Committee. Students may eliminate deficiencies while concurrently than the above may be admitted with deficiency dependent on degree mathematics through differential equations. Students who present less electricity and magnetism, quantum physics and thermal physics, and major in physics including intermediate-level courses in mechanics, should have an undergraduate degree with the equivalent of a 30-hour admitted to graduate study in physics without deficiency, candidates Admissions Committee of the Department of Physics. In addition, to be described in this catalog and have the approval of the Graduate students must satisfy the requirements of the Graduate School as prerequisites to M.S. and Ph.D. Degree Programs:

Primary Areas of Faculty Research: Atomic and molecular physics; biophysics; condensed matter physics; laser physics; nanoscience; physics education; quantum optical physics; space and planetary sciences; surface physics; and theoretical physics.

Elective courses will be used for the remaining required degree hour. The minimum number of physics elective hours, the maximum number of non-physics technical elective hours, and the minimum number of total elective hours are shown in the table.

Students who have had similar courses at another institution may substitute up to 12 credit hours of other courses in lieu of those listed above, on a course-by-course basis, upon petitioning the Graduate Affairs Committee.

Students who have taken the GRE advanced physics test are urged to submit their test scores to the physics department to facilitate advising and placement.

M.S. in Physics

Requirements for the Master of Science Degree: Students may choose between two Master of Science degrees in the physics department. These are the M.S. Physics (30-hour thesis path); and the M.S. Physics (36-hour non-thesis path). Both M.S. degree curricula prepare a student for the Physics Ph.D. degree.

Incoming graduate students will be advised by a departmental graduate adviser for the first two years. Students must form their thesis or advisory committees by the end of their third academic semester and file the appropriate forms with the Graduate School. The thesis committee (thesis-path students) consists of the research adviser as chair, two members of the physics faculty, and one member of the graduate faculty from the Physics Department. The advisory committee (for non-thesis-path students) consists of the individual study project adviser as chair and two members of the physics faculty. Students in this degree program can choose either a 30-semester-hour thesis path or a 36-semester-hour non-thesis path.

Both the thesis and non-thesis M.S. degrees share the following academic requirements: Completion of:

<table>
<thead>
<tr>
<th>Degree</th>
<th>Physics Electives</th>
<th>Technical Electives</th>
<th>Total Electives</th>
</tr>
</thead>
<tbody>
<tr>
<td>M.S. Physics Thesis</td>
<td>9</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>M.S. Physics Non-Thesis</td>
<td>18</td>
<td>0</td>
<td>18</td>
</tr>
</tbody>
</table>

Students will select electives from courses listed in the graduate catalog as appropriate to their field of specialization, with course selection approved by their thesis committee. For the purposes of this degree requirement, any Astronomy (ASTR) graduate course listed in the Graduate Catalog and taught through the physics department will be considered a Physics elective.

Degrees Conferred: M.S., Ph.D. (PHYS)

Degrees Conferred: M.S., Ph.D. (PHYS)
No more than one 4000-level course may be counted toward the 30-hour requirement for the thesis option, and no more than two 4000-level courses may be counted toward the 36-hour requirement for the non-thesis option.

**Requirements for Thesis-Path M.S. Degrees:** Completion of six master’s thesis hours under PHYS 600V and a written thesis successfully defended in a comprehensive oral exam given by the student’s thesis committee.

**Requirements for Non-thesis Path M.S. Degrees:** Completion of three hours under PHYS 502V Individual Study in Advanced Physics and a written project report successfully defended in a comprehensive oral exam given by the student’s advisory committee. Students who pass the Physics Ph.D. candidacy examination will be considered to have satisfied the PHYS 502V requirement of the non-thesis path M.S. degrees.

Students should also be aware of Graduate School requirements with regard to master’s degrees (http://catalog.uark.edu/graduatecatalog/ degreerequirements/#mastersdegreestext).

**Ph.D. in Physics**

**Requirements for the Doctor of Philosophy Degree:** To be admitted to candidacy for the Ph.D. degree the student must a) form a dissertation committee; b) pass the candidacy exam, c) obtain a minimum of B-grade in core physics courses and d) file a Declaration of Intent with the Graduate School.

Incoming graduate students will be advised by a departmental adviser for the first two years. Students must form their dissertation committees by the end of their third academic semester and file the appropriate forms with the Graduate School. The dissertation committee consists of the research adviser as chair, three members of the Physics faculty, and one member of the graduate faculty not from the Physics Department.

The candidacy examination covers three areas: Quantum mechanics, electromagnetism, and classical mechanics, all at the graduate level, although questions at the undergraduate level may also be asked. The exam is given on three days in the week preceding the start of the Spring semester classes. Students entering the graduate program in the Fall semester will take the exam no later than after three semesters of graduate study at the University of Arkansas, and those entering the graduate program in the Spring semester will take it no later than after the fourth semester of graduate study. A passing grade of 55 percent in each area will be required. The students will be allowed a second and final attempt in the failed areas the following year. In the exceptional cases where after the second attempt, the student has failed only one area and his/her score in that area is not below 50 percent, the faculty may allow a third attempt or an oral exam. This exam will be given within six weeks after the second attempt.

Ph.D. students must complete a minimum of 40 semester-hours in 5000- and/or 6000-level courses beyond their Bachelor of Science degrees. Courses taken to fulfill the requirements for the University of Arkansas M.S. physics degrees can be included in this 40 semester-hour requirement. Students who have had similar courses as part of an M.S. physics program at another institution may obtain a waiver for up to 21 credit hours, on a course-by-course basis, upon petitioning to the Graduate Affairs Committee.

Ph.D. students must take:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Semester Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYS 5011</td>
<td>Introduction to Current Physics Research Seminar</td>
<td>(Fa)</td>
</tr>
<tr>
<td>PHYS 5111</td>
<td>Research Techniques Through Laboratory Rotations</td>
<td>(Sp)</td>
</tr>
<tr>
<td>PHYS 5041</td>
<td>Journal Club Seminar</td>
<td>(Sp)</td>
</tr>
<tr>
<td>PHYS 5073</td>
<td>Mathematical Methods for Physics</td>
<td>(Fa)</td>
</tr>
<tr>
<td>PHYS 5413 &amp; PHYS 5423</td>
<td>Quantum Mechanics I</td>
<td>(Fa) &amp; Quantum Mechanics II</td>
</tr>
<tr>
<td>PHYS 5103</td>
<td>Advanced Mechanics</td>
<td>(Fa)</td>
</tr>
<tr>
<td>PHYS 5213</td>
<td>Statistical Mechanics</td>
<td>(Odd years, Fa)</td>
</tr>
<tr>
<td>PHYS 5263L</td>
<td>Experiment and Data Analysis</td>
<td>(Sp)</td>
</tr>
</tbody>
</table>

A minimum grade of B is required in the following core courses:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Semester Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYS 5073</td>
<td>Mathematical Methods for Physics</td>
<td>(Fa)</td>
</tr>
<tr>
<td>PHYS 5413 &amp; PHYS 5423</td>
<td>Quantum Mechanics I &amp; Quantum Mechanics II</td>
<td>(Fa) &amp; (Sp)</td>
</tr>
<tr>
<td>PHYS 5313 &amp; PHYS 5323</td>
<td>Advanced Electromagnetic Theory I &amp; Advanced Electromagnetic Theory II</td>
<td>(Fa) &amp; (Sp)</td>
</tr>
<tr>
<td>PHYS 5103</td>
<td>Advanced Mechanics</td>
<td>(Fa)</td>
</tr>
<tr>
<td>PHYS 5263L</td>
<td>Experiment and Data Analysis</td>
<td>(Sp)</td>
</tr>
</tbody>
</table>

If a minimum grade of B is not obtained, the course may be repeated once. If the student cannot obtain a minimum of B on two attempts, he/she will not be allowed to continue in the Ph.D. program.

Thirteen additional hours in elective physics graduate courses will be required, and they must be selected from the 5000- or 6000-level courses listed in the graduate catalog appropriate to the student’s field of specialization and approved by the student’s advisory committee. For the purposes of this degree requirement, any Astronomy (ASTR) graduate course listed in the Graduate Catalog and taught through the physics department will be considered a physics elective. Additional elective courses outside of the physics department may be taken with dissertation committee approval.

Ph.D. students must also earn 18 hours of credit in Doctoral Dissertation, submit a dissertation, and defend it successfully in a comprehensive oral examination given by the dissertation committee.

Students should also be aware of Graduate School requirements with regard to doctoral degrees (http://catalog.uark.edu/graduatecatalog/ degreerequirements/#phdandedddegreestext).

**Courses**

**PHYS 4113. Physics in Perspective (Odd years, Sp). 3 Hours.**
Human implications of physics, including life’s place in the universe, the methods of science, human sense perceptions, energy utilization, social impacts of technology, and the effect of physics on modern world views. Credit allowed for only one of PHYS 4113 or PHYS 4103. Prerequisite: PHYS 3613.

**PHYS 4213. Physics of Devices (Odd years, Fa). 3 Hours.**
Principles of physics applied in a selection of technologically important devices in areas including computing, communications, medical imaging, lasers, and energy utilization. Students will utilize technical journals. Credit allowed for only one of PHYS 4203 or PHYS 4213. Prerequisite: PHYS 3613.

**PHYS 500V. Seminar (Irregular). 1-3 Hour.**
Regular informal discussions of research reported in journals and monographs. May be repeated for up to 3 hours of degree credit.
This course is cross-listed with MATH 5363.

An introduction to numerical methods used in solving various problems in Maxwell equations, conservation laws, wave propagation, waveguides, radiating magnetostatics, and Faraday's Law.

PHYS 5323. Advanced Electromagnetic Theory II (Sp, Fa). 3 Hours.
Maxwell equations, conservation laws, wave propagation, waveguides, radiating systems, scattering, special relativity, and radiation by moving charges.

PHYS 5363. Scientific Computation and Numerical Methods (Fa). 3 Hours.
An introduction to numerical methods used in solving various problems in engineering and the sciences. May not earn credit for this course and MATH 4353 or MATH 4363.

This course is cross-listed with MATH 5363.

PHYS 5363. Scientific Computation and Numerical Methods (Fa). 3 Hours.
Non-relativistic quantum mechanics; the Schrödinger equation; the Heisenberg matrix representation; operator formalism; transformation theory; spinors and Pauli theory; the Dirac equation; applications to atoms and molecules; collision theory; and semiclassical theory of radiation. Prerequisite: PHYS 4073.

PHYS 5423. Quantum Mechanics II (Sp). 3 Hours.
Continuation of PHYS 5413 Prerequisite: PHYS 5413.

PHYS 5513. Atomic and Molecular Physics (Odd years, Sp). 3 Hours.
Survey of atomic and molecular physics with emphasis on the electronic structure and spectroscopy of 1 and 2 electron atoms and diatomic molecules. Includes fine and hyperfine structure, Zeeman and Stark mixing of states, collision phenomena, radiative lifetimes, and experimental techniques. Prerequisite: PHYS 4073 or PHYS 5413.

PHYS 5523. Theory of Relativity (Even years, Fa). 3 Hours.
Conceptual and mathematical structure of the special and general theories of relativity with selected applications. Critical analysis of Newtonian mechanics; relativistic mechanics and electrodynamics; tensor analysis; continuous media; and gravitational theory.

PHYS 5613. Introduction to Biophysics and Biophysical Techniques (Sp, Fa). 3 Hours.
Origins of biophysics, biological polymers and polymer physics, properties of DNA and proteins, techniques to study DNA and proteins, biological membrane and ion channels, biological energy, experimental techniques to study single DNA and proteins. Two experiments are included: (1) DNA Gel electrophoresis; (2) Measurement of double-stranded DNA melting point. This course is cross-listed with PHYS 4613.

PHYS 5653. Subatomic Physics (Irregular). 3 Hours.

This course is cross-listed with PHYS 4653.

PHYS 5713. Condensed Matter Physics I (Sp, Fa). 3 Hours.
The course covers the Drude theory and the Sommerfeld theory of metals, crystal lattices, reciprocal lattices, X-ray diffraction, Bloch's theory of electrons in periodic potential, formation of band gap, lattice vibration, and cohesive energy in solids. Prerequisite: PHYS 5413.

PHYS 5723. Physics at the Nanoscale (Sp). 3 Hours.
This is a cross-disciplinary course that is focused on teaching nanoscience and engineering by studying surface science, the building and analysis of quantum-confined structures, and related nano manufacturing processes. Students will achieve an integrated knowledge of the concepts of surface science, quantum mechanics, nano processing and manipulation, and techniques of materials research. This course is cross-listed with MEPH 5723.

PHYS 5734. Laser Physics (Sp). 4 Hours.
A combined lecture/laboratory course covering the theory of laser operation, laser resonators, propagation of laser beams, specific lasers such as gas, solid state, semiconductor and chemical lasers, and laser applications. Prerequisite: PHYS 3414 and PHYS 3544.

PHYS 5753. Applied Nonlinear Optics (Even years, Fa). 3 Hours.
Topics include: practical optical processes, such as electro-optic effects, acousto-optic effects, narrow-band optical filters, second harmonic generation, parametric amplification and oscillation, and other types of nonlinear optical spectroscopy techniques which are finding current practical applications in industry. Prerequisite: PHYS 3414 and PHYS 3544.
Fundamentals of the selected techniques suitable for characterization on the nanoscale. Focus on diverse methods such as x-ray and neutron spectroscopy, scanning probe microscopies, optical methods, electron diffraction methods and more.

PHYS 5773. Introduction to Optical Properties of Materials (Sp). 3 Hours.
This course covers crystal symmetry optical transmission and absorption, light scattering (Raman and Brillouin) optical constants, carrier mobility, and polarization effects in semi-conductors, quantum wells, insulators, and other optically important materials. Prerequisite: PHYS 3414 and PHYS 3544 or permission of Instructor.

PHYS 588V. Selected Topics in Experimental Physics (Irregular). 1-3 Hour.
May be repeated for up to 3 hours of degree credit.

PHYS 590V. Master of Arts Research (Sp, Su, Fa). 1-6 Hour.

PHYS 600V. Master of Science Thesis (Sp, Su, Fa). 1-6 Hour.
Master of Science Thesis. May be repeated for degree credit.

PHYS 6413. Quantum Mechanics III (Even years, Fa). 3 Hours.
Relativistic quantum mechanics, second quantization, with applications to quantizing electromagnetic fields and to many-body theory. Introduction to Feynman diagrams. Prerequisite: PHYS 5423.

PHYS 6513. Advanced Topics in Complexity (Irregular). 3 Hours.
The goal of the course is to give students tools to investigate the behavior of complex systems and to analyze the relationship of non-linear dynamics and chaos theory to complex biological and non-biological systems. A special emphasis will be given to understanding the way neurons work as biological computing elements.

PHYS 6613. Quantum Optics (Even years, Fa). 3 Hours.
Properties of light and its interaction with atoms, particular attention given to the laser and recent experiments. Classical theory of resonance; Optical Bloch Eqs.; 2 level atoms in steady fields; pulse propagation; semiclassical theory of the laser, coherent states and coherent functions; gas, solid, and dye lasers; photon echoes and superradiance; quantum electrodynamics and spontaneous emission. Prerequisite: PHYS 5413 or equivalent.

PHYS 6713. Condensed Matter Physics II (Even years, Sp). 3 Hours.
The course covers surface physics, physics of homogeneous and inhomogeneous semiconductors, dielectric and ferroelectric physics, defects in crystals, spin interaction and magnetic properties, superconductivity, and band structure calculation. Prerequisite: PHYS 5713 and PHYS 5413.

PHYS 700V. Doctoral Dissertation (Sp, Su, Fa). 1-18 Hour.
Doctoral Dissertation. May be repeated for degree credit.