3 Credits of Upper-Level COS

- Chosen from any College of Science course at the 300 level or above. Other discipline-based courses may be permitted with permission of the undergraduate program director.

Note:

Many of the courses listed above have additional prerequisites. Nonetheless, the Computational and Data Sciences Minor is within efficient reach of most students majoring in science, mathematics, engineering, or computer science, since these students will generally have the prerequisites for the classes listed above.

Minor Total: 15 credits

■ Physics and Astronomy

Phone: 703-993-1280
Web: spacs.gmu.edu

Faculty

The School of Physics, Astronomy, and Computational Sciences (SPACS) was reorganized into two departments as of fall 2015, the Department of Computational and Data Sciences and the Department of Physics and Astronomy. Listed below is the entire faculty of the former SPACS.


Associate professors: Camelli, Cressman, Griva*, Klimov*, Marzougui, Rosenberg, Sheng, So, Tian, Weigel, Weingartner, R. Yang*, Zoltek

Assistant professors: Nikolic, Yigit, Zhao

Term associate professor: Djordjevic, Ewell, Geller, Oerter

Term assistant professors: Gliozzi, Vemuru, Wyczalkowski

Term instructors: Ericson

Emeriti: Ceperley, Ehrlich, Evans, Mielczarek

Research faculty: Bilitza, Chung, Dere, Duxbury, Economou, Hoang, Huang, Illiopoulos, Mariska, Meier, Mut, Odstrcil, Poland, Richards, Sforza, Shabaev, Shebalin, Titarchuk

*Faculty holding primary appointments in other academic units

The Department of Physics and Astronomy is dedicated to the dissemination and advancement of physics and astronomy through instruction, research, and outreach.

The department provides rigorous training for physics and astronomy students and prepares them to be successful, confident, and versatile in their ability to apply physics and astronomy principles within any chosen field. The department also aims to deliver and instill a broad-based understanding of general physics and astronomy principles and practices to the wider university
community through our Mason Core (general education) courses. Our student-centric curriculum and instruction use a mixture of traditional and current pedagogical techniques informed by on-going educational research. It is our goal to help students to develop versatility and creativity through repeated analytical practices and problem-solving training in their coursework and faculty-led research projects.

Research in the department focuses on pushing the frontiers of physics and astronomy in a broad range of topics using theoretical, experimental, observational, and computational approaches. The department maintains many active collaborations with scientists across different disciplines within the university community and with other national and international institutions. The department believes strongly in incorporating both graduate as well as undergraduate students in our research programs. It is our goal to see students arriving with an enthusiasm and curiosity for physics and astronomy and leaving as true scientists ready to conduct their own scientific investigations.

Courses

This department offers all courses designated ASTR and PHYS in the Courses section of this catalog.

Undergraduate Programs

The department offers the Physics, BS and the Astronomy, BS. Also available are the Physics Minor, the Astronomy Minor, and the Renewable Energy Interdisciplinary Minor.

Undergraduate Research Opportunities

The department offers many opportunities for undergraduate students to get involved with research. Students should consult with faculty working on research topics of interest to them, based on their exploration of the department's website.

Honors Programs

Physics majors who have maintained an overall GPA of at least 3.50 in physics courses and a GPA of 3.50 in all courses taken at George Mason University may apply to the physics honors program when they complete the first semester of their junior year. To graduate with honors in physics, a student is required to maintain a minimum GPA of 3.00 in physics courses and successfully complete PHYS 405 and PHYS 406 with a GPA of at least 3.50 and a grade of at least 'A-' in PHYS 406.

Astronomy majors who have completed the prerequisites for ASTR 405, have a GPA of at least 3.50 in ASTR and PHYS courses taken at Mason, and have a GPA of at least 3.50 in all courses taken at Mason may apply for admission to the astronomy honors program. To graduate with honors in astronomy, a student must maintain a GPA of at least 3.50 in their ASTR/PHYS courses. Students accepted into the honors program must complete ASTR 405 and ASTR 406 with a GPA of at least 3.50 and a grade of 'A-' or better in ASTR 406. Students in ASTR 405/ASTR 406 will complete a research project and write a thesis working under the supervision of a faculty member. At the end of ASTR 406, the student will write a substantial thesis paper and make a presentation of results to their honors committee.

Writing Intensive Requirement

George Mason requires all students to complete at least one course designated as "writing intensive" in their majors at the 300-level or above. Students majoring in physics fulfill this requirement by successfully completing PHYS 407. Astronomy majors fulfill the requirement by completing ASTR 402.

Bachelor's/Accelerated Master's Degree
Information regarding this program can be found in the Physics, BS/Applied and Engineering Physics, Accelerated MS section of this catalog.

**Teacher Licensure**

Students who wish to become teachers should consult the College of Education and Human Development section of this catalog and attend an information session early in their undergraduate career. For more information, visit the Graduate School of Education's website.

**Physics for Non-majors**

PHYS 243, PHYS 244, PHYS 245, and PHYS 246 are recommended for biology, geology, and premedical students, and mathematics students who seek a BA degree. PHYS 101, PHYS 102, PHYS 103, and PHYS 104 are intended for non-science majors. PHYS 160, PHYS 161, PHYS 260, PHYS 261 or PHYS 265, PHYS 262, and PHYS 263 constitute a calculus-based sequence in general physics to be taken by physics and engineering majors, and chemistry, computer science, and mathematics students who are pursuing a BS degree. Students may receive credit for only one of the following three sequences: PHYS 243, PHYS 244, PHYS 245, PHYS 246; PHYS 103, PHYS 104; or PHYS 160, PHYS 161, PHYS 260, PHYS 261, PHYS 262, PHYS 263.

**Graduate Programs**

This department offers the Applied and Engineering Physics, MS. The department also supports the Energy and Sustainability concentration in the Interdisciplinary Studies, MAIS. Additionally, the department offers a Physics, PhD. These graduate programs are strongly supported by the extensive research activities of the faculty, including many collaborations with scientists and engineers at regional government laboratories.

**Bachelor of Science**

**Astronomy, BS**

**Banner Code:** SC-BS-ASTR

This program of study is offered by the Department of Physics and Astronomy in the College of Science.

The Astronomy, BS prepares students for graduate school, a career in research or teaching positions, or employment in industry, business, or education fields where analytical skills and a scientific background are advantageous. Students who are considering a double major should talk to the undergraduate coordinator. Note that at least 18 credits used to fulfill an Astronomy, BS cannot be used to fulfill another major or minor. Some course substitutions are allowed for double majors, subject to approval from the Department of Physics and Astronomy.

Students must fulfill all requirements for bachelor's degrees including the Mason Core. In addition, students must complete a total of 52 credits in physics and astronomy and 14 credits in mathematics with a minimum GPA of 2.00. Through the coursework below, astronomy majors satisfy the Mason Core requirements in 'Natural Science' and 'Quantitative Reasoning'. Also, by taking ASTR 402, astronomy majors satisfy the university's writing-intensive requirement.

**Degree Requirements**

**Required Astronomy Courses (10 credits)**
• ASTR 210 - Introduction to Astrophysics Credits: 3
• ASTR 328 - Stars and Interstellar Medium Credits: 3
• ASTR 402 - RS: Methods of Observational Astronomy Credits: 4

Additional Astronomy Courses (6 credits)
Take two of the following:

• ASTR 403 - Planetary Sciences Credits: 3
• ASTR 404 - Galaxies and Cosmology Credits: 3
• PHYS 428 - Relativity Credits: 3

Required Physics Courses (21 credits)

• PHYS 160 - University Physics I Credits: 3 (Mason Core: Natural Science course)
• PHYS 161 - University Physics I Laboratory Credits: 1 (Mason Core: Natural Science course)
• PHYS 260 - University Physics II Credits: 3 (Mason Core: Natural Science course)
• PHYS 261 - University Physics II Laboratory Credits: 1 (Mason Core: Natural Science course)
• PHYS 262 - University Physics III Credits: 3 (Mason Core: Natural Science course)
• PHYS 263 - University Physics III Laboratory Credits: 1 (Mason Core: Natural Science course)
• PHYS 303 - Classical Mechanics Credits: 3
• PHYS 305 - Electromagnetic Theory Credits: 3
• PHYS 308 - Modern Physics with Applications Credits: 3

Required Math Courses (14 credits)

• MATH 113 - Analytic Geometry and Calculus I Credits: 4 (Mason Core: Quantitative Reasoning course)
• MATH 114 - Analytic Geometry and Calculus II Credits: 4
• MATH 213 - Analytic Geometry and Calculus III Credits: 3
• MATH 214 - Elementary Differential Equations Credits: 3

15 credits
Chosen from the following (at least 12 credits must be from upper-level courses):

• ASTR 301 - Astrobiology Credits: 3
• ASTR 408 - Senior Research Credits: 3
• PHYS 306 - Wave Motion and Electromagnetic Radiation Credits: 3
• PHYS 307 - Thermal Physics Credits: 3
• PHYS 402 - Introduction to Quantum Mechanics and Atomic Physics Credits: 3
• ASTR 403 - Planetary Sciences Credits: 3, ASTR 404 - Galaxies and Cosmology Credits: 3, or PHYS 428 - Relativity Credits: 3, if not taken as part of additional astronomy course requirement above, may be used here.
• Other ASTR or PHYS course with the permission of the department

Mason Core and Elective Credits (54 credits)
In order to meet a minimum of 120 credits, this degree requires an additional 54 credits, which may be applied towards any remaining Mason Core requirements (outlined below), requirements for bachelor's degrees, and elective courses. Students are strongly encouraged to consult with their advisors to ensure that they fulfill all requirements.

**Mason Core**

Please note that some Mason Core requirements may already be fulfilled by the major requirements listed above.

Expand each item below for a link to specific course lists for each category:

**Foundation Requirements (15-19 credits)**

- Mason Core UWCU - Written Communication Credits: 6
- Mason Core UOC - Oral Communication Credits: 3
- Mason Core UQR - Quantitative Reasoning Credits: 3
- Mason Core UITC - Information Technology Credits: 3-7

**Core Requirements (22 credits)**

- Mason Core UFA - Arts Credits: 3
- Mason Core UGU - Global Understanding Credits: 3
- Mason Core ULIT - Literature Credits: 3
- Mason Core UNSL - Natural Science Credits: 7
- Mason Core USBS - Social and Behavioral Sciences Credits: 3
- Mason Core UWC - Western Civilization/Western History Credits: 3

**Synthesis/Capstone Requirement (minimum 3 credits)**

- Mason Core USYN - Synthesis/Capstone Credits: minimum 3

**Degree Total: Minimum 120 credits**

**Physics, BS**

**Banner Code:** SC-BS-PHYS

This program of study is offered by the Department of Physics and Astronomy in the College of Science.

The Physics, BS prepares students for graduate school and careers in education, business, or industry. Students in the fields of mathematics, science, and engineering who are considering a double major in physics should discuss this option with the respective undergraduate coordinators. Note that at least 18 credits used to fulfill the Physics, BS cannot be used to fulfill another major or minor. Some course substitutions are allowed for double majors, but these should be discussed in advance.

Students must fulfill all requirements for bachelor's degrees including the Mason Core. In addition, students must complete a total of 45 credits in the major and 17 in mathematics, with a minimum GPA of 2.00, distributed as follows. Through the coursework below, physics majors satisfy the Mason Core requirements in 'Natural Science' and 'Quantitative Reasoning'. The intensive writing requirement is fulfilled by taking PHYS 407.
This undergraduate program offers students the option of applying to the Physics, BS/Applied and Engineering Physics, Accelerated MS or the Physics, BS/Curriculum and Instruction, Accelerated MEd (Secondary Education Physics Concentration). See each listing for specific requirements.

**Alternative Introductory Sequence**

Normally, students who intend to major in physics should take the physics introductory sequence (PHYS 160, PHYS 161, PHYS 260, PHYS 261, PHYS 262, and PHYS 263). Students who decide to major in physics after completing PHYS 243, PHYS 244, PHYS 245, and PHYS 246 may do so but only with written permission of the Department of Physics and Astronomy. Those students are required to take 4 additional credits in approved physics courses.

**Degree Requirements**

**Physics Core Courses (27 credits)**

Note: Students double majoring in engineering and physics may substitute ECE 305 for PHYS 305, and ECE 333/ECE 334 for PHYS 407.

- PHYS 160 - University Physics I Credits: 3 (Mason Core: Natural Science course)
- PHYS 161 - University Physics I Laboratory Credits: 1 (Mason Core: Natural Science course)
- PHYS 260 - University Physics II Credits: 3 (Mason Core: Natural Science course)
- PHYS 261 - University Physics II Laboratory Credits: 1 (Mason Core: Natural Science course)
- PHYS 262 - University Physics III Credits: 3 (Mason Core: Natural Science course)
- PHYS 263 - University Physics III Laboratory Credits: 1 (Mason Core: Natural Science course)
- PHYS 303 - Classical Mechanics Credits: 3
- PHYS 305 - Electromagnetic Theory Credits: 3
- PHYS 306 - Wave Motion and Electromagnetic Radiation Credits: 3
- PHYS 307 - Thermal Physics Credits: 3
- PHYS 308 - Modern Physics with Applications Credits: 3
- PHYS 402 - Introduction to Quantum Mechanics and Atomic Physics Credits: 3
- PHYS 407 - Senior Laboratory in Modern Physics Credits: 3

**Physics Electives (6 credits)**

Students take 6 credits selected from the following:

- PHYS 251 - Introduction to Computer Techniques in Physics Credits: 3
- PHYS 306 - Wave Motion and Electromagnetic Radiation Credits: 3
- PHYS 307 - Thermal Physics Credits: 3
- PHYS 405 - Honors Thesis in Physics Credits: 3 or PHYS 406 - Honors Thesis in Physics Credits: 3
- PHYS 408 - Senior Research Credits: 2-3 or PHYS 409 - Physics Internship Credits: 3
- PHYS 416 - Special Topics in Modern Physics Credits: 1
- ASTR 328 - Stars and Interstellar Medium Credits: 3 or PHYS 428 - Relativity Credits: 3

**Mathematics (17 credits)**

- MATH 113 - Analytic Geometry and Calculus I Credits: 4 (Mason Core: Quantitative Reasoning course)
- MATH 114 - Analytic Geometry and Calculus II Credits: 4
- MATH 203 - Linear Algebra Credits: 3
• MATH 213 - Analytic Geometry and Calculus III Credits: 3
• MATH 214 - Elementary Differential Equations Credits: 3

Analytical Methods (3 credits)

Choose one of the following:

• PHYS 301 - Analytical Methods of Physics Credits: 3
• MATH 313 - Introduction to Applied Analysis Credits: 3
• MATH 314 - Introduction to Applied Mathematics Credits: 3

Additional Science Courses (12 credits)

Choose no more than 5 credits from the following courses:

• PHYS 121 - Uses of Physics Credits: 1
• PHYS 122 - Inside Relativity Credits: 1
• PHYS 123 - Inside the Quantum World Credits: 1
• PHYS 124 - Experimental Explorations in Physics Credits: 2
• ASTR 210 - Introduction to Astrophysics Credits: 3
• ASTR 301 - Astrobiology Credits: 3

And choose at least 7 credits from the following courses:

• CS 112 - Introduction to Computer Programming Credits: 4
• Additional approved upper-level physics, astronomy, computational and data sciences, chemistry, electrical engineering, or mathematics courses (for examples, see the areas of emphasis below)

Emphasis Options

In meeting all or part of the requirement for 12 credits of Additional Science Courses (above), students may be guided by the following model emphases. Students should plan a program of study in consultation with their advisor.

Emphases and suggested courses for each are listed below.

Emphasis in Applied Solid State Physics

This emphasis is for students who wish to pursue a career in the semiconductor industry. To complete this emphasis, students should take 12 credits selected from the following courses:

• PHYS 512 - Solid State Physics and Applications Credits: 3
• ECE 430 - Principles of Semiconductor Devices Credits: 3
• ECE 431 - Digital Circuit Design Credits: 3

And one from the following:

• PHYS 405 - Honors Thesis in Physics Credits: 3
• PHYS 406 - Honors Thesis in Physics Credits: 3
• PHYS 408 - Senior Research Credits: 2-3
• PHYS 409 - Physics Internship Credits: 3

Emphasis in Astrophysics
This emphasis is for students who are planning to attend graduate school in astrophysics or pursue a career in industry. To complete this emphasis, students should take 12 credits selected from the following courses:

- PHYS 428 - Relativity Credits: 3
- ASTR 328 - Stars and Interstellar Medium Credits: 3
- ASTR 404 - Galaxies and Cosmology Credits: 3
- MATH 446 - Numerical Analysis I Credits: 3
  Students may choose only one from the following:
  - PHYS 405 - Honors Thesis in Physics Credits: 3
  - PHYS 406 - Honors Thesis in Physics Credits: 3
  - PHYS 408 - Senior Research Credits: 2-3
  - PHYS 409 - Physics Internship Credits: 3

**Emphasis in Computational Physics**

This emphasis is for students who wish to pursue a career that applies computers to the solution of physical problems and data analysis. To complete this emphasis, students should take 12 credits selected from the following courses:

- PHYS 510 - Computational Physics I Credits: 3
- MATH 446 - Numerical Analysis I Credits: 3
- MATH 447 - Numerical Analysis II Credits: 3
  And one from the following:
  - PHYS 405 - Honors Thesis in Physics Credits: 3
  - PHYS 406 - Honors Thesis in Physics Credits: 3
  - PHYS 408 - Senior Research Credits: 2-3
  - PHYS 409 - Physics Internship Credits: 3

**Emphasis in Electronics**

This emphasis is for students who wish to pursue a career in industry, applying a strong background in electronics to physical problems. To complete this emphasis, students should take 12 credits selected from the following courses:

- ECE 301 - Digital Electronics Credits: 3
- ECE 333 - Linear Electronics I Credits: 3
- ECE 430 - Principles of Semiconductor Devices Credits: 3
- ECE 431 - Digital Circuit Design Credits: 3
- ECE 433 - Linear Electronics II Credits: 3
  Students may choose only one from the following:
  - PHYS 405 - Honors Thesis in Physics Credits: 3
  - PHYS 406 - Honors Thesis in Physics Credits: 3
  - PHYS 408 - Senior Research Credits: 2-3
  - PHYS 409 - Physics Internship Credits: 3

**Emphasis on Graduate School Preparation**

Although any of the options listed here provide the successful student with a fully adequate background to enter graduate school, this emphasis is for students whose career goals definitely include graduate work in physics. To complete this emphasis, students should take 12 credits selected from the following courses:

- PHYS 410 - Computational Physics I Credits: 3
Emphasis in Medical Physics

Physics majors generally have an excellent acceptance record in applying to medical, dental, or veterinary schools. Although there is no formal set of courses within physics that is uniquely suitable, students should meet with a physics advisor and a health sciences advisor for information about the university’s Medical Sciences Advisory Committee. For more information, call 703-993-1050.

Because schools in the health sciences vary both in their philosophies and specific requirements, it is wise for students to become aware of such information well in advance of applying for admission. Although specific requirements vary, most programs do require applicants to complete at least one year of biology. Other requirements generally include organic chemistry.

- PHYS 408 - Senior Research Credits: 2-3
- CHEM 313 - Organic Chemistry Credits: 3
- CHEM 314 - Organic Chemistry II Credits: 3
- CHEM 315 - Organic Chemistry Lab I Credits: 2
- CHEM 318 - Organic Chemistry Lab II Credits: 2

Emphasis in Physics Education

This emphasis is intended for students wishing to pursue a career teaching secondary school physics. The goal of the program is to allow students to receive a license to teach physics in Virginia secondary schools within 120 credits.

It is recommended that students seeking a career in physics education take PHYS 306 and PHYS 307 to fulfill the additional physics requirement (see above) for the major. In addition to the standard requirements for the physics major, students should enroll in 3 credits of directed study in physics laboratory instruction under PHYS 390.

The following courses are required to qualify for the teaching license. A grade of ‘C’ or better is required for all licensure coursework. Students who complete EDRD 419 and either EDCI 473 or EDCI 483 fulfill 6 of the 12 credits of the Additional Science Courses requirement (see above) and should consult the physics advisor on which courses fulfill the remainder of the requirement.

- PHYS 390 - Topics in Physics Credits: 1-4 (physics laboratory instruction) for 3 credits
- EDCI 473 - Teaching Science in the Secondary School Credits: 3
- EDCI 483 - Advanced Methods of Teaching Science in Secondary School Credits: 3
- EDRD 419 - Literacy in the Content Areas Credits: 3
- EDCI 490 - Student Teaching in Education Credits: 6 (Mason Core: Synthesis course)
- EDUC 372 - Human Development, Learning, and Teaching Credits: 3 (Mason Core: Social and Behavioral Science course)
- EDUC 422 - Foundations of Secondary Education Credits: 3
- Pass the Praxis Core and Praxis II exams

Mason Core and Elective Credits (55 credits)
In order to meet a minimum of 120 credits, this degree requires an additional 55 credits, which may be applied towards any remaining Mason Core requirements (outlined below), requirements for bachelor's degrees, and elective courses. Students are strongly encouraged to consult with their advisors to ensure that they fulfill all requirements.

Mason Core

Please note that some Mason Core requirements may already be fulfilled by the major requirements listed above.

Expand each item below for a link to specific course lists for each category:

**Foundation Requirements (15-19 credits)**

- Mason Core UWCU - Written Communication Credits: 6
- Mason Core UOC - Oral Communication Credits: 3
- Mason Core UQR - Quantitative Reasoning Credits: 3
- Mason Core UITC - Information Technology Credits: 3-7

**Core Requirements (22 credits)**

- Mason Core UFA - Arts Credits: 3
- Mason Core UGU - Global Understanding Credits: 3
- Mason Core ULIT - Literature Credits: 3
- Mason Core UNSL - Natural Science Credits: 7
- Mason Core USBS - Social and Behavioral Sciences Credits: 3
- Mason Core UWC - Western Civilization/Western History Credits: 3

**Synthesis/Capstone Requirement (minimum 3 credits)**

- Mason Core USYN - Synthesis/Capstone Credits: minimum 3

**Degree Total: Minimum 120 credits**

**Bachelor/Accelerated Master’s**

**Physics, BS/Applied and Engineering Physics, Accelerated MS**

This program of study is offered by the Department of Physics and Astronomy in the College of Science.

This program allows academically strong undergraduates with a demonstrable commitment to research to obtain the Physics, BS and Applied and Engineering Physics, MS degrees by successfully completing 144 credits. Upon completion, students are well-prepared for entry into a professional school or a PhD program in physics or a related discipline. Admitted students take selected graduate courses during their senior year and are able to use up to 6 graduate credits in partial satisfaction of requirements for the undergraduate degree. Upon completion and conferral of the bachelor's degree and with satisfactory performance (grade of 'B' or better) in each of the graduate courses, students are given advanced standing in the master's program and complete an additional 24 credits to receive the master's degree.

See the Graduate Policies section of this catalog for policies related to this program.
Students in an accelerated degree program must fulfill all university requirements for the bachelor's and master's degrees. For policies governing all degrees, see the Academic Policies section of this catalog.

**Application Requirements**

Applicants to all graduate programs at George Mason University must meet the admission standards and application requirements for graduate study as specified in the Admissions section of this catalog.

Successful applicants will have completed at least 90 credits toward their undergraduate degree with an overall GPA of at least 3.50 and will have completed at least 45 credits in physics major coursework. A recommendation letter from a research supervisor is also required. Interested applicants should submit a letter to the undergraduate physics coordinator requesting admission along with the aforementioned recommendation letter. Contact the physics undergraduate or graduate coordinator for further details.

**Accelerated Option Requirements**

At the beginning of the student's final undergraduate semester, students must submit a bachelor's/accelerated master's transition form (available from the Office of the University Registrar) to the College of Science's Office of Academic and Student Affairs. Students must begin their master's program in the semester immediately following conferral of the bachelor's degree.

Students must maintain an overall GPA of 3.00 or higher in graduate coursework.

**Reserve Graduate Credit**

While still in undergraduate status, a maximum of 6 additional graduate credits may be taken as reserve graduate credit and applied to the master's program. Reserve graduate credits do not apply to the undergraduate degree.

**Doctor of Philosophy**

**Physics, PhD**

**Banner Code:** SC-PHD-PHYS

This program of study is offered by the Department of Physics and Astronomy in the College of Science.

All doctoral students accepted into the Physics, PhD take a common core of four courses (see below). By working with the dissertation committee, a student may choose to specialize in an emphasis area such as astrophysics, biophysics, nonlinear physics, planetary sciences, material physics, space weather physics, or others according to his or her particular interests. By the end of their first year, all students should pair with a faculty advisor who will guide them toward doctoral candidacy.

**Admission Requirements**

Those holding a baccalaureate degree in physics or astronomy from a regionally accredited institution, who earned a GPA of 3.00 (out of 4.00) or higher in their last 60 credits, and received acceptable scores on the GRE-GEN are invited to apply for admission. Three letters of recommendation must be submitted, preferably from former professors. The GRE subject test in physics is highly recommended for all interested applicants who received their baccalaureate degrees within the past five years. A degree-seeking graduate applicant with a baccalaureate degree who has not met all admission requirements may be offered provisional admission if sufficient evidence is presented to suggest that the applicant has the ability to pursue graduate work. For more details concerning admission requirements to George Mason University please refer to the Admissions section of this catalog.
Reduction of Credit

For students entering the doctoral program with a master's degree in a related field from a regionally accredited institution, the number of required credits may be reduced up to 30 credits, subject to approval of the program faculty and the college's associate dean. See the Graduate Policies section of this catalog for more information.

Degree Requirements

Students must satisfy all requirements for doctoral degrees expressed in the Graduate Policies section of this catalog.

All students in the Physics, PhD program must earn a minimum of 72 graduate credits. Of these, 48 are required coursework and preliminary research credits, and 24 are doctoral dissertation proposal and doctoral dissertation research credits. For students entering the doctoral program with a master's degree in physics or a related field, or relevant graduate coursework, the 48 credit requirement may be reduced by a maximum of 30 credits.

Doctoral Coursework (48 credits)

Physics Core (12 credits)

Note: The doctoral candidacy (qualifying) examination is based on the topics covered in these four core courses:

- PHYS 684 - Quantum Mechanics I Credits: 3
- PHYS 685 - Classical Electrodynamics I Credits: 3
- PHYS 705 - Classical Mechanics Credits: 3
- PHYS 711 - Statistical Mechanics Credits: 3

Qualifying Examination

All students must successfully pass the four individual sections (quantum mechanics, electromagnetic theory, classical mechanics, and statistical mechanics) of a qualifying examination. The four topics in the qualifying exam are covered in the four core courses (PHYS 684, PHYS 685, PHYS 705, and PHYS 711). All four sections of the qualifying exam will be offered twice a year, typically in the week before the start of the fall and spring semesters. A student can choose to take a particular section or a combination of sections at one sitting. Grades of "pass" or "unsatisfactory" will be given individually for each of the four sections of the exam. If a student receives a grade of "unsatisfactory" in a given section of the exam, he/she is allowed to retake that section in the next cycle but a student must satisfactorily pass all sections of the exam by the end of the third year from the date of enrollment in the PhD program. Students entering the program with equivalent courses taken at another institution can satisfy the core requirement by taking the qualifying exam without taking the course.

At the beginning of each academic year, the program director will appoint members to the qualifying examination committee. This committee is responsible for creating, administering, and grading the qualifying exams offered that year. Additional information and previous qualifying exams can be found here.

Dissertation Committee and Program of Study

Upon successful completion of the qualifying examinations, a dissertation committee should be formed by the student as soon as possible. This chair of this committee must be a graduate faculty member from the Department of Physics and Astronomy. The committee must include at least two additional members from the graduate faculty, one of whom must be from outside the Department of Physics and Astronomy. The composition of the committee must be approved by the program director. The dissertation committee is responsible for directing the student in their chosen field of research. The student should work closely
with their committee to select specialty courses and electives that form a cohesive program of study. The student’s program of study must be approved by the dean before advancement to candidacy.

Specialty Science Courses (6 credits)

Students must complete two out of the following four physics and astronomy electives:

- PHYS 784 - Quantum Mechanics II Credits: 3
- PHYS 785 - Classical Electrodynamics II Credits: 3
- ASTR 680 - Physics of Interstellar Media Credits: 3
- ASTR 730 - Stellar Astrophysics Credits: 3

General Science Electives (27 credits)

27 credits of approved general electives and preliminary research credits:

- PHYS 796 - Directed Reading and Research Credits: 1-12
- PHYS 798 - Research Project Credits: 3
- ASTR 796 - Directed Reading and Research Credits: 1-12
- ASTR 798 - Research Project Credits: 3
  Note: PHYS 796/ASTR 796 may be repeated as needed. General electives may be any graduate-level courses chosen from physics, astronomy and/or other related disciplines approved by the student's advisor or dissertation committee.

Seminar (3 credits)

- PHYS 703 - Seminar in Physics Credits: 1 (must be taken three times)

Advancement to Candidacy

Before a student may be advanced to doctoral candidacy, he/she needs to complete all required coursework, pass the qualifying examination, have the program of study and dissertation proposal approved by the dean, and be recommended by the dissertation committee. Advancement to doctoral candidacy implies that the student has demonstrated adequate breadth and depth of knowledge in the field of study and is capable of conducting research on the boundaries of knowledge.

Dissertation Research (24 credits)

Note: No more than 24 combined credits from PHYS 998/ASTR 998 and PHYS 999/ASTR 999 may be applied toward satisfying the doctoral degree requirements, with no more than 12 credits of PHYS 998/ASTR 998.

- ASTR 998 - Doctoral Dissertation Proposal Credits: 1-12
- ASTR 999 - Doctoral Dissertation Credits: 1-12
- PHYS 998 - Doctoral Dissertation Proposal Credits: 1-12
- PHYS 999 - Doctoral Dissertation Credits: 1-12

Doctoral Dissertation

After advancing to doctoral candidacy, the student works with their dissertation committee to develop their preliminary research into a doctoral dissertation. The dissertation research should represent a significant contribution to its scientific field and should
be deemed publishable in a refereed scientific journal. The dissertation must be defended in a public forum before the dissertation
committee and other interested faculty.

Degree Total: 72 credits

Master of Science

Applied and Engineering Physics, MS

Banner Code: SC-MS-PHAE

This program of study is offered by the Department of Physics and Astronomy in the College of Science.

This degree contains elements of traditional physics programs and the application of physics to a diversity of critical societal
problems. The program is divided into three areas of emphasis. The standard emphasis is intended for students who may wish to
pursue further graduate study in physics leading to a PhD degree in preparation for a career in basic research. The applied physics
emphasis is intended for those who wish to apply the techniques and subject areas of physics to multifaceted problems
encountered in the workplace, particularly in physics, engineering, computational science, and other related areas. The
engineering physics emphasis allows students to select a larger number of courses from electrical engineering or nanotechnology
and other areas.

Many courses are offered during late afternoon or evening hours to allow students with full-time employment to attend easily.
Students employed at area high-technology organizations may take up to 6 credits (out of 30) for work done on the job under the
guidance of a faculty member. This employment-related research may be conducted under an optional 3-credit research project or
an optional 6-credit master's thesis. Master's students who are not employed full time may apply for financial aid or a limited
number of research assistantships.

An accelerated master's option is available to students in the bachelor's program. See Physics, BS/Applied and Engineering
Physics, Accelerated MS for specific requirements.

Admission Requirements

Individuals holding a baccalaureate degree in physics or a related field from a regionally accredited institution and who have
earned a GPA of 3.00 (out of 4.00) in their last 60 credits are invited to apply for admission. If the baccalaureate degree is in a
field other than physics, applicants should have taken several courses beyond the introductory physics courses, such as junior-
level classical mechanics, electricity and magnetism, or electronics. Applicants may be required to make up one or two
deficiencies, based on a graduate physics advisor's assessment, and be provisionally admitted into the program. Three letters of
recommendation must be submitted, preferably from former professors. The general GRE and the GRE subject test in physics are
recommended for applicants who received their baccalaureate degrees within the past five years.

Degree Requirements

Candidates for the degree must successfully complete 30 credits in the categories shown below:

6 Credits of Required Core Courses

- PHYS 684 - Quantum Mechanics I Credits: 3
- PHYS 685 - Classical Electrodynamics I Credits: 3
Course Substitution in Select Emphases

For the applied physics emphasis and the engineering physics emphasis, students may substitute:

- PHYS 502 - Introduction to Quantum Mechanics and Atomic Physics Credits: 3 (for PHYS 684)
- PHYS 513 - Applied Electromagnetic Theory Credits: 3 (for PHYS 685)

15 Credits in One of Three Emphases

Standard Emphasis

Students must take:

- PHYS 705 - Classical Mechanics Credits: 3
- PHYS 711 - Statistical Mechanics Credits: 3

Plus Any 9 Credits

Chosen from:

- PHYS 510 - Computational Physics I Credits: 3
- PHYS 512 - Solid State Physics and Applications Credits: 3
- PHYS 533 - Modern Instrumentation Credits: 3
- PHYS 540 - Nuclear and Particle Physics Credits: 3
- PHYS 575 - Atmospheric Physics I Credits: 3
- PHYS 611 - Electro-optics Credits: 3
- PHYS 612 - Physics of Modern Imaging Credits: 3
- PHYS 613 - Computational Physics II Credits: 3
- PHYS 614 - Thermodynamics and Kinetics of Materials Credits: 3
- PHYS 615 - Fundamentals of Materials Science Credits: 3
- PHYS 620 - Continuum Mechanics Credits: 3
- PHYS 628 - Relativity Credits: 3
- PHYS 630 - Introduction to Biophysics Credits: 3
- PHYS 660 - Space Weather Credits: 3
- PHYS 684 - Quantum Mechanics I Credits: 3
- PHYS 685 - Classical Electrodynamics I Credits: 3
- PHYS 701 - Theoretical Physics Credits: 3
- PHYS 736 - Computational Quantum Mechanics Credits: 3
- PHYS 760 - Space Plasma Physics Credits: 3
- PHYS 780 - Advanced Selected Topics in Physics Credits: 3
- PHYS 784 - Quantum Mechanics II Credits: 3
- PHYS 785 - Classical Electrodynamics II Credits: 3
- ASTR 532 - Phys Interplanetary Med Credits: 3
- ASTR 602 - Methods of Observational Astronomy Credits: 4
- ASTR 603 - Planetary Sciences Credits: 3
- ASTR 604 - Galaxies and Cosmology Credits: 3
- ASTR 660 - Plasma Physics for Space and Astrophysics Credits: 3
- ASTR 680 - Physics of Interstellar Media Credits: 3
- ASTR 730 - Stellar Astrophysics Credits: 3
- ASTR 764 - Computational Astrophysics Credits: 3
- ASTR 765 - High-Energy and Accretion Astrophysics Credits: 3
- ASTR 790 - Topics in Astronomy and Astrophysics Credits: 1-6
- CSI 720 - Fluid Mechanics Credits: 3
- CSI 721 - Computational Fluid Dynamics I Credits: 3
- CSI 722 - Computational Fluid Dynamics II Credits: 3
- CSI 761 - N-Body Methods and Particle Simulations Credits: 3
- CSI 786 - Molecular Dynamics Modeling Credits: 3
- CSI 787 - Computational Materials Science Credits: 3
- CSI 788 - Simulation of Large-Scale Physical Systems Credits: 3

Emphasis Total: 15 credits

Engineering Physics Emphasis

Students must take:

- PHYS 510 - Computational Physics I Credits: 3
- PHYS 533 - Modern Instrumentation Credits: 3
- 9 credits of ECE graduate courses

Emphasis Total: 15 credits

Applied Physics Emphasis

Students must take:

- PHYS 510 - Computational Physics I Credits: 3
- PHYS 533 - Modern Instrumentation Credits: 3

Plus 9 Credits

Chosen from:

- BINF 731 - Protein Structure Analysis Credits: 3
- BINF 741 - Introduction to Computer Simulations of Biomolecules Credits: 3
- CLIM 710 - Introduction to Physical Climate System Credits: 3
- CLIM 711 - Introduction to Atmospheric Dynamics Credits: 3
- CLIM 712 - Physical and Dynamical Oceanography Credits: 3
- CLIM 713 - Atmosphere-Ocean Interactions Credits: 3
- CLIM 714 - Land-Climate Interactions Credits: 3
- CLIM 715 - Numerical Methods for Climate Modeling Credits: 3
- CLIM 750 - Geophysical Fluid Dynamics Credits: 3
- CSI 742 - The Mathematics of the Finite Element Method Credits: 3
- CSI 763 - Statistical Methods in Space Sciences Credits: 3
- CSI 782 - Statistical Mechanics for Modeling and Simulation Credits: 3
- CSI 783 - Computational Quantum Mechanics Credits: 3
- ECE 521 - Modern Systems Theory Credits: 3
- ECE 528 - Introduction to Random Processes in Electrical and Computer Engineering Credits: 3
- ECE 548 - Sequential Machine Theory Credits: 3
- ECE 565 - Introduction to Optical Electronics Credits: 3
- ECE 584 - Semiconductor Device Fundamentals Credits: 3
- ECE 699 - Advanced Topics in Electrical and Computer Engineering Credits: 1-6
- PHYS 581 - Topics in Renewable Energy Credits: 3
- Or any course listed in the Standard Emphasis

Emphasis Total: 15 credits

9 Credits of Electives

- Chosen from courses in physics, chemistry, mathematics, engineering, information technology, and computational sciences and informatics. No more than 6 credits may be chosen from areas outside ASTR, CSI, ECE, NANO, and PHYS.

Elective credits can include a project or thesis:

- ECE 798 - Research Project Credits: 1-3
- ECE 799 - Master's Thesis Credits: 1-6
- PHYS 798 - Research Project Credits: 3
- PHYS 799 - Master's Thesis Credits: 1-6

Notes:

- Students may choose to do either ECE 798/ PHYS 798 or ECE 799/ PHYS 799 (6 credits), but not both. The research project may be conducted at a student's place of employment with the concurrence of a faculty advisor.
- The thesis is a more substantial piece of work performed under the supervision of a faculty member and requires students to make an oral defense. ECE 798/ PHYS 798 may be taken only once. No more than 6 credits of PHYS 799 may be applied to the degree.
- In addition to the requirements stated above, students may also select a research focus in astrophysics, atmospheric physics, biological applications of physics, computational physics, condensed matter, instrumentation (engineering physics), or nonlinear dynamics. A focus requires that students complete 15 credits of approved courses.
- Students in the master's degree program can earn the Computational Techniques and Applications Graduate Certificate from the Department of Computational and Data Sciences by choosing an approved sequence of courses.

Degree Total: 30 credits

Sample Course Lists for Various Focus Areas

Astrophysics

- PHYS 701 - Theoretical Physics Credits: 3
- PHYS 711 - Statistical Mechanics Credits: 3
- ASTR 680 - Physics of Interstellar Media Credits: 3

Atmospheric Physics
- PHYS 510 - Computational Physics I Credits: 3
- CLIM 710 - Introduction to Physical Climate System Credits: 3
- CLIM 713 - Atmosphere-Ocean Interactions Credits: 3

### Biophysics

- PHYS 510 - Computational Physics I Credits: 3
- PHYS 630 - Introduction to Biophysics Credits: 3
- PHYS 711 - Statistical Mechanics Credits: 3
- BINF 731 - Protein Structure Analysis Credits: 3
- NEUR 751 - Applied Dynamics in Neuroscience Credits: 3

### Computational Physics

- PHYS 510 - Computational Physics I Credits: 3
- PHYS 613 - Computational Physics II Credits: 3
- PHYS 780 - Advanced Selected Topics in Physics Credits: 3
- CSI 744 - Linear and Nonlinear Modeling in the Natural Sciences Credits: 3
- CSI 764 - Computational Astrophysics Credits: 3

### Instrumentation/Engineering Physics

- PHYS 510 - Computational Physics I Credits: 3
- PHYS 533 - Modern Instrumentation Credits: 3
- NANO 500 - Introduction to Nanomaterials and Interactions Credits: 3
- NANO 510 - Strategies for Nanocharacterization Credits: 3
- ECE 699 - Advanced Topics in Electrical and Computer Engineering Credits: 1-6

### Material Physics

- PHYS 784 - Quantum Mechanics II Credits: 3
- PHYS 785 - Classical Electrodynamics II Credits: 3
- PHYS 711 - Statistical Mechanics Credits: 3
- PHYS 512 - Solid State Physics and Applications Credits: 3
- PHYS 614 - Thermodynamics and Kinetics of Materials Credits: 3

### Nonlinear Dynamics

- PHYS 510 - Computational Physics I Credits: 3
- PHYS 701 - Theoretical Physics Credits: 3
- PHYS 705 - Classical Mechanics Credits: 3
- MATH 673 - Dynamical Systems Credits: 3
- NEUR 751 - Applied Dynamics in Neuroscience Credits: 3

### Physics
Non-Degree

Astronomy Minor

Banner Code:  ASTR

This minor is offered by the Department of Physics and Astronomy in the College of Science.

The minor requires completion of 18 or 20 credits in physics and astronomy, with a minimum GPA of 2.00. Eight credits of coursework must be unique to the minor. For policies governing all minors, see the Undergraduate Policies section of this catalog.

Minor Requirements

Core (12 or 14 credits)

Students will take one of the following sequences listed below:

Sequence One

- PHYS 243 - College Physics Credits: 3 and PHYS 245 - College Physics Credits: 3
- or
- PHYS 160 - University Physics I Credits: 3 and PHYS 260 - University Physics II Credits: 3
  - Plus:
    - ASTR 111 - Introductory Astronomy: The Solar System Credits: 3
    - ASTR 112 - Introductory Astronomy Lab: The Solar System Credits: 1
    - ASTR 113 - Introductory Astronomy: Stars, Galaxies, and the Universe Credits: 3
    - ASTR 114 - Introductory Astronomy Lab: Stars, Galaxies, and the Universe Credits: 1

Sequence Two

- PHYS 160 - University Physics I Credits: 3
- PHYS 260 - University Physics II Credits: 3
- PHYS 262 - University Physics III Credits: 3
- ASTR 210 - Introduction to Astrophysics Credits: 3

Astronomy Electives (6 credits)

Chosen from the following:

- ASTR 301 - Astrobiology Credits: 3
Minor Total: 18 or 20 credits

Physics Minor

Banner Code: PHYS

This minor is offered by the Department of Physics and Astronomy in the College of Science.

The minor requires 18 credits with a minimum GPA of 2.00, 8 credits of which must be unique to the minor. For policies governing all minors, see the Undergraduate Policies section of this catalog.

Minor Requirements

- PHYS 160 - University Physics I Credits: 3
- PHYS 161 - University Physics I Laboratory Credits: 1
- PHYS 260 - University Physics II Credits: 3
- PHYS 261 - University Physics II Laboratory Credits: 1
- PHYS 262 - University Physics III Credits: 3
- PHYS 263 - University Physics III Laboratory Credits: 1

Two Additional Courses

Chosen from:

- PHYS 303 - Classical Mechanics Credits: 3
- PHYS 306 - Wave Motion and Electromagnetic Radiation Credits: 3
- PHYS 307 - Thermal Physics Credits: 3
- PHYS 308 - Modern Physics with Applications Credits: 3
- PHYS 402 - Introduction to Quantum Mechanics and Atomic Physics Credits: 3
- PHYS 428 - Relativity Credits: 3
- PHYS 305 - Electromagnetic Theory Credits: 3
- PHYS 513 - Applied Electromagnetic Theory Credits: 3

Minor Total: 18 credits

Renewable Energy Interdisciplinary Minor

Banner Code: RNRG

This minor is offered by the Department of Physics and Astronomy in the College of Science.
This college-wide interdisciplinary minor administered by the Department of Physics and Astronomy is designed for students considering a career in the field of renewable energy, or as preparation for graduate work in a wide range of academic disciplines. Renewable energy, as normally understood, includes a variety of methods of energy generation, such as solar, wind, hydro, tidal, and geothermal, as well as energy storage methods and energy conservation. Jobs related to renewable energy lie in a wide range of areas including engineering, business, marketing, finance, installation, software, legal affairs, and research. Projections suggest that employment opportunities in the renewable energy field will increase dramatically in the near future. The Renewable Energy Interdisciplinary Minor is therefore ideally suited for students with majors in engineering, business, and basic science. The Renewable Energy Interdisciplinary Minor comprises 17-20 credits of coursework. Eight credits of coursework must be unique to the minor. For policies governing all minors, see the Undergraduate Policies section of this catalog.

Minor Requirements

Core Courses (10 credits)

- PHYS 331 - Fundamentals of Renewable Energy Credits: 3
- PHYS 385 - Materials Science with Applications to Renewable Energy Credits: 3
- MATH 113 - Analytic Geometry and Calculus I Credits: 4

Physics (1-3 credits)

Choose one from the following:

- PHYS 245 - College Physics Credits: 3
- PHYS 262 - University Physics III Credits: 3
- PHYS 266 - Introduction to Thermodynamics Credits: 1

Other Science or Engineering Course (3-4 credits)

Choose from the following in consultation with minor advisor:

- CHEM 212 - General Chemistry Credits: 4
- CHEM 251 - General Chemistry for Engineers Credits: 4
- GEOL 321 - Geology of Energy Resources Credits: 3
- PHYS 332 - Solar Cells Credits: 3
- ECE 301 - Digital Electronics Credits: 3
- Or other appropriate science or engineering course

Internship (3 credits)

Students may choose one of the following options:

- PHYS 409 - Physics Internship Credits: 3 (focused on renewable energy)
- Or a 3 credit internship focusing on renewable energy in another natural science or engineering field

Minor Total: 17-20 credits