decide on admission to candidacy for each applicant. The Graduate Committee will decide on what weight will be given to the different portions of the Qualifying Procedure.

Upon successful completion of the Qualifying Procedure, the Department will request the Graduate School to admit the student to candidacy for the doctoral degree, once the applicant has completed the required 24 hour residency period.

**Dissertation Committee and Dissertation Examination.** No later than six months after admission to candidacy, the student will request the appointment of a dissertation committee to supervise the student's dissertation. This committee will include five faculty members, with at least one from outside the Department of Physics, at least one doing research in theoretical physics, and at least one doing research in experimental physics. The majority of the committee shall consist of faculty members from the Department of Physics. The committee will be chaired, in most cases, by the student's dissertation supervisor. The committee will meet within two months after its formation to determine if any specific coursework, beyond the core curriculum, is to be required of the student, and to determine if any special requirements might be appropriate for the student's particular research area. At this time (i.e., no later than eight months after admission to candidacy), the committee will be given a formal, written dissertation proposal and an oral presentation on the proposed research by the student.

**Dissertation Defense.** Upon completion of a dissertation demonstrating the student's ability to conduct independent research, the dissertation committee will administer a final oral examination. This oral examination shall consist of a defense of the dissertation. Upon the satisfactory completion of both the dissertation and the final examination, the committee will recommend the student for the doctoral degree.

## Courses (PHYS)

**PHYS 420-3 Electricity and Magnetism II.** Induced electromotive force, quasisteady currents and fields, Maxwell`s equations, electromagnetic waves and radiation, with applications. Prerequisite: PHYS 320 with grade of C or better.

**PHYS 424-4 Electronics for Scientists.** Coordinated two-hour lecture and four-hour laboratory study of electronics. Emphasis is on overall modern electronics and its applications in the experimental research laboratory setting. Topics include DC and AC circuit theory, measurement techniques, semiconductor active devices, operational amplifiers and feedback, digital circuits, Boolean algebra, microprocessors and large scale integration, digital to analog/analog to digital conversion, and data acquisition. Prerequisite: PHYS 203B or 205B and MATH 111 with a grade of C or better.

**PHYS 425-3 Solid State Physics I.** Structure of a crystalline solid; lattice vibrations and thermal properties; electrons in metals; band theory; electrons and holes in semiconductors; opto-electronic phenomena in solids; dielectric and magnetic properties; superconductivity. Prerequisite: PHYS 310, 320, and 430 with grade of C or better.

**PHYS 428-3 Modern Optics and Lasers.** Properties of electromagnetic waves in space and media, polarization and interference phenomena and devices, electro- and magneto-optic effects, optical gain, and lasers. Prerequisite: PHYS 420 with grade of C or better.

**PHYS 430-3 Quantum Mechanics I.** An introduction to quantum phenomena, wells, barriers, Hydrogenic atoms, angular momentum and identical particles. Prerequisite: PHYS 305, 310, and 320 with a grade of C or better. Prior or concurrent enrollment in PHYS 420 is desirable.

**PHYS 431-3 Atomic and Molecular Physics I.** Atomic spectra and structure; molecular spectra and structure. Prerequisite: PHYS 430 with a grade of C or better.

**PHYS 432-3 Nuclear Physics I.** Basic nuclear properties and structure; radioactivity, nuclear excitation, and reactions, nuclear forces; fission and fusion. Prerequisite: PHYS 430 with grade of C or better.

**PHYS 440-3 Applications of Quantum Mechanics.** Applications of quantum mechanics to include time-independent and time-dependent perturbation theory, variational methods, introduction to solid-state physics and materials. Prerequisite: PHYS 430 with grade of C or better.

**PHYS 445-3 Thermodynamics and Statistical Mechanics.** Laws of thermodynamics; Principles and Applications of Classical and Quantum Statistical Mechanics; Introduction to Phase Transitions. Prerequisites: PHYS 305 and PHYS 301 both with a grade of C or better; MATH 251 with a grade of C or better.

**PHYS 450-3 Advanced Laboratory Techniques.** Introduces students to experimental research and encourages them to develop and carry out experiments. Prerequisite: PHYS 305 and PHYS 355 with a grade of C or better. Lab fee: $50.

**PHYS 458-2 Laser and Optical Physics Laboratory.** Properties of laser beams and resonators, fluorescence and two photon spectroscopy, diffraction, Fourier transformation and frequency filtering, electro- and magneto-optic modulation, fiber propagation and related experiments. Prerequisite: PHYS 428 with grade of C or better.

**PHYS 470-1 to 3 Special Projects.** Each student chooses or is assigned a definite investigative project or topic. Prerequisite: PHYS 310, 320 or consent of instructor.

**PHYS 475-3 Special Topics in Physics.** These courses are advanced special topics in physics designed to enable undergraduate and graduate students to become well-versed in a particular and current research area of physics with the intention of preparing them for future research and/or industrial applications. They are offered as the need arises and interest and time permit. Students are required to give presentations. Special approval needed from the instructor.

**PHYS 476B-3 Introduction to Biological Physics.** This course provides an introduction to how physics principles and techniques are applied to study and describe complex and emergent processes found at the biological and biomolecular level. This course combines several topics not usually covered in standard undergraduate science courses to qualify and quantify cell structure, mechanics, dynamics, self-assembly, and biological functionality. Prerequisites: Two semesters of an introductory physics sequence (PHYS 203A,B or PHYS 205A,B) with minimum grades of C, MATH 150 or concurrent enrollment.

**PHYS 476C-3 Introduction to Computational Physics.** This course provides foundational knowledge in the usage of computers for solving natural problems in different types of physical systems. The class will give a thorough understanding of various numerical techniques such as interpolating/extrapolating data, integrating ordinary and partial differential equations, and solving linear algebra problems. Students will be guided to write programs for solving several applied physics problems in classical and modern physics. A brief survey of High Performance Computing will also be presented giving students a working knowledge of scientific computing. Prerequisites: Two semesters of an introductory physics sequence (PHYS 203A,B or PHYS 205A,B), with minimum grades of C and concurrent enrollment in PHYS 305. PHYS 301, PHYS 310 and PHYS 320 are not required but recommended.

**PHYS 476M-3 Introduction to Materials Science and NanoPhysics.** This course will serve as an introductory course in Materials Science and Nanoscale Physics. Topics to be covered include: The need for studying Materials Science, classification of materials, advanced concepts in materials manufacturing, modern materials, nanoscale materials, electrical, thermal, magnetic and optical properties of materials, tailoring materials for application development, Techniques of Materials characterization, Nanomaterials and Nanotechnology, and Societal Impact. Prerequisites: Two semesters of an introductory physics sequence (PHYS 203A,B or PHYS 205A,B), with minimum grades of C, MATH 150 or concurrent enrollment.

**PHYS 476Q-3 Quantum Entanglement.** This course provides an introduction to the theory of quantum entanglement and its use in quantum information science, especially for the task of communication. Topics include quantum teleportation, entanglement measures, and nonlocality. Prerequisite: MATH 221 with a grade of C or better.

**PHYS 500A-3 Mathematical Methods in Physics.** Vector spaces and operators in physics. Hilbert spaces and complete orthonormal sets of functions. Elements and applications of the theory of analytic functions. Methods for the solution of partial differential equations of physics.

**PHYS 500B-3 Mathematical Methods in Physics.** Vector spaces and operators in physics. Hilbert spaces and complete orthonormal sets of functions. Elements and applications of the theory of analytic functions. Methods for the solution of partial differential equations of physics.

**PHYS 510-3 Classical Mechanics.** Generalized coordinates and forces. Lagrangian, Hamiltonian, and variational formulations of mechanics. Noether`s Theorem. Central forces, oscillations.

**PHYS 520A-3 Electromagnetic Theory.** Determination of static, electrostatic, and magnetostatic fields. Microscopic and macroscopic theory of insulators and conductors. Maxwell`s equations; radiation, propagation and scattering of electromagnetic waves. Electrodynamics and special theory of relativity. Selected topics.

**PHYS 520B-3 Electromagnetic Theory.** Determination of static, electrostatic, and magnetostatic fields. Microscopic and macroscopic theory of insulators and conductors. Maxwell`s equations; radiation, propagation and scattering of electromagnetic waves. Electrodynamics and special theory of relativity. Selected topics.

**PHYS 530A-3 Quantum Mechanics II.** Basic principles; the harmonic oscillator and the hydrogen atom; scattering; approximation and perturbation methods; spin, statistics.

**PHYS 530B-3 Quantum Mechanics II.** Basic principles; the harmonic oscillator and the hydrogen atom; scattering; approximation and perturbation methods; spin, statistics.

**PHYS 531A-3 Advanced Quantum Mechanics.** Quantum theory of radiation; applications of field theory to elementary particles; covariant quantum electrodynamics; renormalization; special topics. Content varies somewhat with instructor. Prerequisite: PHYS 530. Special approval needed.

**PHYS 531B-3 Advanced Quantum Mechanics.** Quantum theory of radiation; applications of field theory to elementary particles; covariant quantum electrodynamics; renormalization; special topics. Content varies somewhat with instructor. Prerequisite: PHYS 530. Special approval needed.

**PHYS 535A-3 Atomic and Molecular Physics II.** Recent experimental methods in atomic and molecular spectroscopy with applications. Detailed quantum mechanical and group theoretical treatment of atomic and molecular systems. Reactions between atomic systems. Special approval needed from the instructor.

**PHYS 535B-3 Atomic and Molecular Physics II.** Recent experimental methods in atomic and molecular spectroscopy with applications. Detailed quantum mechanical and group theoretical treatment of atomic and molecular systems. Reactions between atomic systems. Special approval needed from the instructor.

**PHYS 545A-3 Statistical Mechanics II.** Principles of classical and quantum equilibrium statistics; fluctuation phenomena; special topics in equilibrium and non-equilibrium phenomena.

**PHYS 545B-3 Statistical Mechanics II.** Principles of classical and quantum equilibrium statistics; fluctuation phenomena; special topics in equilibrium and non-equilibrium phenomena.

**PHYS 550-3 Computational Physics.** Using modern computers to solve physics problems. Integration of ordinary and partial differential equations, interpolation and extrapolation, finite element analysis, linear and nonlinear equations, eigensystems, optimization, root finding, Monte Carlo simulations, etc.

**PHYS 560A-3 Nuclear Physics II.** Fundamental properties and systematics of nuclei, scattering theory, nuclear two-body problem, nuclear models, nuclear many-body problem, electromagnetic properties of nuclei, radioactivity, nuclear reactions. Prerequisite: PHYS 530. Special approval needed from the instructor.

**PHYS 560B-3 Nuclear Physics II.** Fundamental properties and systematics of nuclei, scattering theory, nuclear two-body problem, nuclear models, nuclear many-body problem, electromagnetic properties of nuclei, radioactivity, nuclear reactions. Prerequisite: PHYS 530. Special approval needed from the instructor.

**PHYS 565A-3 Solid State Physics II.** Fundamental concepts in solid state physics. Lattice vibrations, band theory of solids, the Fermi surface, dynamics of electrons. Transport, cohesive, optical, magnetic and other properties of solids. Special approval needed from the instructor.

**PHYS 565B-3 Solid State Physics II.** Fundamental concepts in solid state physics. Lattice vibrations, band theory of solids, the Fermi surface, dynamics of electrons. Transport, cohesive, optical, magnetic and other properties of solids. Special approval needed from the instructor.

**PHYS 570-1 to 36 Special Projects in Physics.** Each student works on a definite investigative topic under the supervision of a faculty sponsor. The projects are taken from the current research in the department. Resourcefulness and initiative are required. Graded S/U only. Special approval needed from the instructor.

**PHYS 571A-3 X-Ray Diffraction and Electron Microscopy.** (See ME 504) Special approval needed from the instructor.

**PHYS 571B-3 X-Ray Diffraction and Electron Microscopy.** (See ME 504) Special approval needed from the instructor.

**PHYS 575-1 to 12 (1 to 4 per topic for a maximum of three topics) Special Topics in Physics.** The courses reflect special research interests of the faculty and current developments in physics. They are offered as the need arises and interest and time permit. Students are required to give presentations. Special approval needed from the instructor.

**PHYS 581-1 to 3 (1,1,1) Graduate Seminar.** Lectures on special topics by students, faculty, or invited scholars; participation is required of all graduate students. For credit each student may present a seminar in the form of a lecture on a theoretical or experimental topic, a demonstration experiment or apparatus critique. Graded S/U only.

**PHYS 598-1 to 50 (1 to 12 per semester) Research.** Maximum credit 50 hours. Graded S/U only. Special approval needed from the instructor.

**PHYS 599-1 to 6 Thesis.**

**PHYS 600-1 to 30 Dissertation.** Minimum 24 credit hours required for Ph.D. degree. Special approval needed from the instructor.

**PHYS 601-1 per semester Continuing Enrollment.** For those graduate students who have not finished their degree programs and who are in the process of working on their dissertation, thesis, or research paper. The student must have completed a minimum of 24 hours of dissertation research, or the minimum thesis, or research hours before being eligible to register for this course. Concurrent enrollment in any other course is not permitted. Graded S/U or DEF only.

PHYS 699-1 Postdoctoral Research. One credit hour per semester. Concurrent enrollment in any other course is not permitted. Must be a Postdoctoral Fellow.