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
- 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 Matter 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
- Paul Cassak - Ph.D. (University of Maryland)
  Plasma 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
• Aldo Romero - Ph.D. (University of California - San Diego)
  Condensed Matter Physics
• Tudor Stanescu - Ph.D. (University of Illinois)
  Condensed Matter Physics
• John Stewart - Ph.D. (University of Illinois-Urbana Champaign)
  Physics Education Research

ASSISTANT PROFESSORS
• Sarah Burke Spolaor - Ph.D. (Swinburne Institute of Technology)
  Astrophysics/Astronomy
• Cheng Cen - Ph.D. (University of Pittsburgh)
  Condensed Matter Physics
• Edward Flagg - Ph.D. (University of Texas - Austin)
  Condensed Matter Physics
• 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

RESEARCH ASSOCIATE PROFESSORS
• Amy Keesee - Ph.D. (West Virginia University)
  Experimental Plasma Physics

RESEARCH ASSISTANT PROFESSOR
• Julian Schulze - Ph.D. (Rurh University - Bochum)
  Plasma 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 Relativity
• H. Arthur Weldon - Ph.D. (Massachusetts Institute of Technology)
  Particle Physics

Admission
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. 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. Contact the department for additional information.

Master of Science

MAJOR REQUIREMENTS

Minimum grade of C or higher is required in all courses applied toward degree.

Major Requirements

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYS 611</td>
<td>Introduction to Mathematical Physics</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 631</td>
<td>Advanced Classical Mechanics 1</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 633</td>
<td>Electromagnetism 1</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 651</td>
<td>Quantum Mechanics 1</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 761</td>
<td>Statistical Mechanics</td>
<td>3</td>
</tr>
</tbody>
</table>

Select either non-thesis or thesis option

Non-Thesis Option:

Physics Electives

Thesis Option:

Physics Elective

PHYS 697 Research

Total Hours 15

Total Hours 30

*24 hours for thesis option, 30 hours for non-thesis

Doctor of Philosophy

The Ph.D. requires 36 hours of courses at the 600 or 700-levels. These twelve courses must include seven of the following basic courses:

MAJOR REQUIREMENTS

<table>
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<tr>
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</thead>
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<td>3</td>
</tr>
<tr>
<td>PHYS 634</td>
<td>Electromagnetism 2</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 651</td>
<td>Quantum Mechanics 1</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 652</td>
<td>Quantum Mechanics 2</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 761</td>
<td>Statistical Mechanics</td>
<td>3</td>
</tr>
</tbody>
</table>

Select at least two from the following:

<table>
<thead>
<tr>
<th>Course</th>
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<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYS 772</td>
<td>Semiconductor Physics</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 773</td>
<td>Collective Phenomena in Solids</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 774</td>
<td>Optical Properties of Solids</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 783</td>
<td>Advanced Kinetic Theory of Plasmas</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 784</td>
<td>Advanced Magnetohydrodynamic Theory of Plasmas</td>
<td>3</td>
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</tbody>
</table>

and/or

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYS 791</td>
<td>Advanced Topics</td>
<td>3</td>
</tr>
<tr>
<td>ASTR 702</td>
<td>Stellar Structure and Evolution</td>
<td>3</td>
</tr>
<tr>
<td>ASTR 703</td>
<td>Galactic Astronomy</td>
<td>3</td>
</tr>
<tr>
<td>ASTR 704</td>
<td>General Relativity</td>
<td>3</td>
</tr>
</tbody>
</table>

Plus three additional graduate courses in physics or astronomy

Comprehensive Examination

Dissertation Proposal

Dissertation

Dissertation Defense

Total Hours 36
PH.D. 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. The exam is given twice a year, in August and in January. To be eligible to take any candidacy exam, the student must be in good standing (see below).

The oral part of the candidacy exam is a presentation to the faculty on the student’s doctoral committee. The student gives a lecture on some published research that has been assigned by his or her research advisor.

The doctoral committee has four members. Three or more members must be members of the WVU graduate faculty. Three members must be from the faculty of the Department of Physics and Astronomy. The fourth member may be internal or external to WVU. If external to WVU, the fourth member must hold a PhD in a field related to the candidate's dissertation research. If internal to WVU, the fourth member must be from a department other than Physics and Astronomy. All members must have a PhD.

RESEARCH REQUIREMENTS

Research is the central focus of the degree and is directed by a faculty advisor 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, condensed matter physics, physics education research, and plasma physics.

Major Learning Outcomes

PHYSICS AND ASTRONOMY

The central missions of the Graduate Program in Physics and Astronomy 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 and Astronomy 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 pass two sections of the written candidacy examination by the end of three years.
- Ph.D. students must pass the remaining third section of the written candidacy examination by the end of four years.
- 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 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 their 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.

PHYSICS COURSES

PHYS 554. Outline of Modern Physics. 3 Hours.
PR: One year introductory college physics. (Primarily for education majors; not open to physics majors.) Elementary study of atomic and molecular structures and spectra, solid state and nuclear physics, relativity and elementary particles.

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 621. Optics. 3 Hours.
PR: PHYS 112 or equivalent and MATH 251. A basic course in physical optics covering radiation theory, diffraction, interference, polychromatic waves, scattering, polarization, double refraction, and selected topics in quantum optics.

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.