Graduate Student Handbook

Department of Physics and Astronomy
University of Missouri
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I. Introduction

Welcome to the Graduate Program of the Department of Physics and Astronomy at the University of Missouri! This Graduate Handbook provides detailed overviews of the Department's programs and requirements, along with many of the internal policies, practices and resources. It does not establish a contractual relationship between students and the Department or University, but is intended to be used to guide students in the steps necessary to complete a graduate degree in the Department. Regulations, at times, do change, and we will endeavor to communicate any such changes promptly and produce updated versions of this handbook, as necessary.

An electronic version of this Handbook, containing active hyperlinks, can be found on the homepage of the Department of Physics and Astronomy at http://physics.missouri.edu/wp-content/uploads/2012/08/fileGradStudentHandbook.pdf

The detailed requirements for obtaining an MS or PhD degree in Physics are given in this graduate student handbook. The requirements include:

- a specific number of course hours completed within a given period of time,
- passing evaluation examinations,
- completion of research and a thesis based on research, as well as
- keeping a prescribed time line including filing various forms.

While this process may sound intimidating, it actually is not: with proper attention to details, your graduate work will go smoothly, and you will proceed quickly to your desired goal.

The faculty and staff of the Department are committed to providing a productive and pleasant environment for students pursuing their graduate degrees, on academic as well as personal levels. We hope that your graduate years with us will be successful and a rewarding experience! This Handbook should help you during these years, and it is your responsibility to familiarize yourself with its content.

II. Overview and Management of the Graduate Program

A graduate student in the Department of Physics and Astronomy at the University of Missouri is responsible for his/her educational program and his/her progress toward becoming a professional physicist. The Department offers opportunities for that preparation which include courses, seminars, availability of contemporary literature in the field, office space, and facilities for research with an excellent faculty having wide-ranging interests and expertise.

1. The Office of Research and Graduate Studies (ORGS)

The University of Missouri's Office of Research and Graduate Studies (formerly the Graduate School) provides the basic structure and minimum degree requirements for all graduate programs of the University. However, the graduate degree programs are established and administered by individual departments according to the needs and standards of the various fields and professions. The Department of Physics and Astronomy has established both Master's and PhD programs which, in many aspects, have requirements that exceed the basic degree requirements of the ORGS.

The detailed rules and regulations of the ORGS, along with various resources, are available online at http://gradstudies.missouri.edu. In many instances, the ORGS rules are repeated in this Handbook. In the (unlikely) event of a direct conflict, the ORGS policies have priority over Department policies.

2. The Department

The graduate program in the Department of Physics and Astronomy is formally administered by the Director of Graduate Studies (DGS). Policies specific to the degree programs are established by the Graduate Studies Committee, or are recommended by the DGS or the Committee to the Faculty of the Department.

The immediate supervision of students is carried out by their research advisors and degree Supervisory Committees. If a student does not have a research advisor, he/she will be under the direct supervision of the DGS.

Students should first seek guidance about policies and other issues related to the graduate program from their research advisors. The DGS is always available for additional clarifications, to assist students in bringing matters to the Graduate Studies Committee, or to resolve problems or disputes. The DGS reports to the Department Chair, and the Chair is also available for consultation or advice whenever needed.

3. PAGSA

The Physics and Astronomy Graduate Student Association (PAGSA) is an organization whose membership includes all Physics and Astronomy graduate students. Its main purpose is to further the interests of the Department's graduate students and to lend a common voice for communication with the Faculty, the DGS and the Chair. Furthermore, the PAGSA organizes regular meetings, such as the Physics Journal Club, as well as special events such as the annual Department Picnic.

The PAGSA website (http://pagsa.missouri.edu/) is kept up to date on current events and is a valuable source of information for graduate students:

- Upcoming events, including links to the Columbia community calendars
- Colloquium, Seminar, and Journal Club dates and speakers
- Recent news
- Links to general graduate student resources

4. Contacts

Department Chair:	Professor Sashi Satpathy (satpathys@missouri.edu) Office: 234 Physics, phone: 882-6086
Associate Chair:	Professor Dorina Kosztin (kosztind@missouri.edu) Office: 224 Physics, phone: 882-2238
Director of Graduate Studies:	Professor Carsten Ullrich (ullrichc@missouri.edu) Office: 424 Physics, phone: 882-2467
Qualifying Exam Committee Chair:	Professor Ioan Kosztin (kosztini@missouri.edu Office: 308 Physics, phone: 882-7241
Coordinator for Teaching Assistants:	Professor Yun Zhang (zhangyun@missouri.edu) Office: 226 Physics, phone: 882-6816
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III. MS Degree Requirements

The Master of Science (MS) degree in physics prepares students for a variety of scientific careers. Since physics is the most fundamental of the physical sciences, graduate-level studies in the field provide essential knowledge for application in many areas. Students with strong backgrounds in physics, as well as in areas ranging from biology to engineering, are encouraged to consider a personalized MS program in physics. Graduates have many job opportunities in a variety of areas.

1. Course Work

The MS Degree requires completion of a minimum of 30 course hours beyond the Bachelor's Degree (at least 15 hours of those in 8000 level courses) with a GPA (grade point average) of 3.0 (B) or better, and completion of the Departmental Qualifying Examination at least at the MS pass level. The basic residency requirement stipulates that 24 hours of this work be courses taken at MU (i.e., no more than 6 hours may be transfer credits). In a normal program, this requirement is met by the end of the second year at MU. The required courses for a Master's Degree are:

- Physics 8610: Advanced Mechanics (3 credit hours)
- Physics 8620: Electrodynamics I (3)
- Physics 8660: Methods in Mathematical Physics (3)
- Physics 8680: Thermodynamics and Statistical Mechanics (3)
- Physics 8710: Quantum Mechanics I (3)

Other additional courses may be taken from 7000 and 8000 level courses in astronomy, mathematics, chemistry, biology, engineering, and physics to make a total of 30 hours of course work. Courses from other departments require the advisor's and DGS' permission. In some cases, a student who is a transfer graduate student or who has a particularly strong undergraduate background may have had course work which satisfies the requirement of one or more of these core courses. Exemption from taking these courses at MU may be granted upon written application to the departmental Graduate Studies Committee.

2. Research

It is essential for the MS degree that students carry out some research. Three hours of research, Physics 8090, should be taken, but not more than nine hours of reading and research courses may be included in the 30 hour requirement. (Note: This 9 hour limitation is a departmental requirement and is more restrictive than the ORGS requirement.) A formal MS thesis is not required in Physics. Students, in consultation with their advisers, can choose to write an optional MS thesis (see Section III.4 below).

3. Qualifying Examination

The student must pass the Departmental Qualifying Examination (see Section V) at least at the MS pass level. Upon completion of the Qualifying Exam, the student fills out the

form M3, "Report of the Master's Examining Committee", and gathers the signatures of the Qualifying Examination Committee members. This form is then signed by the Director of Graduate Studies and forwarded to the ORGS.

4. Thesis option

A thesis is not required for the MS degree in Physics. However, students have the option to form a thesis committee (form M2) and write an MS thesis. In this case, they can obtain the MS degree without having to pass the Qualifying Exam; however, they need to defend their thesis. Details regarding the thesis process for MS students can be found here: http://gradstudies.missouri.edu/academics/thesis-dissertation/index.php

5. Graduation Requirements

After performing satisfactory work for the first year, the student with the adviser's assistance completes the form M1, "Plan of Study for the Master's Degree," an outline of the course of study for the student's graduate program, and forwards the application through the Departmental Graduate Studies Committee to the ORGS. The plan of study form must be filed no later than the session preceding the session in which the student expects to receive the degree. Upon approval of the M1 form by the ORGS, the student is a candidate for the degree.

MS degree requirements of the Department of Physics and Astronomy are designed to be completed in 4 semesters (see the MS time line in section III.8). Notice that this time line is shorter than the MS time limit which is set by the ORGS (a maximum of 8 years).

The candidate must be enrolled at the MU campus during the semester in which the program of study, outlined in the "Plan of Study for the Master's Degree", is expected to be completed. During the first six weeks of this semester, the candidate must personally confirm with the ORGS for all graduation arrangements.

6. MS Degree in Passing

Students who are enrolled in the PhD program can obtain the MS degree “in passing” once they have satisfied all the MS requirements. All they need to do is complete the Graduate Change of Degree form (requesting that the MS degree be added to their degree program) and get the signature of the DGS.

7. Forms

M1 form: Plan of Study for the Master's Degree.
M2 form: Request for Thesis Committee.
M3 form: Report of the Master's Examining Committee.
Graduate Student Change of Committee form.
Plan of Study Course Substitution form
Graduate Change of Degree form

8. Time line for the MS Degree

The following time line applies for those students who seek the MS as their terminal degree in the Department of Physics and Astronomy at MU. The MS requirements are designed in such a way that the degree can be obtained within 4 semesters. Students who choose the MS thesis option are subject to a similar 4-semester time line. Students who wish to depart significantly from this time line need to submit their request in writing to the Graduate Studies Committee, which will decide in consultation with the student's advisor.

1st Semester

- Take the "free shot" Qualifying Exam (see Section V) at the start of the semester.
- Take required courses (see Section III.1).

2nd Semester

- Take required courses.
- Choose a research advisor and begin doing research.
- Submit plan of study (form M1).

3rd Semester

- Take required and/or elective courses.
- Continue doing research.
- Take the Qualifying Exam at the start of the semester.
- Submit form M3 if Qualifying Exam has been passed at MS level.

4th Semester

- Take required and/or elective courses, and complete MS course requirements.
- If not yet passed, take the second attempt at the Qualifying Exam at the start of the semester. Submit form M3 if Qualifying Exam has been passed at MS level.
- Continue doing research.
- Apply for graduation at http://gradstudies.missouri.edu/academics/graduation-commencement/index.php. Notice that the online application deadlines are quite early! To graduate in Spring, you must apply in December or January. To graduate in Summer, you must apply in May. For further details, see http://gradstudies.missouri.edu/academics/graduation-commencement/timeline-deadlines/index.php.
- Think ahead and start looking for jobs.

IV. PhD Degree Requirements

1. Course Work and Residency Requirement

The doctor of philosophy (PhD) degree is designed to educate scientists to be capable of independently formulating and solving problems of fundamental scientific importance. A PhD Degree requires completion of a minimum of 18 course hours beyond the Master's Degree, with a grade of 3.0 (B) or better, and completion of the departmental Qualifying Examination at the PhD pass level. The degree candidate must also meet the residency requirements. There is no foreign language requirement.

The required courses for a PhD Degree (in addition to those for the MS Degree in physics) are as follows:

- Physics 8640, Electrodynamics II (3 credit hours)
- Physics 8720, Quantum Mechanics II (3)
- Two graduate-level (>8000) courses in the student's area of specialization (6)
- A graduate-level (>8000) course in an area other than the student's area of specialization (3)

Additional graduate-level courses to make a total of 18 hours beyond the Master's Degree are required. See the list of graduate courses in Physics and Astronomy for electives. In addition, students can choose selected 7000 and 8000 level courses in Mathematics, Chemistry, Biology and Engineering upon consultation with his/her advisor and the departmental DGS.

Altogether, MU requires a minimum of *72 credit hours of graduate work* (the sum of course work and research credit hours) beyond the baccalaureate degree.

The residency requirements are as follows: A doctoral student must complete at least two nine-hour semesters or three six-hour semesters in an 18-month period at MU. All courses taken to satisfy the residency requirement must be approved by the student's doctoral program committee. During this period, the student must be fully involved in academic pursuit, be it study, teaching, or research. The ORGS specifically requires that a minimum of 15 hours of course work at the 8000 level (exclusive of research, problems and independent study experiences) be taken at MU.

2. Transfer of Credit

A student who has completed a master's degree at MU or elsewhere may, upon recommendation of the advisor and approval by the departmental Director of Graduate Studies and the ORGS, transfer a maximum of 30 credit hours toward the total hours required for the doctoral degree. Transfer credit for doctoral students who do not have an earned master's degree is limited to a maximum of 12 hours of graduate credit.

3. Selection of the Doctoral Program Committee

Upon passing the Qualifying Examination at the PhD pass level, the student is accepted as a PhD degree candidate. The student should file the form D1, "Qualifying Examination Results and Doctoral Committee Approval Form". The student must select (if he or she has not already done so) a consenting adviser from doctoral faculty members who are dissertation supervisors in the Department. The student's adviser officially recommends, for the approval of the ORGS, a four-member Doctoral Program Committee, including one outside member who is a graduate faculty member from a different MU program (but not from outside MU).

4. Plan of Study

The doctoral program committee guides the student in planning a program of study. The Chair of the Doctoral Program Committee, after conferring with the student and the Doctoral Program Committee, submits to the ORGS a report, including a copy of the proposed course of study and any request for transfer of graduate credit. This plan of study will, when completed,

- prepare the student for research in the chosen field of Physics or Astronomy,
- satisfy the credit-hour and residency requirements.

The student must substantially complete the course work outlined in the "Plan of Study for the Doctoral Degree" form (D2), to the satisfaction of the Doctoral Program Committee and the Dean before being considered for the Comprehensive Examination.

5. Comprehensive Examination

The Comprehensive Exam (CE) is the most advanced general exam towards the PhD. It consists of both written and oral parts. The student must be enrolled to take the CE. It is to be administered only when the university is officially in session, and must be passed at least seven months before the final dissertation defense. However, according to the recommended PhD time line (see Section IV.9), *the CE should be taken before the end of the 6th semester*. Taking the CE later than the 6th Semester requires approval by the Graduate Studies Committee and by the student's advisor. A request must be submitted in writing to the Graduate Studies Committee before the end of the 6th semester; otherwise, the student may fail the CE. The CE has the following format:

- The student prepares a research proposal in the following suggested format:
    - Page limit: 1-page abstract, up to 15 pages main narrative (including figures), plus extra pages for references. This is the typical format for research proposals to federal funding agencies such as NSF or DOE. The document should be single spaced with 11 pt font size and 1 inch margin.
    - The main narrative should contain a brief introduction and overview of your research, a summary of the work carried out so far, and a plan for the remaining research to be done. There should be a clear vision and motivation for the proposed work and expected outcome. You should try

to convince the reader that this research is scientifically significant and technically feasible.

- The research proposal must be submitted as hard copies and electronically to each member of the Doctoral Committee 10 days in advance of the exam date.
- If the student's advisor so chooses, the CE may include a set of written questions prepared and graded by the members of the Doctoral Committee. The student will have two weeks prior to the CE date to answer the questions.
- The CE should be announced to the Department a week in advance.
- On the day of the CE, the student gives an oral presentation (based on the submitted research proposal) of the work done so far and planned future research. The presentation should not be longer than 1 hour.
- The members of the Doctoral Committee will ask questions specifically related to the presentation. The Committee members may also ask more general questions to test the knowledge of the student not only in his or her specific field of research, but also in other subjects that are part of the required PhD coursework. For the part of the CE where the Committee examines the student, the public is excluded.

For the CE to be successfully completed, all or all but one of the committee members must vote to pass the student on the entire examination, both written and oral. A report of this examination (form D3), carrying the signatures of all members of the committee, must be submitted to the ORGS no later than two weeks after the CE.

A failure of either the written or oral section of the examination constitutes failure of the CE. If a failure is reported, the committee will include in the report an outline of the general weaknesses or deficiencies of the student's work. The student and the committee will work together to identify steps the student might take to become fully prepared for the next examination. If at any time the student believes that the advice given by the committee is inadequate, the student may send a written request for clarification to the committee. A copy of this request should be sent to the ORGS as well. The committee must respond to this request in writing within two weeks and a copy must be filed with the ORGS. A student who fails may not take a second examination for 12 weeks. Failure to pass two CEs automatically prevents PhD candidacy.

6. Doctoral Candidacy and Continuous Enrollment

Candidacy for a doctoral degree is established by passing the Comprehensive Exam. Status as a continuous enrollment doctoral student begins the term after the term in which the comprehensive exam was successfully completed. Candidacy is maintained by enrolling in 9090 research for two semester hours each fall and winter semester and for one semester hour each summer session up to and including the term in which the dissertation is defended. Continuous enrollment provides access to an adviser's support, doctoral program committee guidance and University research facilities for completion of the dissertation. Failure to continuously enroll in 9090 research until the doctoral degree is awarded terminates candidacy.

Candidacy may be reestablished by paying the registration and late fees owed and completing the requirements specified by the student's doctoral program committee.

Registration fees owed may not exceed the amount owed for seven terms, regardless of the number of terms beyond seven for which the student failed to continuously enroll. The committee's requirements may include a second comprehensive examination of evidence of currency in the research field as suggested by publications in refereed journals. Candidacy is reestablished when the student's adviser and the departmental Director of Graduate Studies submit a written request to the ORGS explaining the basis for the decision. Once approved, a Request to Re-enroll form must be completed by the student and sent to the department for processing.

7. Dissertation and Defense

The dissertation must be written on a subject approved by the candidate's Doctoral Program Committee, must embody the results of original and significant investigation, and must be the candidate's own work. Candidates should consult the ORGS's website for Thesis and Dissertations Guidelines: http://gradstudies.missouri.edu/academics/thesis-dissertation/index.php

All dissertation defenses shall be open to all Physics and Astronomy faculty and graduate students. Dissertation defense dates should be publicly announced in advance. The candidate must be enrolled to defend the dissertation, which is administered when MU is officially in session. A report of the dissertation defense form (D4), carrying the signatures of all members of the committee, is sent to the ORGS before the deadline preceding the anticipated date of graduation. For the dissertation to be successfully defended, the student's doctoral committee must vote to pass the student on the defense with no more than one dissenting or abstaining vote.

8. Forms

After passing the Qualifying Examination at the PhD pass level, a student should begin submitting degree program forms which will aid the department and the ORGS in tracking the student's progress toward degree completion. These forms include:

- D1 form: Qualifying Examination Results & Doctoral Committee Approval form - verifies the qualifying process and confirms the student's adviser and doctoral committee. Submit to the ORGS by the end of the semester in which the student passes the Qualifying Examination at the PhD pass level.
- D2 form: Plan of Study for the Doctoral Degree Form - presents the course work to be included in the student's program of study. Submit to the ORGS by the end of the semester in which the Qualifying Examination is passed at the PhD level.
- D3 form: Doctoral Comprehensive Examination Results Form - records the official results of the doctoral comprehensive examination. File with the ORGS within 30 days of completing the comprehensive examination.
- D4 form: Report of the Dissertation Defense Form - reports the official results of the dissertation defense. File within 30 days of completing the defense.

9. Time line for the PhD Degree

The following time line is designed for students to obtain their PhD degree after 10 semesters. Since students have diverse backgrounds, this time line may not be suitable for everyone. If a significant departure from this time line is anticipated, students must consult their advisor and the DGS for approval. *Permission to take the Comprehensive Exam later than the 6th Semester requires a written request to the Graduate Studies Committee.*

1st Semester

- Take the "free shot" Qualifying Exam (see Section V) at the start of the semester.
- Take required courses (see Sections III.1 and IV.1).

2nd Semester

- Take required courses.
- Choose a research advisor and begin doing research.

3rd Semester

- Take the first regular attempt of the Qualifying Exam at the start of the semester.
- Take required and/or elective courses.
- Continue doing research.

4th Semester

- Take the second attempt of the Qualifying Exam at the start of the semester (if necessary). If you pass at only MS level but not at PhD level, finish with MS.
- Take required and/or elective courses, and complete MS course requirements.
- Continue doing research.
- Obtain the MS degree ''in passing''. This is optional, but all PhD students are strongly encouraged to do this. The following easy steps are necessary:
  - Submit MS plan of study (M1 form) and M3 form (Qualifying Exam),
  - Submit Change of Degree form to have your MS degree added to your PhD degree ,
- Apply online at http://gradstudies.missouri.edu/academics/graduation-commencement/index.php to obtain the MS degree. Don't miss the online application deadlines! To graduate in Spring, you must apply in December or January. To graduate in Summer, you must apply in May. For further details, see http://gradstudies.missouri.edu/academics/graduation-commencement/timeline-deadlines/index.php.

5th Semester

- Select your PhD committee, and submit forms D1 and D2.
- Continue to do research and to take required and/or elective courses.
- Set a date for the Comprehensive Exam.

6th Semester

- Continue to do research and to take required and/or elective courses.
- Complete your Comprehensive Exam and submit form D3.
- Taking the Comprehensive Exam later than the 6th Semester requires approval by the Graduate Studies Committee and the student's advisor. A request must be submitted in writing to the Graduate Studies Committee. If this is not done before the end of the semester, you may fail the Comprehensive Exam.

7th and 8th Semester

- After passing the Comprehensive Exam, you have established your PhD candidacy.
- Continue to be enrolled in Physics 9090 (Research) until you defend your thesis.

9th Semester

- Start writing your thesis.
- Set a date for your PhD defense, and meet with your PhD committee three months before the defense.

10th Semester

- Submit your PhD thesis to the committee two weeks before the defense date.
- Defend your thesis and submit form D4.
- Apply for graduation online at http://gradstudies.missouri.edu/academics/graduation-commencement/index.php
- Think ahead and start looking for jobs.

V. The Qualifying Examination

To be officially admitted to the Physics Ph.D. program, graduate students must pass the Departmental Qualifying Examination (hereafter referred to as "QE"). At the same time, the QE plays the role of the required final examination for the M.S. degree.

1. Administration of the QE

The QE is prepared, administered, and graded by the Ph.D. Qualifying Examination Committee (QE-Committee), whose chair is appointed by the Department Chair. The QE-Committee consists of at least four members of the graduate faculty selected by the Chair of the QE-Committee and approved by the Department Chair.

The QE will be given twice a year during the first week of the Fall and Winter Semesters. The QE consists of two written parts. Part 1 (Part 2) will take place on Tuesday (Thursday) of the first week of the Semester from 5:00 to 8:00 pm. Students who need to take the QE will be informed in due course about the location of the exam of the QE, along with other pertinent information.

Incoming students must take the QE at the beginning of their 1st Semester ("free shot"). The main purpose of the "free shot" is to acquaint new students with the QE. This "free shot" QE should be regarded mainly as a diagnostic test. In addition, each student has two more chances to take and pass the QE at the beginning of their 3rd and 4th Semesters.

2. Content of the QE

Both parts of the QE will test problem solving skills and will cover four major topics in Physics. Part 1 (given on Tuesday) will have two Classical Mechanics and two Quantum Mechanics problems, while Part 2 (given on Thursday) will have two Electricity and Magnetism and two Thermodynamics and Statistical Physics problems. The first (second) problem in each topic will be at an undergraduate (introductory graduate) level.

QE books will be provided with all necessary instructions. All work must be done in the QE books.

3. Assessment of the QE

Each exam will be graded by two QE-Committee members working independently of one another. Neither grader will make any marks on the paper being graded. On each problem the results of the two grades are averaged unless there is a significant discrepancy, in which case the score will be resolved in conference. To preserve anonymity during grading, each QE book will be identified by a letter code (assigned and kept secret by the Chair of the QE-Committee) instead of the name of the student.

Each time the QE is given the QE-Committee will decide on a minimum score which will be required for qualification at the Ph.D. and M.S. levels, roughly S1~60% and S2~40%, respectively.

- Students who score above S1 (S2) are passed at Ph.D. (M.S.) level by the QE-Committee.
- If in all three attempts a student scores below S2, he/she should not qualify at Ph.D. level
- If at least in one of the three attempts a student scores between S2 and S1, his/her level of qualification at the Ph.D. level will be decided by the graduate faculty based on his/her performance in: (1) research (as judged by his/her research advisor and by other graduate faculty), and (2) course work. Each such case will be decided by a secret faculty vote; for pass a 2/3 of graduate faculty vote will be required.
- If at least in one of the three attempts a student scores between 20% and S2, his/her level of qualification at the M.S. level will be decided by the faculty based on the overall academic performance of the student.

Students typically will be informed of the outcome of their QE during the third week of the Semester.

4. Additional Information

To indicate the level of coverage of each topic, the following table lists representative textbooks and the respective course numbers for this department. The introductory graduate courses should have been taken by every student after the first year.

Topic	Intro Undergraduate	Advanced Undergrad	Intro Graduate
Mechanics	Halliday & Resnick or equivalent, Phys 2750	Marion & Thornton Phys 4140	Goldstein Phys 8610
Quantum Mech.	any modern physics textbook, Phys3150	Liboff, Griffiths Phys 4800, 4810	Sakurai Phys 8710
Electricity & Magnetism	Halliday & Resnick or equivalent, Phys 2760	Griffiths Phys 4100, 4130	Jackson Phys 8620
Thermo & Stat. Phys.	Halliday & Resnick or equivalent, Phys 2750	Reif Phys 4120	Huang Phys 8680

For each topic, the level of difficulty of the first problem typically lies in the introductory to advanced undergraduate range. The second problem is typically at the advanced undergraduate to introductory graduate level.

To aid students in their preparations, copies of previous QEs may be obtained upon request from the Chairperson of the QE-Committee.

VI. Financial Support

Since the department of Physics and Astronomy is committed to the success of its incoming graduate students, several financial aid packages are available to give maximum support to students so that they can pursue their academic work free from financial problems. Incoming students are usually granted a teaching assistantship (TA), but in some cases research assistantships (RA) can be given to first-year students. In addition, all regular teaching and research assistants are granted a full tuition waiver by the University.

Teaching Assistantships

Teaching Assistants receive a stipend for the nine month academic year that is at a level competitive with most other U.S. institutions. These assistantships generally require up to 20 hours weekly, which includes preparation, classroom, and grading (see Section VII.2).

Research Assistantships

Research Assistantships are generally awarded to advanced students. Their financial award is comparable with the TA stipend. The RA position allows the student the opportunity to pursue research full time. Since the RA position is so fundamental to the graduate experience, it is department policy to strongly encourage all students to apply for an RA position by the end of their second year of studies (see also Section VII.3).

O.M. Stewart Summer Scholarships

Several O.M. Stewart Summer Scholarships of up to $3,000 are available to students who are enrolled eight weeks during summer session working on a research project with a faculty advisor and/or taking courses.

Other Awards for Excellence

Other awards for excellence in teaching or research by a graduate student may be given by the ORGS upon nomination by the Department of Physics and Astronomy.

The ORGS also awards a number of travel scholarships. Students are encouraged to apply for these to help cover the costs of attending conferences. For application procedures, see http://gradstudies.missouri.edu/financials/graduate-awards-travel-scholarships/index.php

VII. Department and University Policies

1. Participation and Assessment

Our graduate students are expected to take a full and active part in departmental activities. Participation in research programs, departmental lectures and colloquia are considered an integral part of a graduate program.

Students are required to document their activities using the Graduate Student Progress System. The Graduate Student Progress System is designed to facilitate the collection of information necessary to properly assess the progress of graduate students. The system can also initiate a feedback loop between student and adviser, allow academic programs to generate aggregate reports on their student's achievements, and create a curriculum vita for a student.

2. Requirements for Teaching Assistants

A full-time graduate TA is expected to work for 20 hours per week.

Preparation. Lab TAs must thoroughly prepare themselves for the labs. Preparation includes (but is not limit to) reading the lab manual, working through all activities, answering all the questions in the lab book, and resolving any possible ambiguities with course instructors.

Teaching techniques, laboratory setup, and other important teaching related information is covered in the course Physics 8040 which is recommended for all TAs.

In the classroom. TAs should be fully engaged in the interactions with students. This includes giving a short (10 to 20 minutes) introductory lecture at the beginning, and more importantly offering help and advice while students work through the labs.

Grading of lab work. TAs are required to grade students' lab work in a professional and timely manner. Graded lab work should be returned to the students in the classroom, with a maximum of two weeks from the collection to the returning of the graded lab work. TAs should enter the scores in a spreadsheet which is to be given to the course instructor at the end of the semester as part of the final grade.

Office hours. TAs are required to keep one hour of office hours each week outside lab time. The purpose of office hours is to give students the opportunity to come and ask questions about the labs.

Proctoring and grading of exams. TAs are also responsible for proctoring and grading exams as arranged by course instructors.

3. Responsibilities of Research Assistants

Once a student begins research, the research advisor usually becomes the official advisor. If a student's research advisor is in another department, the student will still have a departmental advisor on the Physics Department faculty. It is important that you meet with your advisor regularly to discuss your goals, coursework and expectations. Your advisor is your personal consultant on academic matters and serves as a liaison between you and the Physics Department in procedural matters.

It is important to realize that RA support in the department comes through very competitive externally funded research grants. Faculty members spend a lot of effort in writing such grant proposals. The actual cost of an RA to a grant is approximately twice of what a student receives in salary, because it includes University overhead and fringe benefit costs for health care, tuition, etc. Funding is very competitive, and RA support for students must be justified to the funding agencies based upon the scientific output.

An RA enables the student to work full-time as part of a research group, doing current research in his or her chosen field. A student receives an RA appointment through an individual agreement with a faculty member who then serves as the student's research advisor.

As an RA, your primary responsibility is to accomplish the research goals laid out by your research advisor. The professor can assign duties or tasks as needed for satisfactory progress on the grant. Such assignments can vary with the research field or the professor. Normally, the time involved with research activities will greatly exceed the nominal 20 hours/week associated with an RA appointment, the extra hours typically being credited under a research or thesis course registration.

The department strongly encourages an RA to keep the advisor informed about day-to-day research activities. Students should enroll for classes by consulting with their advisor. Courses outside the Physics Department may be taken only with an approval by the advisor. In situations where the research advisor sees that the student is not making satisfactory progress towards research, the RA support may be terminated. The grant from which RA support is derived is normally subject to annual renewal and possible termination. In such cases if the overall progress of the student has been satisfactory, the department might be able to provide a TA support to the student.

4. GPA and Good Standing, Probation, and Dismissal

Examination and grade requirements set by the ORGS can be found at
http://gradstudies.missouri.edu/academics/progress/grading-credit.php

To obtain their degrees, students must have an overall GPA of 3.0 in all graduate courses taken at MU and not just those courses listed on a plan of study. Notice that the GPA is computed only from the "letter grades" A, B, C, and F. Courses graded on an S/U basis are not part of the GPA.

At the end of each semester, students with a cumulative GPA below 3.0 are placed on probation. If at the end of the following semester the cumulative GPA is 3.0 or better, the probationary status is removed. A student on probation failing to raise the cumulative GPA to 3.0 may, on the recommendation of the department or area program, be allowed a second probationary semester.

A student is subject to dismissal upon failure to raise the cumulative GPA to 3.0 by the end of the second probationary semester, or at any time a semester/term or cumulative GPA falls below 2.0 (Summer session is not counted as a semester).

In addition to dismissal for failure to meet the examination and grade requirements, the department has the right to place on probation, and after at least 30 days of probation, to dismiss from their program any graduate student who is deemed to be making insufficient academic progress or whose work is not of the quality required. The faculty adviser or academic program chair must inform the ORGS as soon as the student is notified and the probationary period begins. The dismissal may occur at any time during a student's work toward a graduate degree.

5. Course Load, Enrollment, and Status

- **Your first semesters.** In the first two years, your priority will be to take the required core courses. This means that you have to enroll for up to 3 courses per semester, which equals 9 credit hours. Taking more than 3 courses per semester is not recommended.
- **Specialized courses.** When it comes to choosing elective or special topics courses, discuss with your advisor which courses you should take.
- **Research credit.** Before passing the Comprehensive Exam, students take Physics 8090 for research credit. After the Comprehensive Exam, your PhD candidacy is established and you must enroll in Physics 9090. Consult with your research advisor how many research credit hours you should take.
- **Courses outside the Physics Department.** There is no tuition waiver for courses that are offered in other departments, unless you get special permission from the DGS and your advisor. You can only take courses which are directly needed and useful for your research.
- **International students.** Be familiar with the International Center's web site: http://international.missouri.edu/, which contains the necessary information to maintain your status. You must have a valid passport, valid I-20 or DS-2019, take enough credit hours, and work legally. For details, see http://international.missouri.edu/come-to-mu/students/immigration-status/maintaining-visa-status.php.
- **Tuition waivers.** To receive a tuition waiver, graduate students need a 0.25 FTE (Full-Time Employment). If you are a full-time RA this is automatically the case (your research advisor pays for your tuition). If you are a full-time TA then (since you work 20 hours per week) you are officially on a 0.5 FTE.
- **Full-time enrollment.** 9 credit hours in Fall/Spring and 4 credit hours in Summer are considered full-time enrollment for graduate students.

- **Minimum enrollment for domestic students.** The ORGS does not set minimum enrollment requirements for domestic MS students and pre-comprehensive PhD students.
- **Minimum enrollment for international students:** In the fall and spring semesters, 6 credit hours if you are an RA or TA, otherwise 9 hours. In summer, no enrollment is mandated; however, you need to be enrolled for at least 1 credit hour if you wish to receive any departmental support or summer fellowship. For details, se**e** http://international.missouri.edu/come-to-mu/students/enrollment-guidelines/index.php**.**
- **Enrollment for post-comprehensive PhD students.** Beginning the semester after the completion of comprehensive exam, students (both international and domestic) are required to maintain enrollment of 2 hours during the spring and fall semesters and 1 hour during the summer.
- **Other minimum enrollment requirements.** Students should consult their funding source (the department, advisor, or funding agency for fellowships or assistantships, or the financial aid office) to make sure that they are meeting their minimum enrollment requirements, if there are any, in order to maintain funding and/or student loan deferment. *Typically, half-time enrollment (4 hours in Fall/Spring and 2 hours in Summer) is required to maintain certain benefits such as FICA (payroll tax for social security and medicare) exemption and deferring of student loan payments.*

VIII. Graduate Student Survival Skills

1. Life in the Department.

- **Your advisor.** This will be the key person for you, and will be advising, mentoring and guiding you towards your degree. Make sure you meet your advisor on a regular basis and talk to him/her as often as possible. In case of a conflict with your advisor, first come and talk to the DGS and then to the department chair, if necessary.
- **Be involved in the department.** Since this is the place where you will be spending most of your time, be involved and participate in departmental events! This includes the weekly seminars and colloquia, PAGSA meetings, journal club, department picnics, and any other special events.
- **Office space.** The department provides you with an office space. This can be a cubicle in one of the graduate student offices, or a desk in your advisor's lab. Remember to keep your office space neat. If you need music, use headphones.
- **Get to know people and resources.** The office staff is there to help you and you should get to know them. Familiarize yourself with the departmental resources such as mailbox, fax, and copy machine.
- **Be in touch.** It is extremely important that you check your email at least twice a day so that you can always be reached. Most of the important information is via email these days, and you need to stay connected. This includes weekends.
- **Time off.** Everybody deserves a break, even graduate students. Before you take time off for holidays, vacation, or traveling, inform your advisor! Don't just disappear. In most cases, your advisor will be happy to let you take time off, but they will want to know for how long and whether and how you can be reached.
- **Leave of absence.** Under special circumstances, the Department and the ORGS may grant you a 1-2 semester leave of absence. Talk to the DGS if you want to do this. Policies can be found on the ORGS's web page.

2. Science and Research.

- **Find an advisor.** This is the single most important thing. If you don't have an advisor when you first come here, start looking around immediately and find out who does what. Talk to the professors, they will gladly take the time and explain their research.
- **Working hours.** Being a graduate student is not a 9-5 job. You will have flexible working hours, and there is no time sheet as long as you get your work done. Occasionally you will go through periods of more intense work load, which may require that you work in the evenings and on weekends. Every successful scientist will tell you that the secret lies in hard work through self-motivation.
- **Be independent.** Your advisor will give you a research project, provide you with basic training, and guide you step-by-step towards becoming a fully-fledged researcher. But the advisor cannot do everything for you: you need to be active and take the initiative.

- **How to make your advisor happy:**

  - *Complete work on time.* If you're told to do something by tomorrow, do it by tomorrow. If not, let your advisor know and explain why. Do not procrastinate.
  - *Arrive to meetings and seminars on time.* A 3 o'clock meeting means you should show up at 3 o'clock. If you're late for an appointment, use your phone.
  - *Work hard.* It makes a great impression if you are seen working on a weekend or after hours.
  - *Keep up-to-date with literature.* Nowadays, all science journals are online. Make sure you read the new issue of Science, Nature, Physical Review Letters, Astrophysics Journal, and other relevant journals every week. Your advisor will be very impressed if you find some important paper in the literature by yourself.
  - *Think independently.* Every time you meet your advisor, present at least one new idea and/or ask one new question. It's OK if your idea turns out to be nonsense; you are showing your advisor that you are interested.
  - *Write well.* Scientific writing is a very important skill that can be learned. There are two ways: learn by studying examples of well-written papers in the literature (follow your advisor's recommendation), and utilize university resources offered by the ORGS: http://gradstudies.missouri.edu/resources/writing-research-presentation/index.php

- **What to expect from your advisor:**

  - *Feedback.* Submit work to your advisor frequently for feedback. Request more details if you don't understand the feedback given.
  - *Regular meetings.* Meet at least once a week to discuss progress. Even if you are on-track, regular meetings can bring new ideas to mind.
  - *Travel arrangements.* If your advisor is leaving town for an extended period of time, schedule times to talk via phone (Skype).
  - *Course advice.* Discuss special topics courses which would be beneficial to your research.
  - *Research topics.* Find research projects which are mutually interesting to you and your advisor. The first few projects you work on may be entirely of your advisor's creation, but when you get a feel for the science you will be specializing in, your advisor should be open to project suggestions. (At the same time, you should understand your advisor's area of expertise, as well as the grants he/she may already have, and should consider those aspects when coming up with a research topic).
  - *Collaboration.* If you think it would be useful to contact another expert on the topic of your research, bring this up with your advisor and explain how they could benefit the project.
  - *Conferences.* Present your research! Ask your advisor about funding for conferences, they may be able to help or at least point you to funding agencies on/off campus. There is also travel money available from the University (see VI) or from professional organizations.

- *Connections.* When traveling to conferences, have your advisor introduce you to fellow scientists in your field.
- *Help in finding a job.* Ready to graduate? Discuss your future goals with your advisor! He or she may be able to help you find a job, especially if you want to find a postdoc/academic position.
- *Recommendation letters.* Your advisor will be an important source for recommendation letters even in the years after you have graduated.

- **Scientific integrity.** As a beginning active researcher, you have responsibilities beyond you own personal realm. For example, while an incident of plagiarism in a term paper may affect only your grade, the same incident in a research publication will also affect your advisor and potentially colleagues at other institutions. A publication by the National Academy of Sciences - *On Being A Scientist* - can give helpful guidance to both student and advisor on this issue. Here's a quote:

  > *Beyond honest errors and errors caused through negligence are a third category of errors: those that involve deception. Making up data or results (fabrication), changing or misreporting data or results (falsification), and using the ideas or words of another person without giving appropriate credit (plagiarism)—all strike at the heart of the values on which science is based. These acts of scientific misconduct not only undermine progress but the entire set of values on which the scientific enterprise rests. Anyone who engages in any of these practices is putting his or her scientific career at risk. Even infractions that may seem minor at the time can end up being severely punished.*

  More information on academic integrity can be obtained from MU's Office of Student Rights & Responsibilities at http://osrr.missouri.edu/graduates/index.html
- **Join a professional organization.** Every Physics graduate student should be a member of the American Physical Society (APS). Membership is free for the first year. You'll get the journal "Physics Today", and lots of other useful benefits.
- **More on science survival skills.** Consult the PAGSA web site for additional resources (http://pagsa.missouri.edu/). Two books which may be useful:
  "A PhD is not enough: a guide to survival in science" by Peter J. Feibelman
  "Survival skills for scientists" by Frederico Rosei.

3. Miscellaneous.

- **Student information.** The most comprehensive source of information for student life is the following MU web page: http://www.missouri.edu/students/ . There is a great student newspaper, The Maneater, which is distributed for free on campus during the semester. Columbia has two local newspapers, the Missourian (run by the MU Journalism School) and the Tribune. Both are good sources of local news.
- **The internet.** The web is a fantastic resource for information, and has become an indispensable tool for research. But there are two key rules:
  - Do not go to inappropriate web sites or play computer games while at work.
  - Do not plagiarize. For instance, when writing a paper or thesis, do not cut-and-paste from Wikipedia or from anywhere else. See "Academic integrity" above.
- **IT and computer services.** Information on student email and computer resources can be found here: http://doit.missouri.edu/.
- **The MU bookstore.** Visit the bookstore and find out what services it offers. TigerTech is located in the bookstore's basement, and offers computers and other tech stuff with student discounts. See http://www.mubookstore.com/.
- **The MU Library.** Get to know the MU Library and the services it offers. Figure out how to borrow books and use the copy services. http://mulibraries.missouri.edu/
- **Getting around.** Columbia Public Transport offers various bus routes, see http://www.gocolumbiamo.com/PublicWorks/Transportation/
- **Be safe.** Columbia is, in general, a safe city, but some caution is advised in downtown or any parking garage late at night. Avoid walking alone in the dark.
- **Be healthy.** Study your health insurance coverage and know where to go and what to do when you're sick. The Student Health Center offers most of the basic services you will need: http://studenthealth.missouri.edu/
- **Stay in shape.** Your student fees automatically include the MU recreational center. It's a great place to work out and meet people. http://www.mizzourec.com/.
- **Emergency information.** Call 911 in case of fire, accidents or serious medical emergencies. In other cases, call the MU police department at 992-7201.

IX. List of Courses

For a list of all courses offered during a particular semester, please see the Schedule of Courses in MyZou.

Physics 7085: Problems (credit by arrangement)
Laboratory work involving study of literature of special experiments in physics. Introduces research methods.

Physics 7087: Seminar in Physics (1).
Topics of current interest selected for discussion. May be elected repeatedly. S/U Graded only. Prerequisite: 8150.

Physics 7110: Light and Modern Optics (4).
Interaction of light with matter, spectroscopic techniques, wave optics, interferometry, multilayer films, polarization, nonlinear optics, design of optical instruments, matrix methods, waveguides, fiber optics, acousto-optic and photo-elastic modulation. Includes both Lectures and Laboratory. Prerequisite: Physics 2760 or equivalent.

Physics/Astronomy 7180: Solar System Science (3) (same as Geology and Astronomy 7180).
Investigates physical states, interior structures and comparative geology of solar systems bodies: planets, moons, asteroids, comets, sun. Solar system formation and evolution. Prerequisites: Physics 1220 or 2760 or instructor's consent.

Physics 7190: Physics and Chemistry of Materials (3) (same as Nuclear Engineering 7319 and Chemistry 7490).
This course will cover fundamental and applied aspects relating to the Physics, Chemistry and Biology of material with specific emphasis on Nanoscience and Nanomedicine. Consists of lectures and experiments in nanoscience. Prerequisite: Physics 2760 and Chemistry 1320 or equivalent and consent of instructor.

Physics/Astronomy 7201: Topics in Physics (3)
Organized study of selected topics. Subjects and earnable credit may vary from semester to semester. Instructor’s consent required.

Physics 7230: Scanning Electron Microscopy and X-Ray Microanalysis (3)
This course is designed for senior undergraduate/graduate students and covers the basic principles and practical considerations using the scanning electron microscope (SEM) and energy-dispersive spectrometry (EDS) in the characterization of materials. The structure of the course consists of a series of lectures followed by computer simulation labs covering the lecture topics. This is followed by hands-on lab assignments reinforcing the same material while also servicing as operational training and analytical methods. Also covered in this course are sample preparation techniques, digital imaging and data acquisition and processing. Prerequisites: Physics 3150 and instructor's consent.

Physics/Astronomy 7301: Topics in Astronomy and Astrophysics (3)
Selected topics from solar system, stellar, galactic and extragalactic astronomy, and astrophysics. May be repeated for credit. Graded on A/F basis only.

Physics 7310: Physics in Cell and Developmental Biology (3) (same as Biological Science 7310).
Discusses the role of physical mechanisms in specific cellular and developmental processes and phenomena, in particular those characterizing the embryonic stage of multicellular organisms. Each process and phenomenon is first described in biological terms and then within a physical model, with special emphasis on the interplay between the two descriptions. Prerequisite: Physics 1220 or 2760 and BIO SC 2300 or instructor's consent.

Physics 7360: Extragalactic Astronomy (3)
This course introduces students to the most basic knowledge of extragalactic astronomy, starting from Milky Way and extending to the most distant universe. Topics covered will include galaxy morphology and classification, groups and clusters of galaxies, active galactic nuclei, and galaxy formation and evolution. Prerequisite: Physics 2760.

Physics 7400: Physics of Electronic Devices (3)
This course is designed for graduate and undergraduate students of Physics and Electrical Engineering who have an interest in learning the basic physical idea underlying the operation of electronic devices. The course consists of lectures, handout lecture notes, problem sets, two mid-term and one final exam. Prerequisites: basic knowledge of modern physics (electromagnetism and quantum mechanics) at the level of Physics 3150 or equivalent, or approval by instructors.

Physics 7410: Analysis of Biological Macromolecules and Biomaterials (3)
This interdisciplinary, team-taught course introduces basic concepts and experimental techniques for studying bio-macromolecules and biomaterials. A problem based learning / writing intensive approach uses four modules: proteins, membranes, Cellular Interactions, and Biomaterials. Prerequisite: Physics 2760.

Physics7420: Introduction to Biomedical Imaging (3)
This course offers a broad introduction to medical imaging. Topics to be covered include the physics basics and instrumentation of X-rays, CT, PET, SPECT, ultrasound, MRI, and optical imaging, as well as recent developments in biomedical imaging. Prerequisite: Physics 2760.

Physics 7450: Introduction to Cosmology (3)
Develops the physical concepts necessary for understanding the major recent discoveries in cosmology, such as the acceleration of the universe and dark energy. No prior knowledge of general relativity is assumed. Prerequisite: Physics 3150 or equivalent or instructor's consent. Graded on A/F basis only.

Physics 7500: Computational Biological Physics (3)
Provides a practical introduction (hands-on approach) to the study of the structure and function of biomolecular systems by employing computational methods and theoretical concepts familiar from the physical sciences. Prerequisites: graduate standing and Physics 1220 or 2760 or instructor's consent.

Physics/Astronomy 7550: Cosmochemistry (3)
Chemistry of cosmic dust and molecules. Prerequisites: Physics 2760 or 1220; instructor's consent.

Physics 7600: Semiconductor Optics (3)
It is an introductory-level course in the field of optical processes in semiconductors (both inorganic and organic) and solid-state optoelectronics, designed both for graduate and undergraduate students of Physics, Chemistry, and Electrical engineering. Prerequisite: Physics 3150 or instructor's consent. Graded on A/F basis only.

Physics 7650: Modern Condensed Matter Physics (3)
Introduces the basic concepts and gives an overview of the latest developments of modern condensed matter physics at the forefront of (nano)science and technology. Combines lectures and computational laboratory, where students use and develop interactive computer simulations. Prerequisite: Physics 3150 or instructor's consent. Graded on A/F basis only.

Physics 7750: Interstellar Medium (3)
The course discusses observational properties and physical and chemical processes occurring in the interstellar medium. Topics include interstellar diffuse and molecular clouds, HII regions, dust grains, interstellar chemistry, star formation, supernova remnants, and interstellar shock waves. Prerequisites: graduate standing and Physics 1220 or 2760.

Physics 7850: Computational methods in Physics (3)
Use of modern computational techniques in solving a wide variety of problems in solid state, nuclear, quantum and statistical physics. Prerequisite: Physics 4800 or instructor's consent.

Physics 8040: Study of Techniques of Teaching College Physics (1-3).
Objectives, methods, and problems related to teaching college physics. Some credit in this course is required for all students teaching physics. May repeat for 3 hours maximum.

Physics 8090: Research in Physics and Astronomy (credit by arrangement).
Graduate research in physics and astronomy. Prerequisites: graduate standing required. Graded on an S/U basis only.

Physics 8101: Topics of Physics and Astronomy (1-3)
Organized study of selected topics. Subjects and earnable credit may vary from semester to semester. Prerequisite: instructor's consent. Departmental consent for repetition.

Physics 8110: Physics for high School Teachers I (4)
This s a physics course designed primarily for high school teachers. Topics include motion, forces, Newton's Laws, electricity, and magnetism. The course uses research based pedagogical methods utilizing inquiry, modeling, and hands-on techniques. Prerequisite: instructor's consent. Graded on A/F basis only.

Physics 8120: Physics for high School Teachers II (4)
This is a physics course designed primarily for high school teachers. Topics include applications of Newton's laws, energy, waves, optics, heat, and astronomy. The course uses research based pedagogical methods utilizing inquiry modeling, and hands-on techniques. Prerequisite: instructor's consent. Graded on A/F basis only.

Physics 8130: Physics for high School Teachers III (2)
This is a physics course designed primarily for high school teachers. Topics include modern physics and history of science. The course uses research based pedagogical methods utilizing inquiry, modeling, and hands-on techniques. Prerequisite: instructor's consent. Graded on A/F basis only.

Physics 8150: Condensed Matter Physics I (3).
Crystal structure, reciprocal lattice, phonons, neutron & x-ray scattering, free electron theory of metals, Fermi surfaces, energy bands, static properties of solids, semiconductors, devices and quantum structures, optical properties, excitons, introduction to magnetism, and superconductivity. Prerequisite: 4800 or equivalent.

Physics 8160: Condensed Matter Physics II (3).
The basic Hamiltonian, phonons, theory of the electron gas, second quantization, hartree and Hartee-Fock approximation, local-density, tight-binding theory, electron-electron interaction and screening, Fermi liquid theory, transport properties, impurities, Green's functions, Localization, Quantum Hall effect, magnetism, superconductivity. Prerequisite: 8150. Continuation of 8150.

Astronomy 8301: Topics in Astronomy and Astrophysics (3).
Selected topics from solar system, stellar, galactic and extragalactic astronomy, and astrophysics. May be repeated to a maximum of six hours. Prerequisite: instructor's consent.

Astronomy 8350: Science Outreach (3).
(same as Biological Sciences [BIO SC] and Animal Sciences [AN SCI] 8725) This course is aimed at promoting public understanding and appreciation of science. The students will develop presentations that increase awareness of the impact of science on many aspects of our daily lives. Graduate Standing or instructor's consent required.

Physics 8400: Low Energy Neutron Scattering (3).
Theory, application of low energy neutron scattering to investigation of structure and dynamics of aggregate matter, to include lattice vibrations, ordered spin systems, spin waves, diffusive motions in liquids; experimental techniques discussed. Prerequisite: 8150.

Physics 8450: Plasma Physics (3).
Single particle motion, plasma kinetic theory, magnetohydrodynamics and other fluid theories, waves in unmagnetized and magnetized plasmas, transport phenomena, instabilities, controlled fusion. Prerequisite: instructor's consent.

Physics/Astronomy 8550: Stellar Structure and Evolution (3).
Reviews of atomic and molecular spectra. Investigates quantum radiation law, emission and adsorption processes, radiation transfer theory, continuous and discrete line spectra of stars, stellar composition. Prerequisites: Astro 4250, Physics 4800, or instructor' consent.

Physics 8560: Quantitative X-Ray Microanalysis and Advanced Imaging (3).
This course is designed for graduates/senior undergraduate students. This course covers the theory and methodology to quantitatively analyze materials using both energy-dispersive (EDS) and wavelength-dispersive (WDS) spectrometry along with image processing and analysis techniques. Prerequisites: Physics 8230

Physics 8610: Classical Mechanics (3).
The interplay of dynamics and symmetry, Hamilton's principle and Neother's theorem, Lagrangian, Hamiltonian, Hamilton-Jacobi theories of mechanics. Mechanics in special relativity. Rigid body motion, small oscillations, canonical transformations and fields as continuous mechanical systems. Prerequisite: 4140 or equivalent.

Physics 8620: Electrodynamics I (3).
Electrostatic potential and fields, boundary-value problems in electrostatics, methods of images, Green's functions, multipole expansion, dielectrics, magnetostatics, magnetic materials, Maxwell's' equations, time-varying fields. Prerequisites: Physics 8610 or instructor's consent.

Physics 8640: Electrodynamics II (3).
Electromagnetic wave propagation, reflection, refraction, wave guides, cavities antennas and diffraction, tensors, special relativity, the Lorentz group, dynamics of relativistic particles and fields radiation by moving charges, retardation, bremsstrahlung. Additional topics may include magnetohydrodynamics and plasma physics. Prerequisites: Physics 8620 or instructor's consent.

Physics 8660: Methods in Mathematical Physics (3).
Concentrates on mathematical techniques used in modern physics. Infinite series, functions of a complex variable, differential equations, Fourier series and integral, etc. Prerequisite: Physics 4700 or instructor's consent.

Physics 8680: Thermodynamics and Statistical Mechanics (3).
Thermodynamics as applied in physics, chemistry; laws of distribution; statistical methods of study matter, radiation. Prerequisite: 8710 or concurrently.

Physics 8700: Non-Equilibrium Statistical Mechanics (3).
This course provides an introduction to the theoretical and mathematical description of classical stochastic systems with examples from biophysics and condensed matter physics. Prerequisite: Physics 8680.

Physics 8710: Quantum Mechanics I (3).
Non-relativistic quantum theory in Hilbert space. States and self-adjoint observables, unitary time evolution

in various pictures, the path-integral, identical particles, Fock space, angular momentum, and some perturbation theory. Prerequisite: Physics 8610.

Physics 8720: Quantum Mechanics II (3).
More perturbation theory, variational methods, semi-classical methods and application to radiation theory, scattering theory, linear response theory, and rudiment of relativistic quantum mechanics, including the Klein-Gordan and the Dirac equations. Prerequisite: Physics 8710.

Physics 8730: Quantum Mechanics III (3).
Properties of many-particle systems at low temperature. General Formalism for Fermi and Bose systems, Theory of superconductivity and superfluidity, Introduction to quantum spin model - Diagrammatic formulation of quantum electrodynamics. Scattering of electrons and positrons, introduction to radioactive corrections. Prerequisites: Physics 8720. Graded on S/U basis only.

Physics 8801: Topics in Solid State Theory (3).
Selected topics in solid-state theory, including various elementary excitations in solids and their interactions. May be elected more than once. Prerequisite: instructor's consent.

Physics 8820: Relativity and Gravitation (3).
Special and general theories of relativity. Discussion of accelerated observers and the principle of equivalence. Einstein's gravitational field equations, black holes, gravitational waves, and cosmology. Prerequisite: Physics 8610 and Physics 8620.

Physics 9090: Research (credit by arrangement).
Research leading to PhD dissertation. Prerequisite: PhD candidacy has been established. Graded on an S/U basis only.