

# College of Natural Sciences and Mathematics

## 2016-2017 Graduate Catalog

### Department of Biological Sciences

*Bruce Bamber, chair*

*Deborah Chadee, associate chair*

*Tomer Avidor-Reiss, graduate adviser*

The department of biological sciences offers graduate degrees at master's and doctoral levels. Students entering the M.S. or Ph.D. programs are expected to have an adequate background in natural sciences and in mathematics. Usually, this will require knowledge of differential and integral calculus, college physics, organic and general chemistry, and biology. Students may be admitted on a provisional basis if they do not have an adequate academic background, but they will be expected to acquire it as rapidly as possible.

#### Requirements for the M.S. in Biology Program (Cell/Molecular Biology Concentration)

**Option A (Thesis):** For the degree of master of science in biology (cell/ molecular biology concentration), a student must complete a minimum of 30 semester hours of graduate course work approved by an advisory committee, including BIOL 6000, 6010, 6090, 6100, 6200 and 6930 (two hours) and additional course and research credits for 13 to 17 hours. In some cases, a written comprehensive examination may be required at the end of the first year for students with deficiencies in their coursework. The student must complete six to 10 hours of BIOL 6960, write an original research thesis, and pass an oral examination on the thesis.

**Option B (Non-thesis):** For the degree of master of science in biology, a student must complete a minimum of 30 semester hours of graduate course work approved by an advisory committee, including BIOL 6010, 6090, 6100 and 6930 (two hours) and additional course and research credits for a total of 30 hours. A maximum of three hours in BIOL 6960, 6980 or 6990 may be included in the minimum 30 hours. The student must write an original research paper based on library research that meets the approval of the student's advisory committee and pass an oral examination defending the research hypothesis. Normally, students choosing Option B will not be encouraged to pursue graduate study beyond the M.S. degree.

Up to 10 hours of graduate credit may be transferred from another accredited institution, as recommended by the student's advisory committee.

#### Requirements for the Master of Science and Education

For the degree of master of science and education, students must meet requirements for the degree as stated in the Judith Herb College of Education graduate section of this catalog. In addition, no more than 8 hours may be earned in 5000-level courses. Students doing their theses in biology rather than in education must fulfill the same thesis-related requirements as other biology M.S. candidates.

## Requirements for the Ph.D. in Biology Program (Cell/Molecular Biology Concentration)

The doctoral degree in biology (cell/molecular biology concentration) is awarded to a student who has demonstrated mastery in the field of biology and a distinct and superior ability to make substantial contributions to the field. It is not awarded merely as a result of courses taken, nor for years spent in studying or research. The quality of work and the resourcefulness of the student must be such that the faculty can expect a continuing effort toward the advancement of knowledge and significant achievement in research and related activities.

In general, work for the Ph.D. takes five years of study beyond the bachelor's degree. A substantial portion of this time is spent in independent research leading to a dissertation. Up to 30 hours toward a master's degree may apply as part of the student's doctoral program. Normally 90 semester hours of study beyond the bachelor's degree are required for the Ph.D.

Each student must complete an individualized program of study in the area of cell/molecular biology approved by the student's advisory committee and the department. This course of study must include BIOL 8000, 8010, 8090, 8100 8200 and 8930 (three hours) and additional course and research credits to attain the minimum number of semester hours. Ph.D. candidates must pass a written and oral qualifying examination in the spring of their second year of the program and a final written and oral dissertation defense examination. After passing the qualifying examination, the student must meet each year with their Dissertation Committee and have a first-authorship manuscript accepted by a peer-reviewed scientific journal in order to be qualified for defense of their dissertation research.

Courses numbered at the 5000 and 6000 levels are intended primarily for students at the master's level. Courses numbered at the 7000 and 8000 levels are intended primarily for students at the post-master's (students with a master's degree, or with more than 34 graduate credit hours) and doctoral levels. Courses carrying a dual listing (numbered at both 5000/7000 or 6000/8000 levels) are available to students at both levels. In these cases, there may be substantive differences in the course requirements for students registered at the advanced level.

The department considers experience in teaching to be a vital and significant component of graduate education. Therefore, all graduate students in the Ph.D. program are required to complete at least one semester of formal teaching experience. M.S. students also are expected to acquire teaching experience as part of their graduate programs.

## Department of Chemistry and Biochemistry

*Jon R. Kirchhoff, chair*

*Cora Lind-Kovacs, associate chair*

*Don R. Ronning, director of graduate studies*

## The Master's Program

The master's program in chemistry increases the professional competence of the chemist beyond the bachelor's degree. Course work, independent research and small group discussions are emphasized to achieve this goal. The master of science degree can be viewed as an important professional goal or as preparation for study toward the doctoral degree. A non-thesis M.S. option is available for students with full-time employment whose current work responsibilities preclude the possibility of conducting the requisite research for the thesis-based M.S. degree. School teachers, non-traditional students, and employees of local industry who want to earn an M.S. degree for promotions and/or to meet eligibility requirements for teaching positions at regional community colleges may wish to pursue this option. A Professional Science Master's in Green Chemistry and Engineering option is available for students who want to concentrate their M.S. studies on green chemistry principles and incorporate aspects of green engineering, business, and other professional skills into their M.S. degree in chemistry. The PSM option is intended for students seeking jobs in industry, selected government agencies, or non-governmental organizations that require skills beyond those obtained in a traditional chemistry curriculum. The PSM track in Green Chemistry and Engineering is not a research-based M.S. degree.

## Requirements for the Thesis-Based Master's Program

For the degree of master of science, students must meet the following departmental requirements:

- a. The courses presented must total at least 30 hours of graduate credit, including at least four hours of credit in graduate research.
- b. Registration for research seminar is typically required each term the student is enrolled in graduate research.
- c. Each candidate must present a thesis.
- d. Registration for chemistry colloquium is typically required each term, but no more than four hours of credit may count within the required 30 hours.
- e. Each candidate must demonstrate satisfactory performance on a comprehensive oral examination on his or her thesis research, in addition to the public defense of the thesis at a colloquium presentation.
- f. Upon choosing a research director, an advisory committee will be appointed to supervise the research, to administer the comprehensive oral examination, and to approve the thesis. Each student, in conjunction with the director of graduate studies, the research director, and the student's advisory committee, will prepare a plan of study listing the courses and other requirements for the degree. Upon approval, the plan of study becomes the list of course requirements for the degree. Students are required to take four or more 6000-level courses covering at least three different subdisciplines of chemistry as part of the plan of study.
- g. Each student must register and successfully complete CHEM 6940, *Scientific Communication*.

### **Requirements for the Non-Thesis Master's Program**

For the non-thesis master of science degree, students must meet the following departmental requirements:

- a. The courses presented must total at least 32 hours of graduate credit.
- b. Each student, in conjunction with the director of graduate studies, will prepare a plan of study listing the courses and other requirements for the degree. Upon approval, the plan of study becomes the list of course requirements for the degree. Students are required to take five or more chemistry 6000-level courses (minimum 20 credit hours) as part of the plan of study. To establish breadth in knowledge, at least one course in each of four (out of six) subdisciplines of chemistry (analytical, biochemistry, inorganic, materials, organic, physical) must be completed. Up to 8 hours of 6000-level courses in other fields may also be applied towards the degree with permission of the director of graduate studies.
- c. Registration for chemistry colloquium is required during some terms, but no more than two hours of credit may count within the required 32 hours.
- d. Credit for thesis research or research seminar may not be applied towards the required 32 hours.
- e. Each candidate must participate in CHEM 6940, *Scientific Communication*, and demonstrate satisfactory performance on a departmental literature colloquium presentation.

### **Requirements for the Professional Science Master's Program in Green Chemistry and Engineering**

For the professional science master's degree, students must meet the following departmental requirements:

- a. The courses presented must total at least 36 hours of graduate credit.
- b. Each student, in conjunction with the director of graduate studies and the director of the School of Green Chemistry and Engineering, will prepare a plan of study listing the courses and other requirements for the degree. Upon approval, the plan of study becomes the list of course requirements for the degree. Students are required to take CHEM 6200, CHEM 6210,

CHEE 6010, CHEE 6110, BUAD 6600, either EFSB 6690 or 6590, and 12 credit hours of elective graduate coursework in traditional areas of chemistry or chemical engineering.

- c. Each student must also complete a graduate industrial internship (CHEM/CHEE 6970). The graduate industrial internship must be completed at an industry, governmental organization, or non-governmental organization in an area relevant to green chemistry and engineering. The PSM program director will assist in identifying internship opportunities and must approve all placements. Students who are working or have worked part or full-time in a relevant job may request internship credit for this work experience. The director will evaluate all such requests and give credit if appropriate.
- d. Up to 4 credit hours of 6000-level coursework in a related discipline (e.g., environmental sciences, physics) may be applied to the minimum 12 credit hours of electives if approved by the director of the PSM program and director of graduate studies. Up to 2 credit hours of independent research (CHEM 6980) may also be applied if approved by the director of the PSM program. Research seminar (CHEM 6930) and colloquium (CHEM 6920) cannot be applied towards the 36 hour minimum for the PSM track.

## Requirements for the Master of Science and Education

For the degree of master of science and education, students must meet requirements for the degree as stated in the Judith Herb College of Education graduate section of this catalog.

## The Doctoral Program

The doctoral program in chemistry is designed to ensure that the student has the basic foundation of knowledge and is equipped with the tools necessary to perform independent research. The emphasis on research recognizes the power of original research to arouse the scientific curiosity of the student, to develop and stimulate creativity, and to encourage further discovery through independent study.

The doctoral program is divided into three stages for the typical student. The first stage establishes, through a set of prescribed courses, the foundation for further training. During this stage, a research director is chosen. During the second stage, the student will pursue research toward the dissertation and undertake comprehensive examinations, including the preparation of the required research proposal. After meeting the comprehensive examination requirements, the student is admitted to candidacy in the third stage of the program. This stage is devoted to research and completion of the doctoral dissertation. The departmental degree requirements are listed in the following section. Further details on examinations and admission to candidacy may be obtained from the department.

## Requirements for the Doctoral Program in Chemistry

Candidates for the doctor of philosophy degree must meet the following requirements:

- a. Each student, in conjunction with the director of graduate studies, the student's research director, and the student's advisory committee, will prepare a doctoral program proposal (plan of study) listing the courses and other requirements for the degree. Upon approval, the program proposal becomes the list of course and other requirements for the degree. Students are required to take six or more 8000-level courses covering at least four different subdisciplines of chemistry as part of the plan of study.
- b. Successful completion of a comprehensive qualifying examination for entry to doctoral candidacy.
- c. Registration for chemistry colloquium is typically required each term.
- d. Registration for research seminar is typically required each term the student is enrolled in graduate research.
- e. Each student must satisfactorily complete two semesters of supervised, half-time teaching.



- f. After admission to candidacy, each student is required to spend a minimum of two consecutive semesters in full-time study at The University of Toledo.
- g. Dissertation research must be carried out primarily in laboratories of The University of Toledo.
- h. Each candidate must demonstrate satisfactory performance on a comprehensive oral examination on his or her dissertation research, in addition to the public defense of the dissertation at a colloquium presentation.
- i. Each student must register and successfully complete CHEM 8940, *Scientific Communication*.

## Department of Environmental Sciences

*Timothy G. Fisher, chair*

*Johan F. Gottgens, associate chair*

*Daryl L. Moorhead, graduate adviser*

The department of environmental sciences (DES) offers graduate degrees in geology and biology at the master's level and in biology at the doctoral level. Students entering the M.S. or Ph.D. programs are expected to have an adequate background in the natural sciences and mathematics, but may be admitted on a provisional basis if they lack such a background. Complete program details are available at the department website.

## Requirements for the Master of Science Programs

### Master of Science in Geology

**Option A (Thesis):** A minimum of 30 credit hours of approved graduate coursework is required for the master's degree in geology (average 42 hours). This includes 24 hours of formal courses (excluding EEES 6960 Thesis Research and 6990 Independent Study) with a minimum of 19 hours in DES that must include EEES 5200 Quaternary Geology, 5240 Soil Science, 5410 Hydrogeology, 6100 Glacial Stratigraphy & Geophysics, 6250 Graduate Launch, 6930-009 Departmental Seminar (1 hr. each semester) and the remaining courses selected with approval of the student's thesis committee taken at the 5000 level or above; all but EEES 6930 must be taken for a letter grade (A–F). Additional credit hours will include EEES 6960 Thesis Research and/or EEES 6990 Independent Study, a maximum of 6 hours of which may be taken for a letter grade, and may also include other DES or non-DES courses that need not be taken for a letter grade. The student must also prepare a thesis consisting of a written report on original independent research conducted by the student under the supervision of his or her thesis adviser (or co-advisers) and defend this thesis before his or her advisory committee.

**Option B (Non-thesis):** The non-thesis option for a master's degree in geology differs from the thesis option (above) by requiring 27 hours of formal courses and a maximum of 3 hours of EEES 6960 Thesis Research or 6990 Independent Study; all but EEES 6930 (seminars) must be taken for a letter grade (A–F). The student also must write an original report based on library research and defend this report before his or her advisory committee.

### Master of Science in Biology (Ecology Track)

**Option A (Thesis):** A minimum of 30 credit hours of approved graduate coursework is required for the master's degree in biology (average 42 hours). This includes 24 hours of formal courses (excluding EEES 6960 Thesis Research and 6990 Independent Study) with a minimum of 19 hours in DES that must include EEES 5160 Advanced Environmental Data Management, 6250 Graduate Launch, 6400 Biostatistics, 6600 Foundation of Ecology, 6930-009 Departmental Seminar (1 hr. per semester) and the remaining courses selected with approval of the student's thesis committee taken at the 5000 level or above; all but EEES 6930 (seminars) must be taken for a letter grade (A–F). Additional credit hours will include EEES 6960 Thesis Research and/or EEES 6990 Independent Study, a maximum of 6 hours of which may be taken for a letter grade, and may also include other DES or non-DES courses that need not be taken for a letter grade. The student must also prepare a thesis consisting of a written report on original independent research conducted by the student under the supervision of his or her thesis adviser (or co-advisers) and defend this thesis before his or her advisory committee.

**Option B (Non-thesis):** The non-thesis option for a master's degree in biology differs from the thesis option (above) by requiring 27 hours of formal courses and a maximum of 3 hours of EEES 6960 Thesis Research or 6990 Independent Study; all

but EEES 6930 (seminars) must be taken for a letter grade (A–F). The student also must write an original report based on library research and defend this report before his or her advisory committee.

## **Master of Science and Education in Biology (Ecology Track)**

### **Master of Science and Education in Geology**

The master of science and education (MSE) is a degree offered by the Judith Herb College of Education in collaboration with the College of Natural Sciences and Mathematics. Within the degree program, area concentrations are possible in both biology and geology. Students must meet requirements for the degree as stated in the Judith Herb College of Education graduate section of this catalog.

## **Requirements for the Doctoral Program in Biology (Ecology Track)**

In general, work for the Ph.D. requires a minimum of 90 credit hours of study beyond the bachelor's degree. A substantial portion of this time is spent performing independent research leading to an original thesis that is substantially more in depth than a MS thesis. Work performed toward a MS may apply in part to the student's doctoral program.

Each student must complete an individualized program of study in an area of ecology that is approved by the student's advisory committee. This program must include 24 hours of formal courses (excluding EEES 8960 Thesis Research and 8990 Independent Study) with a minimum of 19 hours in DES that must include EEES 5160 Advanced Environmental Data Management, 8250 Graduate Launch, two semesters of statistics (e.g., EEES 8400 Biostatistics and an advanced statistics course such as EEES 8650 Statistical Modeling in Environmental Sciences), EEES 8600 Foundations of Ecology, 8930-009 Departmental Seminar (1 hr. per semester), and the remaining courses selected with approval of the student's thesis committee taken at the 7000 level or above; all but EEES 8930 (seminars) must be taken for a letter grade (A–F). Additional credit hours will include EEES 8960 Thesis Research and/or EEES 8990 Independent Study, a maximum of 6 hours of which may be taken for a letter grade, and may also include other DES or non-DES courses that need not be taken for a letter grade. Students must pass a written qualifying examination during the first two years of study, an oral comprehensive examination and a defense of their research proposal.

All graduate students in the Ph.D. program are required to complete at least one semester of formal teaching-assistant experience before graduation. In addition, before a student graduates, she or he is to: (1) submit a manuscript on their research to a scholarly, peer-reviewed journal; (2) give a presentation of their research at a professional conference; and (3) make an oral presentation on their research at a scholarly forum (an oral presentation at a professional conference would satisfy both latter requirements, but a poster presentation would not).

## **Department of Mathematics and Statistics**

*Don White, Chair*

*Alessandro Arsie, Associate Chair*

*For Graduate Admissions, please contact the department office*

A full description of programs and requirements, with syllabi for exams, is available from the department office or on its Web site at [www.math.utoledo.edu](http://www.math.utoledo.edu). The paragraphs below represent a synopsis of the essential elements.

### **Requirements for the Master's Programs**

#### **Master of Arts**

To obtain the Master of Arts degree in mathematics, students must complete a minimum of 30 semester hours of graduate credit and meet the following requirements:

1. Complete two-semester sequences in Abstract Algebra (5330, 5340), Real Analysis (5820, 5830), and Topology (5450, 5460), and a semester course in Complex Variables (5880).
2. Complete one, two-semester sequence at the 6000 level in Algebra (6300, 6310), Topology (6400, 6410), Differential Geometry (6450, 6460), Differential Equations (6500, 6510), Real Analysis (6800, 6810), or Complex Analysis (6840,

- 6850).
- Complete one of the following courses: Classical Differential Geometry (5540), Ordinary Differential Equations (5800), Partial Differential Equations (5810), Calculus of Variations and Optimal Control (5860), or any course at the 6000 level listed under item 2.
  - The student must pass a three-part comprehensive examinations or write a master's thesis. If a thesis is elected, the student must take an oral examination on the general area of the thesis.

## Master of Science

The degree of Master of Science can be obtained in one of two options.

**Option A – Applied Mathematics:** To obtain the degree of Master of Science in the applied mathematics option, the student must complete a minimum of 30 semester hours of graduate credit and meet the following requirements:

- Complete two-semester sequences in Numerical Analysis (5710, 5720), Real Analysis (5820, 5830), and Differential Equations (6500, 6510), and a semester course in Complex Variables (5880).
- Remaining courses may be chosen from the following: Applied Functional Analysis (6150), Differential Geometry (5540), Differential Equations (6500, 6510), Dynamical Systems (6520, 6530), Methods of Mathematical Physics (6720), Functional Analysis (6820), Complex Variables (5880), Discrete Structures and Analysis of Algorithms (5380), Probability Theory (5680), Introduction to Mathematical Statistics (5690), Operational Mathematics (5850), or Calculus of Variations (5860).
- The student must pass a two-part comprehensive examination or submit and defend a master's thesis.

**Option B – Statistics:** To obtain the degree of Master of Science in the statistics option, the student must complete a minimum of 35 semester hours of graduate credit and meet the following requirements:

- Complete Introduction to Theory of Probability (5680), Introduction to Mathematical Statistics (5690), Advanced Statistical Methods I (5600), Advanced Statistical Methods II (5610), Linear Statistical Models (5620), Theory and Methods of Sample Surveys (5630), Statistical Computing (5640), Categorical Data Analysis (6620), Nonparametric Statistics (6630), Topics in Statistics (6640), Statistical Inference (6650), and Multivariate Statistics (6690).
- Pass a two-part comprehensive examination, one part in probability and statistical theory and one part in applied statistics.

## Master of Science and Education or Master of Arts and Education

For the degree of Master of Arts and education, students must meet requirements for the degree as stated in the Judith Herb College of Education graduate catalog. The following requirements must also be met:

- A minimum of 36 hours of graduate credit must be completed. Colloquium (6930) and Proseminar (6940) do not count toward the 36 hours.
- The total graduate and undergraduate program must include the following: at least six hours of abstract algebra and/or linear algebra, six hours in geometry, statistics, probability and/or computer programming, three to six hours of analysis (beyond calculus), three hours of complex analysis and one course in logic and foundations.
- The student must pass comprehensive examinations in three of the areas of study of mathematics. The exact areas are to be arranged with the adviser.
- For information on the education course requirements, see the program description provided by the Judith Herb College of Education.

## Requirements for the Doctoral Program

The doctorate in mathematics is offered with concentrations in either mathematics or statistics. The broad requirements for these programs are as follows:

1. Each student must pass a preliminary examination at the Master's level by the end of the first year and a qualifying examination within two years of entering the program. Mathematics students must pass two topics chosen from algebra, topology and analysis. For statistics students, the two topics must be measure-theoretic probability and probability and statistics.
2. A minimum of 90 hours of graduate credit must be completed; 60 hours if the student holds a master's degree upon entry. Colloquium (6930) and Proseminar (6940) do not count in these hours. Mathematics students must complete two-semester sequences at the 6000 level in algebra, topology, real analysis and complex analysis. Statistics students must complete probability and statistics, measure-theoretic probability, statistical methods, data analysis and multivariate statistics.
3. The student must pass an oral examination in the general area of the intended thesis research within one year of passing the qualifying examination.
4. All doctoral students are expected to participate in the Proseminar (6940) on undergraduate teaching methods and to spend two consecutive semesters in supervised teaching. Enrollment in the Proseminar is mandatory every semester if credit hour limitations allow it.

The student must write a Ph.D. doctoral dissertation under the direction of a faculty member. Before completing the dissertation, the student must report on it in an open seminar. An outside examiner must approve the completed dissertation, and the student must defend it before a faculty committee appointed for that purpose.

## Department of Physics and Astronomy

*Sanjay V. Khare, chair*

*Song Cheng, graduate adviser*

### Requirements for the Master's Degree

For the master of science or master of science and education, a student must complete 30 hours of graduate credit that includes the following:

- (a) PHYS 6140 and an additional 15 hours of graduate course credit in physics, with six of the 15 hours numbered above 6000. Credit in PHYS 5900, 6010 and/or 6020 will not count toward either degree.
- (b) The student must present a satisfactory thesis based on directed research, for no more than eight credit hours.
- (c) The remaining hours within the 30 total may be chosen from graduate courses approved by the student's committee. In some cases students working toward the Ph.D. may earn the M.S. degree without formal presentation of the M.S. thesis if they have passed the Ph.D. qualifying examination, satisfied the course requirements for the M.S., and completed a research project under the supervision of a research adviser. Students meeting these requirements may petition the department to grant the M.S. without formal presentation of a thesis.

### M.S. in Physics with Materials Science Option

A master of science degree in physics with a materials science option is available. For this degree, a student must complete 30 hours of graduate credit, including the following:

- (a) PHYS 6140, 6540, 6550 and an additional 12 hours of graduate course credit in physics with six of the 12 hours numbered above 6000 (no degree credit for PHYS 5900, 6010 or 6020).
- (b) The student must present a satisfactory thesis based on directed research, for no more than eight credit hours.
- (c) The remaining hours within the 30 total may be chosen from any graduate courses approved by the student's committee.

### Professional Science Masters in Photovoltaics



The PSM-PV is designed for students with an undergraduate degree in Physics, Chemistry, an Engineering discipline (e.g. Electrical, Chemical, or Mechanical), or an otherwise related field. For the degree of Professional Science Masters in Photovoltaics, a student must complete 37 hours of graduate credit including the following.

PHYS 6020 (Physics Journal Seminar, 2 hrs), PHYS 6250 (Classical Electrodynamics I, 3 hrs),

PHYS 6280 (Photovoltaic Materials and Device Physics Laboratory, 3 hrs), PHYS 6320 (Quantum Mechanics I, 3 hrs), PHYS 6630 (Semiconductors I, 3 hrs), PHYS 6940 (Industrial Internship, 6 hrs), PHYS 6960 (MS Thesis Research in PV, 2 hrs), PHYS 6980 (Fundamentals of Solar Cells, 3 hrs), PHYS 6990 (Independent Study, 3 hrs), and BUAD 6600 (Supply Chain Management, 3 hrs), INFS 6560 (System Analysis and Design, 3 hrs), and either EFSB 6590 (New Venture Creation, 3 hrs) or EFSB 6690 (Technology Commercialization, 3 hrs). No thesis is required; however, students are expected to make an oral presentation based on research and independent study.

## Master of Science and Education

For the degree of master of science and education, students must meet requirements for the degree as stated in the Judith Herb College of Education graduate section of this catalog.

## Requirements for the Doctoral Program

For the doctor of philosophy degree, a student must complete a total of 90 hours of graduate credit including the following: MATH 6730; PHYS 7220, 7250, 7260, 7320, 7330 and 7450; at least 18 additional hours of credit in physics in courses numbered higher than 6100 approved by the student's committee; and 30 to 48 hours allowed for the dissertation research, depending on the nature of the research and the needs of the student. Credit in PHYS 5900, 6/8010, 6/8020, 6/7030 or 7910 will not count toward degree requirements.

The doctoral degree requirements include a Ph.D. qualifying examination, a comprehensive examination, and a final oral examination. Passing the qualifying examination is a prerequisite for status as a Ph.D. candidate in physics. After passing the qualifying examination, the doctoral student must select a field of specialization. A faculty committee is formed, chaired by the research adviser, to evaluate the student's progress and to establish an appropriate program of course work. This committee administers the oral comprehensive examination, after which only the dissertation research requirement remains. The graduate program ends with the student presenting the dissertation and defending it satisfactorily in an oral examination.

### Ph.D. in Physics with Concentration in Astrophysics

The Ph.D. in physics with concentration in astrophysics satisfies all the requirements for the Ph.D. in physics while preparing students for a career in astronomy and astrophysics.

To fulfill the requirement of 18 hours of credit in physics courses numbered above 6100, the concentration requires:

- PHYS 6/7810-20-30-40 [Stellar Astrophysics I and II, Galactic Astronomy I and II]
- Two related elective courses, which may include: PHYS 6/7710 [Atomic Physics], PHYS 6/7720 [Atomic and Molecular Spectroscopy], PHYS 6/7740 [Nuclear Physics], PHYS 8860 [General Relativity], or PHYS 8870 [Cosmology] or other appropriate courses

In addition:

- Three hours of PHYS 6/8980 [Special Topics] on an astrophysics-related topic or PHYS 6/8890 [Current Issues in Astrophysics]
- A satisfactory dissertation in astronomy or astrophysics with a supervisor who is a member of the Ritter Astrophysical Research Center.

## Ph.D. in Physics with Concentration in Materials Science

The Ph.D. in physics with concentration in materials science satisfies all the requirements for the Ph.D. in physics while preparing students for a career in materials science.

In addition, the concentration requires:

- Two core courses in the fundamentals of materials science:
  - PHYS 8540 Structure, Defects and Diffusion
  - PHYS 8550 Thermodynamics and Phase Transformation in Condensed Systems;
- Two additional elective courses in materials science and engineering chosen from a list of courses approved by the faculty of the Center for Materials Science and Engineering; and
- A dissertation in a materials-related field with a supervisor who is a member of the Center for Materials Science and Engineering.

## Ph.D. in Physics with Concentration in Medical Physics

The Ph.D. in physics with concentration in medical physics satisfies all of the requirements for a Ph.D. in physics degree while preparing students for a career in medical physics. The medical physics-related courses, which total at least 27 credit hours, are provided by the College of Medicine and Life Sciences. The student's faculty advisory committee will consist of faculty members from the department of physics and astronomy and the medical physics fields. The committee may also include other members appropriate for this degree. A dissertation research project is chosen that will have relevance to both physics and medical physics. The Ph.D. requirement of 18 additional credit hours outside the core courses will be satisfied by the specified additional graduate courses in physics and in medical physics.

