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THE U-M GRADUATE PROGRAM IN PHYSICS within the College of Literature, Science, and Arts offers advanced students an extraordinary learning experience and a wide array of opportunities for research, scholarship, and teaching.

Graduate Support Groups

The U-M has many groups which support the graduate community in general and physics graduate students, specifically.

Grad Phi is an organization for Physics and Applied Physics graduate students. Grad Phi provides a forum for students to discuss issues they have dealing with teaching, research, classes, and quality-of-life each semester in a meeting with complimentary refreshments. They also plan social events, such as parties and picnics, and help coordinate events with **Society of Physics Students (SPS)** and the Physics Department. The Physics and Applied Physics graduate students also play on many intramural sports teams, like softball and soccer, which are coordinated, in part, through Grad Phi. Grad Phi's membership is free and all events are open to all graduate students in the Physics and Applied Physics Departments.

Women physics graduate students often participate in the University's **Association for Women in Science at the University of Michigan (AWIS-U-M),** which brings together women undergraduates, graduate students, postdoctoral researchers, and faculty. Membership is offered to both women and men who support the goals of being dedicated to achieving equity and full participation for women in science, technology, and engineering. AWIS is involved, both on the national and chapter level, in education, networking, lobbying government, and raising the public's awareness of opportunities and barriers for women in science. Please see http://www.umich.edu/~awisum/ for more information.

Funding

Graduate students in the Physics Department are funded through a combination of fellowships, Graduate Student Instructorships (GSIs), and Graduate Student Research Assistantships (GSRAs). **The Physics Department is committed to funding all graduate students who are making Good Progress.**

Fellowships

Full funding for graduate students is a 50% appointment. Each admission letter sent by the U-M Physics Department includes a guaranteed support package for the first year. Most students are admitted with a combination of a 25% Graduate Student Instructor (GSI) appointment and a matching Department Fellowship. However, other offer packages are available, and each of them is detailed below. The Department guarantees

funding for the first year of study. It is expected that students secure funding in subsequent years.

Ford Fellowship
This fellowship is granted each year. The award, sponsored by the Ford Motor Company, provides two full years of support that includes tuition and fees, a twelve-month stipend, health insurance, and a budget to cover books and other expenses.

Regents' Fellowships
The U-M Board Of Regents established the Regents' Fellowships to be given annually to outstanding incoming graduate students. The fellowship is a two-year award consisting of a stipend, full tuition waiver, and health insurance. This award is one of the most prestigious U-M fellowships available to entering physics students and is awarded in recognition of outstanding undergraduate accomplishment and future promise.

Colegrove Graduate Fellowship in Physics
The Forrest (Don) Colegrove Graduate Fellowship in Physics provides one year of stipend and tuition to an outstanding first-year graduate student. The award is given every other year beginning Fall 2006.

Rackham Science Award
The Rackham Science Award (RSA) was established for entering graduate students at U-M who are members of racial and ethnic groups that are historically underrepresented in graduate education in the United States. This program is intended to furnish a base of financial support to assist these students to pursue graduate degrees at U-M. African American, Native American, Hispanic/Latino/Latina, and Asian American students in fields where they have been historically under-represented, are eligible for the Rackham Science Award. Awards are made on a competitive basis on the recommendation of the Physics Department's admissions committee. The RSA is a one year, non-renewable fellowship. Students who receive this funding will be eligible to apply for one summer of funding from the RSA Summer Fellowship for Under-Represented Students and two years of funding from the RSA Continuation Fellowship for Under-Represented Students. The recipient will also receive two years of Department support which will be a 50% GSI, 50% GSRA or a combination of the two. Rackham's full year of RSA fellowship consists of two terms of tuition, 12 months of GradCare health insurance and 8 months of stipend equivalent to a 50% GSI/GSRA position. Please see the Rackham Graduate School website http://www.rackham.umich.edu/Fellowships/guideln/2070.pdf for more information.

Physics Department Fellowships
Physics Department Fellowships are available through the generous gifts and endowments of friends and donors. These fellowships provide supplemental funds for first year students who are given Graduate Student Instructor (GSI) positions. This means for the first academic year, the student will be responsible for teaching two undergraduate introductory laboratory sections per term. The normal full time teaching appointment (50% GSI) is four labs. By reducing the number of hours spent in the

classroom, the Department hopes that new students will have more time to become involved with research groups.

After the first year, most students join research groups and become fully supported as Graduate Student Research Assistants (GSRAs). In the event that research funding is not available, the department will, in most cases, continue to support the student as a GSI provided that the student is in good standing with the program (subject to position availability and term limits—see section on GSIs and GSRAs, page 5).

All admitted students who are not eligible for a Regents, Ford Fellowship, or Merit Fellowship are automatically considered for a Physics Department Fellowship. Please see the U-M Physics Department website: http://www.physics.lsa.umich.edu/academics/undergrad/funding.asp#grad for more information.

Outside Fellowships

The U-M Physics Department and the Rackham Graduate School will enhance support for many outside fellowships such as National Science Foundation (NSF) Graduate Fellowships and Minority Graduate Fellowships. The NSF annual stipend is supplemented usually without additional duties, and year-round comprehensive health insurance is provided. The program is subject to the same stipulations regarding academic progress as the Regents Fellowship. For more information, please see http://www.rackham.umich.edu/Fellowships/ for Rackham fellowships.

In the summer months, some graduate students have the opportunity to participate in the Quality Education for Minorities (QEM) Network Summer Science Internship Program (SSIP). These science internships provide undergraduate and graduate students the opportunity to interact with agencies and organizations involved in making science policy. It also exposes them to science education issues and programs related to the education of minorities. Past assignments have included work in science-oriented agencies and organizations such as the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), the Smithsonian Institution, the Environmental Protection Agency, and the QEM Network's Mathematics, Science, and Engineering Component, where students were able to apply their knowledge and contribute to the organization's programs. For more information and an application packet, see http://qemnetwork.qem.org/ .

Awards and Prizes

Bequests and donations from alumni and friends of the Department have made it possible to present several endowed awards and prizes to graduate students who have excellent academic and research credentials. The awards are presented each year at the annual Physics Awards Ceremony.

The ***Wirt & Mary Cornwell Prize*** is given to a graduate student who, during the four previous years, has demonstrated great intellectual curiosity and given the most promise

of original study and creative work in physics. Currently the award is a cash prize in the amount of $10,000.

The ***Peter Franken Award*** is a cash prize given to a first or second year graduate student who has done outstanding work in physics.

The ***Outstanding First-Year Student Instructor*** is awarded to a graduate student who has demonstrated excellence in teaching.

The ***Kent M. Terwilliger Memorial Thesis Prize*** is a cash prize given to a graduating Ph.D. student and recognizes outstanding research and presentation of research results.

The ***Marcellus L. Wiedenbeck Award*** was established by the family of Marcellus Lee "Marc" Wiedenbeck's 40 years of service on the Michigan faculty. This cash award is presented to a graduate student that exemplifies outstanding teaching abilities.

GSIs and GSRAs

Graduate Student Instructor (GSI) positions are given on a term-by-term basis. Typically, the student is either given a 25% appointment (2 labs or 10 hours per week) or a 50% appointment (4 labs or 20 hours per week) depending on the student's support needs. Duties usually consist of teaching elementary laboratory sections. Students should note that the College of Literature, Science, and the Arts restricts GSI support to a maximum of 10 terms.

Individual, funded research groups autonomously provide Graduate Student Research Assistantships (GSRAs) on a term-by-term basis. Students are often required to complete a trial period working with a group–usually not longer than one term–before funding is granted, usually as a 0.50 appointment.

General information for GSIs and GSRAs: appointments of 0.25 or greater for at least four months include full tuition and the opportunity to participate in health and life insurance programs. Four-month GSI appointments at less than 0.25 include partial tuition at varying rates. GSIs are represented by a union, the Graduate Employees Organization (GEO). Membership in the union, or a payment of a service fee not to exceed union dues, is a condition of employment. Combination GSI/GSRA appointments are available and are determined on a case-by-case basis. It is expected that students in the third year and beyond will be supported entirely by GSRA appointments.

GSIs in Introductory Labs

Graduate Student Instructors (GSIs) staff most Introductory Physics Laboratory sections. Graduate students use the assignment as a means to gain financial support and become exposed to teaching. The goal of the Physics Introductory Laboratories is to give each enrolled undergraduate student hands-on experience with a few classic measurements and to reinforce the concepts presented in their lecture and discussion sections. GSIs help

facilitate this experience. The laboratories correspond to both the Introductory Mechanics and Electromagnetism courses.

The U-M Physics Department needs GSIs who are energetic and committed. In fact, those qualities are critical to the success of the Physics Introductory Laboratories. In return, GSIs receive not only compensation but also a unique opportunity to provide physical insights to students who, for the most part, will not engage in formal physics study when the course ends. This process is generally as enlightening for the teacher as for the student since, for each GSI, it is often their first entry into the ranks of instructor. It offers the GSI an opportunity to interact with others who will live in an ever-intensifying technological world and can benefit from the physical understanding that the laboratory experience engenders.

Since GSIs have regular contact with enrolled students, they are in the best position to provide input to enhance the course. The lab manuals are regularly edited and updated, and the Department looks to the GSI community for suggestions. GSIs have contributed curriculum materials provided to the students, and a few have even evaluated potential new experiments and software as part of their association with the Physics Introductory Laboratories. A weekly meeting with a faculty supervisor provides a two-way opportunity to discuss the instructional program. There are also selected senior GSIs who can be sought out for advice and help on an informal basis.

GSIs are required to successfully complete the Department's discipline specific, graduate level GSI teaching course, ***Physics 993: Graduate Student Instructor Training Program,*** before teaching the Introductory Laboratory course. This is a 20-hour, one credit course designed specifically for first time Physics Introductory Laboratory Instructors. The course consists of 12 hours of classroom work and 8 additional hours of work during the semester, consisting of consultation with the course instructor and graduate student mentors. Please see the Services for Graduate Student Instructors section of the Center for Research on Learning and Teaching (CRLT) website: http://www.crlt.umich.edu/gsi.html for more detailed information.

Physics Department Community

The Department includes approximately 60 faculty members who teach and mentor approximately 140 graduate students. About 48 Department staff members provide essential support to teaching, research, and advising. The Department holds a number of social gatherings, including a daily cookie/coffee hour, weekly colloquia, potluck gatherings, and Halloween and Holiday parties. Each fall the Chair delivers a "State of the Department" address to the entire Department, and at the end of the winter semester an awards ceremony is held at which undergraduate and graduate students are recognized for outstanding achievements (see also the **Awards and Prizes** section on page 4).

The Department offers a large variety of general and field-specific seminars. First year students attend **Mini-Colloquium** (Physics 501), which is a series of short lectures conducted by Physics faculty about their fields of research. The U-M Physics

Department is especially proud of its **Saturday Morning Physics** lectures. Each talk is illustrated with multimedia technology and live demonstrations. These public presentations, meant for the passionately curious, are informative and entertaining and attract more than 300 University and community members (see http://www.physics.lsa.umich.edu/nea/smp/). Important to the intellectual vitality of the Department are the weekly **Departmental Colloquia,** where internationally renowned scientists present lectures for a scientifically literate audience. The colloquia are ideal for graduate students to learn about exciting developments in the broad area of physics. Two annual lectures – **The Ford Motor Company Distinguished Lecture in Physics** and **The Ta-You Wu Lecture** – have become an integral part of the tradition of the Department and are very popular among faculty, graduate, and undergraduate students. The speakers invited to present these lectures are world-renowned scientists. Recent Nobel Laureates who have spoken to the Department include Steven Chu, Eric Cornell, Wolfgang Ketterle, William Phillips, Horst Stormer, and the Department's own Martinus Veltman. Graduate students will benefit from attending weekly field-specific seminars or research group meetings (e.g. Condensed Matter/Atomic Molecular Optical, High Energy Astrophysics, High Energy Particle Theory, High Energy Theory, Spin Physics).

Graduate students also participate in a number of outreach and recruiting programs. The Department offers a one-week **Future Science: Future Engineering Program** for seventh and eighth grade girls who wish to explore the world of science while having fun with physics. Their activities include hands-on laboratory experimentation, computer simulations, and career exploration. Faculty from the U-M Physics Department have partnered with other U-M faculty to present the **Michigan Math & Science Scholars (MMSS) Program,** which offers talented high school students the opportunity to explore math and science at the cutting edge of research. Hands-on learning is emphasized with laboratory experiments, field work, and computer laboratories. Physics graduate students often participate as paid mentors in the MMSS Program. More information is available at http://www.physics.lsa.umich.edu/nea/outreach/mmss.asp.

The Department organizes an annual **Physics Olympiad** for Michigan high school students (see http://www.physcis.lsa.umich.edu/olympiad). The Olympiad features many hands-on activities, the preparation and presentation of which require the active participation of undergraduate and graduate members of SPS and Grad Phi, respectively. Students participating in outreach activities have the opportunity to be creative and to communicate some of their knowledge and skills to others, such as teaching while providing a fun experience to their younger fellow citizens.

Program Requirements

Although no absolutes govern the selection of the nine 500-level physics courses needed for candidacy, students are expected to demonstrate proficiency in the material of ***Physics 505/506: Electricity and Magnetism I and II***, ***Physics 510: Statistical Physics*** and ***Physics 511/512: Quantum Theory and Atomic Structure I and II.*** These courses are the "suggested core." The remaining specific course requirements are listed below and on the Progression to Candidacy Worksheet on page 12. Students must also pass a two-part qualifying exam, participate in supervised non-thesis research **(*Physics 515: Supervised Research*)** or an equivalent endeavor, pass one 600-level course (two credit hours or more with a B (5.0) or better), and pass a preliminary exam. Students must successfully complete 68 Rackham fee hours of courses and submit and defend a dissertation on original research.

Specific Course Requirements

Each student in the Ph.D. program is expected to take:

One year of Electricity and Magnetism – PHYS 505/506
One year of Quantum Theory and Atomic Structure – PHYS 511/512
One course in Statistical Physics – PHYS 510
Four additional 500-level Physics courses
One 600-level Physics course
Four credit hours of a cognate
Four credit hours of supervised, non-thesis research – PHYS 515

Good Progress

Students must maintain Good Progress in order to remain in the program. Students who meet the following guidelines are making Good Progress.

- Good standing with Rackham (not on probation)
- Continuous, high effort research from first summer onwards
- Pass both GQEs by the end of 2nd year
- Become Candidate by beginning of 3rd year
- Form Dissertation Committee within one year of becoming a Candidate
- Graduate by 6th year

Precandidate/Candidate

All students begin the Ph.D. program as **precandidates**. The status of **candidate** is achieved after completion of the specific course requirements previously listed, completion of the qualifying exam, and successful completion of the preliminary exam. See checklist on page 12 for further details.

Physics 501

All first year students are required to register for ***Physics 501 – Mini-Colloquim***. This course meets once per week and consists of presentations on the varied types of research within the Department. The purpose of the course is to expose the students to research opportunities. Students must register both fall and winter terms.

Graduate Qualifying Exams

All students in the Ph.D. program must pass the Graduate Qualifying Exam (GQE) before the beginning of their third year of study. The GQE is a written short answer format and consists of two parts: classical and modern. The exam tests students on material covered in standard advanced undergraduate physics courses. The GQE is given in January and May each year.

Cognates

All Ph.D. students are also required to incorporate four credit hours of a cognate course into their program. A cognate is any course work in another department with a graduate level designation. In most circumstances, a 400-level course in other departments can be considered graduate level and counted as a cognate. Any questions regarding the level of a course can be directed to Student Services in the Registrar's Office at 763-5174 or to the department in question.

Research

In order to advance to candidacy, students must complete at least four credit hours of ***Physics 515: Supervised Research***. ***Physics 515*** requires instructor permission. The course is conducted as an independent study and is usually taken in the second year. See the Graduate Coordinator for registration instructions.

Preliminary Examination

The final step prior to advancement to candidacy is the Preliminary Examination.

- Form your Prelim Exam committee, comprised of three professors, with your research advisor as chair.
- Write a 2-3 page Research Abstract of your current research to distribute to members of the Prelim Exam committee and the Student Services Office well in advance of the exam.
- The exam will be a presentation of research-related material as determined by the chair of the Prelim committee.

As a requirement of the preliminary examination, the student must submit a ***Research Abstract***. An abstract is a two to three page summary intended to show the Prelim

Committee that the student is currently engaged in a research problem. That problem does not necessarily need to be part of the dissertation research, nor is it required to be part of the Prelim exam. A copy of the research abstract must be filed with the Student Services Office.

An ***Oral Examination Evaluation Form*** must be completed by the committee at the conclusion of the preliminary exam and given to the Student Services Office. The student should bring this form to the exam.

After the required steps have been taken, the Physics Graduate Coordinator will complete a ***Recommendation for Candidacy Form*** and will submit it to the Rackham School of Graduate Studies. The Graduate School will advance the student to candidacy soon afterward.

See the following page for The Progression to Candidacy worksheet.

Dissertation/Candidacy Committee

Students must assemble a committee that will guide and observe the research and dissertation process within one year of becoming a Candidate. The Committee should consist of five members. *(In choosing the members of the Committee, the student must obtain prior consent of those persons nominated)*. The Committee Chair should be a faculty member of the U-M Physics Department actively engaged in research allied to that being undertaken by the student. Of the four remaining members, three should be from the U-M Physics Department comprised of at least one member from outside the area of specialization and at least one theorist and one experimentalist. The fifth and final member should be from another department (cognate member). Students must form a Dissertation Committee within one year of becoming a Candidate in order to maintain Good Progress.

Students can pick up the ***Physics Department Committee Nomination Forms*** in the Student Services Office. Upon receipt of the completed form and after passing the preliminary examination, the Graduate Coordinator will submit a ***Dissertation Committee Form*** to the Rackham School of Graduate Studies on the student's behalf.

*(**Note:** A student may select a non-Physics professor as a Committee Chair but **must** have a Physics professor as a co-chair).*

The Dissertation

As the Ph.D. program enters its final stages, the student should rely on the information furnished in the Rackham School of Graduate Studies publication,
The Dissertation Handbook. The handbook is available on-line in PDF format at http://www.rackham.umich.edu/StudentInfo/Publications/DissertationHandbook/**.** It

contains detailed information that includes degree requirements, when and how to schedule meetings, deadlines, and thesis formats.

http://www.rackham.umich.edu/OARD/docsteps.html

At this stage in the program, the student is responsible for completing the above processes in cooperation with the Graduate School. The Physics Student Services Office can be an auxiliary source of support to the student.

Grad Tools

The Rackham School of Graduate Studies at University of Michigan has assembled a special set of tools in the CTools environment to help Rackham doctoral students as they work toward their degrees. These tools are known collectively as Grad Tools. The unique feature of Grad Tools is the Dissertation Checklist, which presents the process for completing the doctoral degree in one personalized view.

The Dissertation Checklist in a student's Grad Tools site automatically inherits the required steps from the Graduate School and from the Physics department. It may also include steps added by the student and by his or her committee members.

In addition to the Dissertation Checklist, Grad Tools provides several tools common to CTools, including a schedule, discussion feature, a place to store forms and documents, and more.

THE PROGRESSION TO CANDIDACY

COURSE WORK: Complete all required course work. ♠ = required core

I. 500-LEVEL PHYSICS: 27 hours of physics courses (roughly 9 courses) with a B- or better:
(Note: To achieve candidacy, you must complete 36 Rackham fee hours. [See pg. 34 of the Rackham Graduate Handbook.] To achieve a doctorate, you must complete a total of 68 fee hours.)

505♠	_____ credits	521	_____ credits
506♠	_____ credits	522	_____ credits
507	_____ credits	523	_____ credits
510♠	_____ credits	530	_____ credits
511♠	_____ credits	540	_____ credits
512♠	_____ credits	541	_____ credits
513	_____ credits	542	_____ credits
519	_____ credits	other	_____ credits of _____
520	_____ credits	other	_____ credits of _____

TOTAL _____ credits vs. _____ Rackham Fee Total

II. Physics 501: Students are required to register for this class in the fall and winter terms of their first year.

Fall Winter

III. 600-LEVEL PHYSICS: 2 hours of 600-level physics course work with a B or better.
(This requirement may be completed after candidacy.)

600+ _____ credits of _____

COGNATE: Take and pass 4 hours of cognate with a B- or better.

_____ credit(s) of _____ _____ credit(s) of _____

QUALS: Take and pass the Qualifying Exams, Part I and Part II by the end of your second year.

Part I: Classical Physics Part II: Modern Physics

RESEARCH: Complete 4 credit hours of supervised, non-thesis research (Physics 515/715).

PRELIM: Take and pass your Preliminary Exam.

Form your Prelim Exam Committee and submit your research abstract according to the department requirements detailed in the Graduate Student Handbook.

Just prior to your prelim, pick up an Oral Examination Evaluation Form from the Student Services Office and take it to your prelim for the chair of your committee.

CANDIDACY: Upon receipt of both the Oral Examination Evaluation Form and your abstract—if you have completed all of the above requirements—the Student Services Office will complete and forward the Nomination for Candidacy Form directly to Rackham. Students are expected to achieve candidacy by the beginning of their third year.

View the Candidacy Deadline list from the Rackham website and know your deadlines.
http://www.rackham.umich.edu/OARD/candidacydeadlines.html

PHYSICS COURSES FOR GRADUATE STUDENTS

Physics 501: Mini-Colloquium.
Prerequisites: Graduate standing. Credits: (1)
Mini lectures about research fields conducted by Physics faculty. *Mandatory for first year students only.*

Physics 505/506: Electricity and Magnetism I and II.
Prerequisites: Graduate standing. Credits: (3)
Electrostatics, time-independent magnetic phenomena, time-dependent electromagnetic fields, free electromagnetic fields, covariant formalism of electrodynamics, scattering and diffraction of electromagnetic waves, wave guides, radiating systems, radiation from moving charges.

Physics 507: Theoretical Mechanics.
Prerequisites: Graduate standing. Credits: (3)
Lagrangian and Hamiltonian formulations, symmetry and conservation laws, central force, rigid body motion, canonical transformations, Hamilton-Jacobi theory, perturbation theory.

Physics 510: Statistical Physics.
Prerequisites: Graduate standing. Credits: (3)
Review of thermodynamics, statistical bases of second law, entropy and irreversibility, equipartition, the Gibbs paradox. Quantum statistics, ideal Fermi gas, ideal Bose-Einstein condensation, phase equilibrium, phase transitions, fluctuations and transport theory.

Physics 511/512: Quantum Theory and Atomic Structure I and II.
Prerequisites: Graduate standing. Credits: (3)
This is a two term sequence on the quantum theory and its applications to non-relativistic atomic, molecular, nuclear and solid state systems; time independent and time dependent perturbation theory; angular momentum, scattering theory; interaction of photons with non-relativistic systems; the Dirac equation.

Physics 513: Advanced Quantum Mechanics I.
Prerequisites: Graduate standing. Credits: (3)
Introduction to the methods of relativistic quantum field theory with applications relevant to high energy and many-body physics. Topics include: Feynman diagrams, calculations of cross sections for simple processes in scalar and spin or field theories, and the electron gas problem.

Physics 515/516: Supervised Research.
Prerequisites: Graduate standing. Credits: (4-6)
Non-thesis research courses. *Independent study.*

Physics 517: Graduate Physics Laboratory.
Prerequisites: Graduate standing. Credits: (3)
Laboratory course intended for the graduate student who has had little experience with experimental physics in his/her undergraduate curriculum.

Physics 518/Applied Physics 518: Microcomputers in Experimental Research.
Prerequisites: Graduate standing. Credits: (3)
A laboratory course designed to give students hands-on experience with modern techniques of data acquisition, handling, and analysis, and graphical presentation of results using microcomputers. Several experiments will be carried out which illustrate how to interface research instrumentation in a variety of commonly encountered laboratory situations.

Physics 519: Group Theory.
Prerequisites: Graduate standing. Credits: (3)
The first half of the semester will be spent on groups of finite order and the second half on continuous groups. For the finite groups, the following will be covered; group representations, the point groups, characters, base vectors, Wigner coefficients, the permutation groups and Young tableaux, with applications to molecules, crystals, and atomic and nuclear spectroscopy. The continuous group part will stress Lie groups and their applications to nuclear and atomic physics and internal symmetries in particle physics. Root vectors, standard forms, Dynkin diagrams with detailed applications of SU(3) and SO(5).

Physics 520: Condensed Matter Physics.
Prerequisites: PHYS 510, 511 and Graduate standing. Credits: (3)
Modern theory of solids with emphasis on electron states, band theory, electron-electron interactions, phonons, electron-phonon interactions, transport theory, semiconductor physics and superconductors.

Physics 521: Elementary Particle Physics I.
Prerequisites: PHYS 512 and Graduate standing. Credits: (3)
Overview of the very successful “Standard Model” of particle physics, with emphasis on the predictions and tests of the theory, why it is now widely believed to describe nature, and also on open questions. Topics to be studied: the ElectroWeak theory and Quantum Chromodynamics, properties of quarks and leptons, Higgs bosons, CP violation, a few topics beyond the Standard Model (grand unifications, supersymmetry, and neutrino masses), and existing and future experimental facilities and detectors.

Physics 522: Atomic Physics and Quantum Mechanics.
Prerequisites: Graduate standing. Credits: (3)
The structure of atoms and the interaction of atoms with fields. Topics: non-relativistic and relativistic hydrogen and positronium; Lamb shift; hyperfine interactions; group theory and the structure of multiple-electron atoms; coupling schemes; Hartree-Fock theory; single-and multi-channel quantum-defect theories; atoms in external fields;

atomic transitions; line width; photoionization; strong-field effects; time reversal; parity violation; quantum chaos.

Physics 523: Advanced Quantum Mechanics II.
Prerequisites: Graduate standing. Credits: (3)
Advanced course in relativistic quantum field theory with emphasis on gauge field theories. Among the topics explored are renormalization and unitarity of abelian and non-abelian gauge theories, spontaneous symmetry breaking, and renormalization group.

Physics 525/526/527: Intro Topics in Astrophysics I, II and III.
Prerequisites: Graduate standing. Credits: (3)
Presentation of the standard model of cosmology, the Hot Big Bang model, development of the parameters of an expanding universe, and illustration of the three types of Friedmann Robertson Walker universes and the thermal history of the universe from its hot early stages through the epoch of recombination.

Physics 529/Applied Physics 529: Techniques of Experimental Physics.
Prerequisites: Graduate standing. Credits: (3)
The goal of this course is to get students acquainted with the concept of modern physics experiment and to help learn important experimental skills and data analysis techniques. Apart from developing an appreciation of experimental approaches used in many areas of modern physics, the student will also gain familiarity with finding and studying previously published results and references; designing experimental procedures; choosing adequate instruments; observing and measuring physical phenomena; performing statistical analysis of the data with understanding of statistical and systematic errors; documenting experimental procedures; reaching conclusions and publishing experimental results; presenting results in public.

Physics 540: Advanced Condensed Matter Physics.
Prerequisites: Graduate standing. Credits: (3)
Use and development of Green's function techniques to study the many-body aspects of electron-electron interactions, electron-phonon interactions, magnetic and superconducting instabilities of a Fermi liquid, formulation and application of the renormalization group to critical phenomena and Anderson localization.

Physics 541: Elementary Particle Physics II.
Prerequisites: PHYS 521 and Graduate standing. Credits: (3)
This course will take several topics from Particle Physics I (PHYS 521) and develop them in the detail appropriate for students planning to work in particle physics. May include predictions and tests of the electroweak theory, QCD, supersymmetry, and CP violation.

Physics 542: Quantum Optics.
Prerequisites: Graduate standing. Credits: (3)
An introduction to the interaction of radiation with matter, beginning with an introduction to the theory of the interaction of classical radiation fields with atoms. Other topics

include optical Bloch equations; linear and nonlinear laser spectroscopy and optical coherent transients; effects such as hole burning, phase conjugation, photon echoes, four-wave mixing and quantum beats; properties of the quantized radiation field.

The 600 level courses are offered on a term-by-term basis. Some of the topics covered in past years have been Solid State(PHYS 620), Lasers (PHYS 651), and Advanced Atomic Physics (PHYS 644). Refer to the current Schedule of Classes to see what courses are offered in a given term.

Physics 990: Dissertation/Precandidate.
Prerequisites: Graduate standing and not admitted as a doctoral Candidate by Graduate School. Credits: (1-8 full term; 1-4 half term)
Independent Study with student's research advisor. Can be repeated for credit.

Physics 993: Graduate Student Instructor Training Program.
Prerequisites: Must have Graduate Student Instructorship, Graduate standing and permission of instructor. Credits: (1)
A seminar for all beginning graduate student instructors, consisting of a two-day orientation before the term starts and periodic workshops/meetings during the fall term. All first time Graduate Student Instructors are required to register for this course.

Physics 995: Dissertation/Candidate.
Prerequisites: Graduate standing and admitted as a doctoral Candidate by Graduate School. Credits: (8 full term; 4 half term)
Independent Study with student's research advisor. Can be repeated for credit. *The defense of the dissertation (the final oral examination) must be held under a full term Candidacy enrollment period.*

The Physics Department's Graduate Coordinator in the Student Services Office can answer general questions about degree program requirements. Specific questions regarding a physics degree program can be answered during a one-on-one meeting with one of the graduate physics faculty advisors. These advisors can assist in planning a program of study, answer questions, and provide advice on career preparation and opportunities. Students must meet with an advisor at the start of their graduate program.