Physics

Degrees Offered

• Master of Science
• Doctor of Philosophy

Nature of the Program

The graduate program is designed to provide a solid background in classical and modern physics, a broad understanding of major research fields, and concentrated research experience in one area. Applicants normally enter with a bachelor of science degree in physics. A student whose background is weak in a particular area is encouraged to register for the appropriate undergraduate course. The normal first-year courses include PHYS 611, PHYS 651, PHYS 631, and PHYS 633 plus possible electives. In the courses, no distinction is made between those students who intend a terminal M.S. degree and those who intend a Ph.D. degree. The minimum grade for credit in graduate courses is C, and a grade point average of 2.75 must be maintained. A GPA of 3.0 is required for graduation with either a M.S. or Ph.D. degree. Progress of all graduate students is reviewed annually by the graduate advisor or their PhD committee.

Financial Aid

With rare exceptions, all students who are admitted receive financial support. Beginning students usually receive teaching assistantships; more advanced students receive research assistantships. Several fellowships are available for outstanding students, allowing full-time concentration on coursework and research and a more rapid progress toward the degree.

FACULTY

CHAIR

• Earl Scime - Ph.D. (University of Wisconsin-Madison)
  Oleg D. Jefimenko Professor, Plasma Physics

PROFESSORS

• Wathiq Abdul-Razzaq - Ph.D. (University of Illinois - Chicago)
  Physics Education
• Paul Cassak - Ph.D. (University of Maryland)
  Plasma Physics
• Leonardo Golubovic - Ph.D. (University of Belgrade)
  Condensed Matter Physics and Statistical Physics
• Matthew B. Johnson - Ph.D. (California Institute of Technology)
  Condensed Matter Physics
• Mark E. Koepke - Ph.D. (University of Maryland)
  Plasma Physics
• James P. Lewis - Ph.D. (Arizona State University)
  Condensed Matter Physics
• Lian Li - PhD (University of Arizona)
  Carroll Professor, Condensed Mater Physics
• Duncan Lorimer - Ph.D. (University of Manchester)
  Astrophysics/Astronomy
• Maura McLaughlin - Ph.D. (Cornell University)
  Eberly Family Professor, Astrophysics/Astronomy
• Earl E. Scime - Ph.D. (University of Wisconsin - Madison)
  Oleg D. Jefimenko Professor, Plasma Physics
• Gay Stewart - Ph.D. (University of Illinois-Urbana Champaign)
  Eberly Professor of STEM Education

ASSOCIATE PROFESSORS

• Loren Anderson - Ph.D. (Boston University)
  Astrophysics/Astronomy
• Alan Bristow - Ph.D. (University of Sheffield)
  Condensed Matter Physics
• Cheng Cen - Ph.D. (University of Pittsburgh)  
  Condensed Matter Physics
• Edward Flagg - Ph.D. (University of Texas - Austin)  
  Condensed Matter Physics
• Mikel Holcomb - Ph.D. (University of California - Berkeley)  
  Condensed Matter Physics
• Paul Miller - Ph.D. (West Virginia University)  
  Physics Education Research
• D.J. Pisano - Ph.D. (University of Wisconsin - Madison)  
  Astrophysics/Astronomy
• Tudor Stanescu - Ph.D. (University of Illinois)  
  Theoretical Condensed
• John Stewart - Ph.D. (University of Illinois-Urbana Champaign)  
  Physics Education Research

ASSISTANT PROFESSORS
• Adam Kobelski - Ph.D. (University of Montana)  
  Solar Physics, Physics Education Research
• Joonhee Lee - Ph.D. (Seoul National University)  
  Biophysics
• Sarah Burke Spolaor - Ph.D. (Swinburne Institute of Technology)  
  Astrophysics/Astronomy
• Sean McWilliams - Ph.D. (University of Maryland)  
  Astrophysics/Astronomy
• Weichao Tu - Ph.D. (University of Colorado-Boulder)  
  Space Plasma Physics
• Kathryn Williamson - Ph.D. (Montana State University)  
  Astronomy Education Research

RESEARCH PROFESSORS
• Vladimir Demidov - Ph.D. (St. Petersburg University)  
  Plasma Physics and Plasma Chemistry

ADJUNCT ASSOCIATE PROFESSORS
• Amy Keese - Ph.D. (West Virginia University)  
  Experimental Plasma Physics
• Julian Schulze - Ph.D. (Ruhr University - Bochum)  
  Plasma Physics

RESEARCH ASSISTANT PROFESSOR
• Yanjun Ma - Ph.D. (University of Pittsburgh)  
  Condensed Matter Physics
• Qiang Wang - Ph.D. (University of Colorado - Boulder)  
  Condensed Matter Physics

PROFESSORS EMERITI
• Larry Halliburton - Ph.D. (University of Missouri - Columbia)  
  Condensed Matter Physics
• Arthur S. Pavlovic - Ph.D. (Columbia University)  
  Condensed Matter Physics
• Mohindar S. Seehra - Ph.D. (University of Rochester)  
  Condensed Matter Physics
• Richard Treat - Ph.D. (University of California - Riverside)  
  General Realativity
• H. Arthur Weldon - Ph.D. (Massachusetts Institute of Technology)  
  Particle Physics
Admissions

Applicants are expected to have a bachelor’s degree in physics with upper-division courses in electricity and magnetism, mechanics, quantum mechanics, thermodynamics, and mathematical methods with a GPA of at least 3.0. Students lacking some of these courses may be admitted provisionally and will be allowed to remedy the deficiencies by taking the appropriate undergraduate courses. The GRE General Test is required. The GRE Physics Subject Test is strongly recommended, particularly for students from non-US institutions. If English is not the student’s native language, TOEFL or IELTS scores are also required. The application deadline is January 15. There is no distinction made between admission to the Ph.D. and M.S. programs. Contact the department for additional information.

Master of Science

- **Credit Hours:** Students are required to complete a minimum number of 31 graduate-level credit hours in Physics or Astronomy.
- **Grade Point Average:** Students must earn a minimum cumulative and major GPA of 2.75, and a minimum grade of C- in all classes applied to the degree.

MAJOR REQUIREMENTS

<table>
<thead>
<tr>
<th>CORE COURSES</th>
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<tbody>
<tr>
<td>PHYS 611</td>
<td>Introduction to Mathematical Physics</td>
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<tr>
<td>PHYS 631</td>
<td>Advanced Classical Mechanics 1</td>
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<td>PHYS 633</td>
<td>Electromagnetism 1</td>
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<tr>
<td>PHYS 651</td>
<td>Quantum Mechanics 1</td>
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<tr>
<td>PHYS 761</td>
<td>Statistical Mechanics</td>
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<td>PHYS 799</td>
<td>Graduate Colloquium</td>
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<tr>
<td><strong>Non-Thesis Option:</strong></td>
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<tr>
<td>5 courses in PHYS or ASTR at the 600 or 700 level *</td>
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<td><strong>Thesis Option:</strong></td>
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<tr>
<td>1 course in PHYS or ASTR at the 600 or 700 level *</td>
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<tr>
<td>PHYS 697</td>
<td>Research</td>
</tr>
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</table>

Total Hours 31

* Except ASTR 697, ASTR 797, PHYS 697, PHYS 797, or PHYS 799.

Degree Requirements

- **Course Requirements:** Students must complete a minimum of 46 credit hours in physics or astronomy at the 600 or 700 level.
- **Calculation of the GPA:** Students must maintain a minimum overall GPA of 2.75, and 3.0 or better in graduate physics or astronomy courses taken at WVU.
- **Research Requirement:** Research is the central focus of the degree and is directed by a faculty adviser over a period of several years. When the research is completed, the student must write a dissertation and defend it before the doctoral committee of four faculty. The average completion time for the Ph.D. is five years beyond the B.S. Research specialties within the department include astrophysics/astronomy, biophysics, condensed matter physics, physics education research, and plasma physics.
- **Candidacy Examinations:** To be admitted to candidacy for the Ph.D., a student must pass both a written and an oral candidacy examination. The written examination consists of three parts: quantum mechanics, electromagnetism, and classical mechanics.
- **Progress Toward Completion:** Students must maintain a GPA of 3.0 or better in graduate physics and astronomy courses taken at WVU. Students must pass all three graduate qualifying exams by the end of their fourth semester. All students are evaluated annually before the end of September by their Ph.D. committee.

Curriculum Requirements

<table>
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<tr>
<th>CORE COURSES</th>
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<tbody>
<tr>
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<td>Quantum Mechanics 1</td>
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PHYS 761  Statistical Mechanics
PHYS 797  Research
PHYS 799  Graduate Colloquium

ADVANCED COURSES:

Select two of the following courses:

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<tr>
<td>ASTR 703</td>
<td>Galactic Astronomy</td>
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<tr>
<td>ASTR 704</td>
<td>General Relativity</td>
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<td>PHYS 772</td>
<td>Semiconductor Physics</td>
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<tr>
<td>PHYS 773</td>
<td>Collective Phenomena in Solids</td>
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<tr>
<td>PHYS 774</td>
<td>Optical Properties of Solids</td>
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<tr>
<td>PHYS 783</td>
<td>Advanced Kinetic Theory of Plasmas</td>
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<tr>
<td>PHYS 784</td>
<td>Advanced Magnetohydrodynamic Theory of Plasmas</td>
</tr>
<tr>
<td>PHYS 791</td>
<td>Advanced Topics</td>
</tr>
</tbody>
</table>

ELECTIVES:

Select three ASTR or PHYS courses at the 600 or 700 level.

Except ASTR 797 and PHYS 797

**Degree Progress**

Typical plans of study for M.S. and Ph.D. students are available in the Graduate Student Handbook. Students are evaluated each year by either the Graduate Advisor or their Ph.D. committee.

To remain in good standing in the program, each student must maintain a 3.0 GPA or better. Upon completion of their third written qualification exam, Ph.D. students have up to 2 years to pass the oral qualification exam. The committee that gives the oral exam must consist of at least four members, with one of these members being external to the department. This committee also forms the Ph.D. advisory committee and the defense exam committee, with the chair of this committee being the student’s research advisor.

After the oral exam, Ph.D. students have 5 years to defend their Ph.D. dissertation. Each year, Ph.D. students must give a presentation and submit a report to the Ph.D. advisory committee for the evaluation of progress towards completion of the Ph.D. degree is reviewed and discussed. The report has to be signed by all members of the committee, along with any comments and recommendations, before being submitted to the Departmental graduate advisor. More information is available in the Physics and Astronomy Graduate Student Handbook.

**Major Learning Outcomes**

**PHYSICS AND ASTRONOMY**

The central missions of the Graduate Program in Physics are to train the next generation of Physicists and Astronomers for productive careers in the global economy and to expand the scientific boundaries of physics and astronomy.

Students earning a M.S. or Ph.D. in Physics will be able to:

- Explain physics and astronomy principles as they pertain to their specific field of research.
- Demonstrate the ability to understand and critically evaluate the existing literature published within their field.
- Independently design and execute new experimental, theoretical, or computational studies that can address important scientific questions in physics and astronomy.
- Effectively communicate their research in oral and written formats, including the ability to author manuscripts suitable for publication in peer reviewed scientific journals.
- Understand the ethical impact of personal and professional behavior.

**Academic Standards**

To be a graduate student in good standing requires the following:

- Maintain a GPA of 2.75 or better in graduate physics courses taken at WVU, excluding PHYS 797.
- A GPA of 3.0 or better is required for graduation.
- All entering Ph.D. students are required to take all three written graduate exams at the beginning of, or immediately prior to, their first semester.
• Following the initial exam, as needed, Ph.D. students can retake exams up to three times, but no later than the beginning of their fourth semester of graduate studies.
• Ph.D. students must select a Ph.D. committee of four faculty after passing the written exams.
• Ph.D. students must complete the oral candidacy examination within three semesters (after completing the third section of the written candidacy examination).
• Students admitted as M.S. degree candidates are not expected to take the graduate qualifying exams but must maintain at GPA of 2.75 and complete their M.S. degree within three years.

ASTRONOMY COURSES

**ASTR 591. Advanced Topics. 1-6 Hours.**
PR: Consent. Investigation in advanced topics that are not covered in regularly scheduled courses.

**ASTR 592. Directed Study. 1-6 Hours.**
Directed study, reading, and/or research.

**ASTR 593. Special Topics. 1-6 Hours.**
A study of contemporary topics selected from recent developments in the field.

**ASTR 594. Seminar. 1-6 Hours.**
Special seminars arranged for advanced graduate students.

**ASTR 595. Independent Study. 1-6 Hours.**
Faculty-supervised study of topics not available through regular course offerings.

**ASTR 691. Advanced Topics. 1-6 Hours.**
PR: Consent. Investigation in advanced topics that are not covered in regularly scheduled courses.

**ASTR 692. Directed Study. 1-6 Hours.**
Directed study, reading, and/or research.

**ASTR 693. Special Topics. 1-6 Hours.**
A study of contemporary topics selected from recent developments in the field.

**ASTR 694. Seminar. 1-6 Hours.**
Special seminars arranged for advanced graduate students.

**ASTR 695. Independent Study. 1-6 Hours.**
Faculty-supervised study of topics not available through regular course offerings.

**ASTR 696. Graduate Seminar. 1 Hour.**
PR: Consent. Each graduate student will present at least one seminar to the assembled faculty and graduate student body of his or her program.

**ASTR 697. Research. 1-15 Hours.**
ASTR 697. Research, I, II, S. 1-15 hr. PR: Consent. Research activities leading to thesis (697), problem report (697), research paper or equivalent scholarly project (697), or a dissertation (797). (Grading is S/U.).

**ASTR 698. Thesis or Dissertation. 1-6 Hours.**
PR: Consent. This is an optional course for programs that wish to provide formal supervision is needed during the writing of student reports (698), theses (698), or dissertations (798). (Grading is Normal.).

**ASTR 699. Graduate Colloquium. 1-6 Hours.**
PR: Consent. For graduate students not seeking coursework credit but who wish to meet residency requirements, use the University’s facilities, and participate in its academic and cultural programs. Note: Graduate students who are not actively involved in coursework or research are entitled, through enrollment in their department’s 699/799 Graduate Colloquium, to consult with graduate faculty, participate in both formal and informal academic activities sponsored by their program, and retain all of the rights and privileges of duly enrolled students. Grading is normal; colloquium credit may not be counted against credit requirements for masters programs. Registration for one credit of 699/799 graduate colloquium satisfies the University requirement of registration in the semester in which graduation occurs.

**ASTR 700. Radio Astronomy. 3 Hours.**
Introduction to radio astronomy theory and techniques suitable for graduate students. Topics covered include radio-wave fundamentals, antenna theory, radiation mechanisms, extragalactic sources, pulsars and cosmology.

**ASTR 701. Computational Astrophysics. 3 Hours.**
Introduction to C programming to solve astrophysical problems. Topics covered include hypothesis testing, Monte Carlo simulations and Fourier techniques for analysis of astronomical data.

**ASTR 702. Stellar Structure and Evolution. 3 Hours.**
Comprehensive discussion of birth, life cycle and end products of stars. Topics covered include main-sequence evolution, giant stars, white dwarfs, supernovae neutron stars and black holes.
ASTR 703. Galactic Astronomy. 3 Hours.
Detailed study of galactic structures. Topics covered include galactic dynamics, rotation and spiral density waves, the interstellar medium and supernova remnants.

ASTR 704. General Relativity. 3 Hours.
Innovative 'physics-first' introduction to Einstein's relativistic theory of gravity. Topics covered include special relativity, curved space time, gravitational collapse and black holes.

ASTR 705. The Interstellar Medium. 3 Hours.
PR: ASTR 694. In-depth look at the interstellar medium (ISM), the material in between stars, with a focus on our own Milky Way Galaxy. Topics covered include the composition of our Galaxy, the phases of the ISM, the properties of the gas and dust in the ISM, dust and gas chemistry, magnetic fields, and dynamic processes.

ASTR 791. Advanced Topics. 1-6 Hours.
PR: Consent. Investigation in advanced topics that are not covered in regularly scheduled courses.

ASTR 792. Directed Study. 1-6 Hours.
Directed study, reading, and/or research.

ASTR 793. Special Topics. 1-6 Hours.
A study of contemporary topics selected from recent developments in the field.

ASTR 794. Seminar. 1-6 Hours.
Special seminars arranged for advanced graduate students.

ASTR 795. Independent Study. 1-9 Hours.
Faculty supervised study of topics not available through regular course offerings.

ASTR 796. Graduate Seminar. 1 Hour.
PR: Consent. Each graduate student will present at least one seminar to the assembled faculty and graduate student body of his or her program.

ASTR 797. Research. 1-15 Hours.
PR: Consent. Research activities leading to thesis (697), problem report (697), research paper or equivalent scholarly project (697), or a dissertation (797). (Grading May be S/U).

ASTR 798. Thesis or Dissertation. 2-4 Hours.
PR: Consent. This is an optional course for programs that wish to provide formal supervision is needed during the writing of student reports (698), theses (698), or dissertations (798). (Grading is Normal.).

ASTR 799. Graduate Colloquium. 1-6 Hours.
PR: Consent. For graduate students not seeking coursework credit but who wish to meet residency requirements, use the University's facilities, and participate in its academic and cultural programs. Note: Graduate students who are not actively involved in coursework or research are entitled, through enrollment in their department's 699/799 Graduate Colloquium, to consult with graduate faculty, participate in both formal and informal academic activities sponsored by their program, and retain all of the rights and privileges of duly enrolled students. Grading is normal; colloquium credit may not be counted against credit requirements for masters programs. Registration for one credit of 699/799 graduate colloquium satisfies the University requirement of registration in the semester in which graduation occurs.

ASTR P106. 3 Hours.

PHYSICS COURSES

PHYS 593. Special Topics. 1-6 Hours.
A study of contemporary topics selected from recent developments in the field.

PHYS 611. Introduction to Mathematical Physics. 3 Hours.
PR: Calculus, differential equations, PHYS 111 and PHYS 112 or equivalent. Complex variables: series, contour integration and conformal mapping; ordinary differential equations; Fourier series, Laplace transforms; Fourier transforms; special functions; Bessel functions and Legendre, Hermite differential equations; Poisson's equation, wave equation, and Laguerre polynomials; introduction to partial differential equations.

PHYS 631. Advanced Classical Mechanics 1. 3 Hours.
PR: PHYS 331 and PHYS 332 and differential equations. Lagrange and Hamilton form of equations of motion, rigid bodies, small and nonlinear oscillations. Transformation theory, relativistic dynamics, and systems with an infinite number of degrees of freedom.

PHYS 633. Electromagnetism 1. 3 Hours.

PHYS 634. Electromagnetism 2. 3 Hours.
**PHYS 651. Quantum Mechanics 1. 3 Hours.**

**PHYS 652. Quantum Mechanics 2. 3 Hours.**

**PHYS 691. Advanced Topics. 1-6 Hours.**
PR: Consent. Investigation of advanced topics not covered in regularly scheduled courses.

**PHYS 693. Special Topics. 1-6 Hours.**
A study of contemporary topics selected from recent developments in the field.

**PHYS 697. Research. 1-15 Hours.**
PR: Consent. Research activities leading to thesis, problem report, research paper or equivalent scholarly project, or a dissertation. (Grading may be S/U.)

**PHYS 710. Nonlinear Dynamics. 3 Hours.**
PR: PHYS 631. Flows, fixed-point analysis, and bifurcations in 1D, 2D, and 3D using analytical, numerical, and geometrical approaches. Limit cycles, chaos, fractals, strange attractors, iterated maps, and Hamiltonian systems.

**PHYS 725. Advanced Atomic and Molecular Physics 1. 3 Hours.**

**PHYS 761. Statistical Mechanics. 3 Hours.**
PR: PHYS 461 and PHYS 651. Ensemble theory, applications to noninteracting systems, as well as perturbative and approximate treatment of interactions. Typical applications include equilibrium constants, polymers, white dwarfs, metals, superfluids, magnetic transitions.

**PHYS 771. Introduction to Solid State Physics. 3 Hours.**
PR: PHYS 471 and PHYS 651 or equivalent. Crystal structure and reciprocal lattices. Waves in crystals. Band structure and metals.

**PHYS 772. Semiconductor Physics. 3 Hours.**

**PHYS 773. Collective Phenomena in Solids. 3 Hours.**

**PHYS 774. Optical Properties of Solids. 3 Hours.**

**PHYS 781. Principles of Plasma Physics. 3 Hours.**
Plasmas occur naturally in electrical discharges and in space and are produced artificially in laboratory devices. This course is a survey of plasma phenomena using fluid and kinetic models.

**PHYS 782. Computer Simulation of Plasma. 3 Hours.**
PR: (PHYS 481 or PHYS 781) and PHYS 633; programming proficiency in C, FORTRAN, or BASIC. Projects teach mathematical and physical foundations of computer simulation algorithms and develop and refine physical understanding and intuition of phenomena encountered in plasma research.

**PHYS 783. Advanced Kinetic Theory of Plasmas. 3 Hours.**
PR: PHYS 481 and PHYS 631 and PHYS 634. The Vlasov equation, quasilinear theory, nonlinear phenomena. Plasma waves and instabilities. Landau damping and finite-Larmor-radius effects.

**PHYS 784. Advanced Magnetohydrodynamic Theory of Plasmas. 3 Hours.**

**PHYS 790. Teaching Practicum. 1-3 Hours.**
PR: Consent. Supervised practice in college teaching of physics. Note: This course is intended to insure that graduate assistants are adequately prepared and supervised when they are given college teaching responsibility. It will also present a mechanism for students not on assistantships to gain teaching experience. (Grading will be P/F.)

**PHYS 791. Advanced Topics. 1-6 Hours.**
PR: Consent. Investigation of advanced topics not covered in regularly scheduled courses.

**PHYS 792. Directed Study. 1-6 Hours.**
Directed study, reading, and/or research.
PHYS 793. Special Topics. 1-6 Hours.
A study of contemporary topics selected from recent developments in the field.

PHYS 794. Seminar. 1-6 Hours.
Special seminars arranged for advanced graduate students.

PHYS 795. Independent Study. 1-9 Hours.
Faculty supervised study of topics not available through regular course offerings.

PHYS 796. Graduate Seminar. 1 Hour.
PR: Consent. Each graduate student will present at least one seminar to the assembled faculty and graduate student body of his or her program.

PHYS 797. Research. 1-15 Hours.
PR: Consent. Research activities leading to thesis, problem report, research paper or equivalent scholarly project, or a dissertation. (Grading may be S/U).

PHYS 798. Thesis or Dissertation. 1-6 Hours.
PR: Consent. This is an optional course for programs that wish to provide formal supervision during the writing of student reports (698), or dissertations (798). Grading is normal.

PHYS 799. Graduate Colloquium. 1-6 Hours.
PR: Consent. For graduate students not seeking coursework credit but who wish to meet residency requirements, use of the University's facilities, and participate in its academic and cultural programs. Note: Graduate students who are not actively involved in coursework or research are entitled, through enrollment in their department's 699/799 Graduate Colloquium to consult with graduate faculty, participate in both formal and informal academic activities sponsored by their program, and retain all of the rights and privileges of duly enrolled students. Grading is P/F; colloquium credit may not be counted against credit requirements for masters programs. Registration for one credit of 699/799 graduate colloquium satisfies the University requirement of registration in the semester in which graduation occurs.

PHYS 930. Professional Development. 1-6 Hours.
Professional development courses provide skill renewal or enhancement in a professional field or content area (e.g., education, community health, geology.) These tuition-waived continuing education courses are graded on a pass/fail grading scale and do not apply as graduate credit toward a degree program.
<table>
<thead>
<tr>
<th>Course Code</th>
<th>Hours</th>
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<tr>
<td>PHYS P101</td>
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