The Department of Physics and Astronomy at the University of Denver combines a tradition of individualized instruction with a contemporary research focus. The department underwent a strong expansion with eight tenure-track and two teaching professor positions filled in the last nine years. Our diverse and dynamic faculty of 11 includes three women and come from seven different countries. We provide an attentive, hands-on research and learning community for undergraduate and graduate students up through the PhD level. The department also offers a low student-to-faculty ratio in all advanced and graduate physics and astronomy courses and stresses individualized attention to each student. The program is recognized by the APS among US PhD-granting departments for our high percentage (50%) of female graduates: placing second nationally at the undergraduate level and third at the graduate level (APS data for the period 2011-2013).

The department has major research thrusts in stellar astronomy/astrophysics, biophysics, and condensed matter physics. Our faculty members are internationally recognized and accomplished researchers. The department is a part of the University of Denver’s interdisciplinary Molecular and Cellular Biophysics program (http://www.du.edu/nsm/departments/biophysics). Major state-of-the-art instrumentation is available both in the department and through collaborations with nearby national institutes in the region (NIST, NREL, and NCAR), where several of our faculty hold associate appointments. Also, the Division of Natural Sciences and Mathematics maintains our own Linux cluster for in-house high-performance computational needs.

master of science in physics, doctor of philosophy in physics

Following are the steps to apply for graduate study in Physics and Astronomy at the University of Denver. If you have any questions about the process, please contact the Office of Graduate Studies (http://www.du.edu/learn/graduates).

Apply Online / Application Deadlines

- Applications for graduate study at the University of Denver must be submitted online. Apply online (https://gradadmissions.du.edu/apply).
- All online materials must be received, and all supplemental materials including transcripts must be on file in the Office of Graduate Studies, by the program’s priority deadline: February 1, to receive full consideration for fall quarter admission. Applications completed after that date will be considered on a rolling basis. The program admits for the fall quarter only.
- A $65 non-refundable application fee is required for an application to be processed. Application fee waivers are available for McNair Scholars.

Course and Degree Prerequisites and Requirements

- Applicants must earn and submit proof of earning the equivalent of a baccalaureate degree from a regionally accredited institution prior to beginning graduate coursework at DU.
- An undergraduate physics and mathematics background equivalent to a bachelor’s degree in physics is required.

Transcripts (http://bulletin.du.edu/graduate/admissions/admissionprocessandstandardsforallapplicants/#text)

- Applicants are required to submit an official transcript from each post-secondary institution they have attended, or are presently attending, where two quarter hours (or one semester hour) or more were completed including study abroad and college coursework completed in high school.
- The applicant is responsible for obtaining all transcripts. Applicants who have earned a degree outside the U.S. must submit transcripts accompanied by certified English translations, if not normally issued in English. DU students and alumni do not need to provide DU transcripts.
- Official study abroad transcripts are required unless the course titles, grades and credit earned abroad appear on another transcript. Transcripts from outside of the U.S. are evaluated by the Office of International Student Admission. This process can take three to four weeks and must be complete by the program’s stated deadline. Therefore, applicants with a degree from outside of the U.S. are encouraged to apply early. Applicants educated outside the U.S. are encouraged to contact the Office of Graduate Studies for assistance regarding transcript-related materials.
- The University of Denver will consider electronic transcripts official from a domestic institution provided by the following approved agencies: Army/American Council on Education Registry Transcript System (AARTS); Docufide/Parchment; National Student Clearinghouse; Naviance; Royall and Company; and, Scrip-Safe.
- Mail official transcripts to:
  
  University of Denver  
  Office of Graduate Studies  
  Mary Reed Building, Room 5  
  2199 S. University Blvd.  
  Denver, CO 80208-4802

- Electronic transcripts should be sent to gradinfo@du.edu.
Language Proficiency (http://bulletin.du.edu/graduate/admissions/additionalstandardsfornonnativeenglishspeakers)

- Official scores from the Test of English as a Foreign Language (TOEFL) or International English Language Testing System (IELTS) are required of all graduate applicants, regardless of citizenship status, whose native language is not English or who have been educated in countries where English is not the native language. Applications will not be processed until the required TOEFL or IELTS score is received. The TOEFL and IELTS scores are valid for two years from the test date. The minimum TOEFL score accepted by the University is 80 (iBT) or 550 (paper-based). The institution code for the University of Denver is 4842. The minimum IELTS score accepted by the University is 6.0. Graduate Teaching Assistants (GTAs) must demonstrate fluency in spoken English by scoring a 26 on the TOEFL speaking section or 8.0 on the IELTS speaking section. Please see the Graduate Policy Manual for complete English language proficiency requirements.
- Applicants may be exempt from English proficiency test requirements if by the time of matriculation they have earned a post-secondary degree from a formally-recognized/accredited university where the language of instruction and examination is English. Such applicants may be exempt from the TOEFL/IELTS requirement but not from other standardized graduate entrance examinations. There are no exemptions for graduate teaching assistants.
- Students whose native language is not English and who are required to submit TOEFL/IELTS (http://bulletin.du.edu/graduate/admissions/additionalstandardsfornonnativeenglishspeakers) scores will be assessed by the University of Denver English Language Center (ELC) prior to matriculation.

Test Scores

- The Graduate Record Examination (GRE) is required. Admission preference will be given to those submitting strong scores on the GRE advanced physics subject test. Scores must be received directly from the appropriate testing agency by the program’s stated deadline. The institution code for the University of Denver is 4842.

Personal Statement

- Your application should include a short statement in your own words, describing why you are interested in attending graduate school and why you chose our department. In your essay, specify your particular physics area of interest and discuss your future career plans.

Recommendation Letters

- Three letters of recommendation are required. Letters should be solicited and uploaded by recommenders through the online application system. Requests for letters should be sent to recommenders well in advance so the letters are on file by the application deadline.

Examinations

- A comprehensive examination is given to assess whether students have attained the standards set by the department to continue their pursuit of the degrees sought. All students are required to pass the comprehensive examination at an appropriate level (MS or PhD), in order to advance their candidacy status. All students pursuing a PhD are required to pass an oral dissertation research proposal in order to be promoted to PhD candidacy.

Financial Support

- To be considered for financial support, domestic applicants should apply early and submit the Free Application for Federal Student Aid (FAFSA) by the priority deadline; February 15. Information about financial aid can be found on the Office of Financial Aid (http://www.du.edu/financialaid/graduate) website. International students are not eligible for federal financial aid.
- The Department of Physics and Astronomy offers graduate teaching assistantships, graduate research assistantships, and graduate studies doctoral fellowships, none of which requires the Free Application for Federal Student Aid (FAFSA).

Application Status

- We encourage you to be actively engaged in the admission process. You can check your application status online. Applicants will receive login information post application submission.

Contact Information

- Mail official transcripts and any supplemental admission materials not submitted with the online application to:
  
  University of Denver  
  Office of Graduate Studies  
  Mary Reed Building, Room 5  
  2199 S. University Blvd.  
  Denver, CO 80208-4802

- Electronic transcripts should be sent to gradinfo@du.edu.
- For more information call (303) 871-2706.

International Applicants

- For complete international applicant information, please visit the Office of Graduate Studies International Student Application Information (http://www.du.edu/learn/graduates/internationalapplicants.html). International applicants are strongly encouraged to have their applications complete, with all materials on file in the admission office, at least eight weeks prior to the program’s application deadline.
The Graduate Policies and Procedures provide complete details regarding admission requirements.

**Doctor of Philosophy in Physics**

A minimum of three years of full-time study beyond the baccalaureate degree, with at least 90 quarter hours of approved graduate credit; Comprehensive Examination; acceptable Dissertation and Oral Defense. There is no departmental foreign language requirement. Enrollment as a graduate student at the University of Denver for at least six quarters, including at least two consecutive quarters of full-time attendance, is required to meet residency standards.

**Degree Requirements**

**Coursework Requirements**
Both 4000- and 3000-graduate level courses may be applied toward the degree, with the approval of the Graduate Committee or the Dissertation Committee.

**Graduate Core Courses**

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<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Hours</th>
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<tbody>
<tr>
<td>PHYS 4511</td>
<td>Advanced Dynamics I</td>
<td>4</td>
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<tr>
<td>PHYS 4611</td>
<td>Adv Electricity &amp; Magnetism I</td>
<td>3</td>
</tr>
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</tr>
<tr>
<td>PHYS 4111</td>
<td>Quantum Mechanics I</td>
<td>3</td>
</tr>
<tr>
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<td>Quantum Mechanics II</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 4811</td>
<td>Statistical Mechanics I</td>
<td>4</td>
</tr>
<tr>
<td>PHYS 4001</td>
<td>Introduction to Research I</td>
<td>1.2</td>
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<tr>
<td>PHYS 4002</td>
<td>Introduction to Research II</td>
<td>1.3</td>
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<tr>
<td>PHYS 4003</td>
<td>Introduction to Research III</td>
<td>1.2</td>
</tr>
</tbody>
</table>

**Additional Coursework**

67-63

**Minimum credits required for the degree**

90

**Minimum credits required for degree:** 90 of which a minimum of 60 must be in Physics and Astronomy including the Graduate Core Courses, which constitute 23-27 quarter hours.

**Non-Course Requirements**

- Regular attendance at the Physics and Astronomy colloquia;
- Annual presentation at the Physics and Astronomy colloquia;
- Comprehensive Examination;
- Advancement to Preliminary Candidacy at the Ph.D. level;
- Formation of the Dissertation Committee;
- Passing Oral Dissertation Research Proposal;
- Advancement to Candidacy at the Ph.D. level;
- Dissertation;
- Dissertation Defense. Three departmental faculty members and an Outside Chair are required for the Oral Defense.

**Other Degree Requirements**

- Good academic standing: a GPA of 3.0 or higher;
- No grades lower than C- are accepted toward the degree;
- No more than one-fourth of the hours accepted toward the degree may be of C+, C, or C- grade;

**MASTER OF SCIENCE IN PHYSICS**

The Department of Physics and Astronomy offers a Master of Science (M.S.) in Physics that prepares the student for a wide variety of jobs in industry, government and educational institutions. Our graduates have obtained industrial or governmental laboratory research positions, entered pre-college or community college teaching, joined planetarium or museum staffs, and become technical representatives of various organizations. With complementary courses in education, M.S. graduates are well qualified to teach at the secondary level. The M.S. in Physics is also a popular course of study and professional improvement for people already working in industry. For those currently employed, research projects can usually be matched to the employer’s programs, and often someone from the industry can serve as co-advisor so that the continuing education benefits both the student and the employer.
Degree Requirements

Coursework Requirements
Both 4000- and 3000-graduate level courses may be applied toward the degree, with the approval of the Graduate Committee or the Master's Committee.

Graduate Core Courses

<table>
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<tr>
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<td>PHYS 4511</td>
<td>Advanced Dynamics I</td>
<td>4</td>
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<td>Adv Electricity &amp; Magnetism I</td>
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<td>1,2</td>
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<tr>
<td>PHYS 4002</td>
<td>Introduction to Research II</td>
<td>1-3</td>
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<tr>
<td>PHYS 4003</td>
<td>Introduction to Research III</td>
<td>1,2</td>
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</table>

Additional Coursework

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<tr>
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<tbody>
<tr>
<td>PHYS 3111</td>
<td>Quantum Physics I (4 Credits)</td>
<td></td>
</tr>
<tr>
<td>PHYS 3112</td>
<td>Quantum Physics II (4 Credits)</td>
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</tbody>
</table>

Minimum credits required for the degree: 45 including the Graduate Core Courses, which constitute 23-27 quarter hours

Non-coursework Requirements

Option I (Research Thesis)
- Comprehensive Examination;
- Advancement to Candidacy at the M.S. level;
- Formation of the Masters Committee;
- Thesis;
- Thesis Defense. Two departmental faculty members and an Outside Chair are required for the Oral Thesis Defense.

Option II (No thesis)
- Comprehensive Examination;
- Advancement to Candidacy at the M.S. level;
- Oral Final Examination covering course work. Two departmental faculty members are required for the Oral Examination.

Other Degree Requirements
- Good academic standing: a GPA of 3.0 or higher;
- No grades lower than C- are accepted toward the degree;
- No more than one-fourth of the hours accepted toward the degree may be of C+, C, or C- grade;
- Regular attendance at the Physics and Astronomy colloquia.

Courses

PHYS 3111 Quantum Physics I (4 Credits)
First of a two-quarter sequence. The Schrödinger equation: interpretation of wave functions; the uncertainty principle; stationary states; the free particle and wave packets; the harmonic oscillator; square well potentials. Hilbert space: observables, commutator algebra, eigenfunctions of a Hermitian operator; the hydrogen atom and hydrogenic atoms. Prerequisites: PHYS 2252, PHYS 2260, PHYS 2556, PHYS 3612 and MATH 2070.

PHYS 3112 Quantum Physics II (4 Credits)
Second of a two-quarter sequence. Angular momentum and spin; identical particles; the Pauli exclusion principle; atoms and solids: band theory; perturbation theory; the fine structure of hydrogen; the Zeeman effect; hyperfine splitting; the variational principle; the WKB approximation; tunneling; time dependent perturbation theory; emission and absorption of radiation. Scattering: partial wave analysis; the Born approximation. Prerequisite: PHYS 3111.
PHYS 3251 Astrophysics: Radiative Processes (4 Credits)
Because light is the primary means by which astronomers learn about the Universe, understanding the production and subsequent behavior of light is key to interpreting astronomical observations. This course introduces students to the physics of astrophysical radiation and its interaction with matter as it travels from its source to our detectors. Topics may include radiative transfer, emission and absorption processes, Compton processes, synchrotron radiation, thermodynamic equilibrium, radiative and collisional excitation, and spectroscopy of atoms and molecules. The course is aimed at advanced undergraduates, as well as graduate students focusing on astrophysics research. Prerequisites: PHYS 2252 and consent of instructor.

PHYS 3252 Astrophysics: Observations (4 Credits)
Astronomy is fundamentally an observational science and as such it is important for practitioners to understand how their data are collected and analyzed. This course is therefore a comprehensive review of current observational techniques and instruments, aimed at advanced undergraduates, as well as graduate students focusing on astrophysics research. This class introduces students to the capabilities and limitations of different types of instruments while exploring the sources and types of noise and providing statistical tools necessary for interpreting observational data. Prerequisites: PHYS 2252 and consent of instructor.

PHYS 3270 Workshop: Practical Astronomy (1-5 Credits)
Capstone coursework featuring studies in experimental, computational, and/or theoretical work in astronomy and astrophysics.

PHYS 3311 Advanced Laboratory I (1 Credit)
First of a three-quarter sequence. Advanced experimental techniques in physics. Meets with PHYS 2311. Prerequisite: instructor's permission.

PHYS 3312 Advanced Laboratory II (1 Credit)
Second of a three-quarter sequence. Advanced experimental techniques in physics. Meets with PHYS 2312. Prerequisite: instructor's permission.

PHYS 3313 Advanced Laboratory III (1 Credit)
Third of a three-quarter sequence. Advanced experimental techniques in physics. Meets with PHYS 2313. Prerequisite: instructor's permission.

PHYS 3510 Analytical Mechanics I (4 Credits)
Lagrangian and Hamiltonian mechanics. Prerequisites: PHYS 1113, PHYS 1213, or PHYS 1214 and MATH 2070 and consent of instructor.

PHYS 3611 Electromagnetism I (4 Credits)
First of a two-quarter sequence. Vector algebra; differential vector calculus (gradient, divergence and curl); integral vector calculus (gradient, divergence and Stokes' Theorems); line, surface and volume integrals; Electrostatics: the electric field, electric potential, work and energy in electrostatics; method of images, boundary value problems and solutions to Laplace's equation in Cartesian, spherical and cylindrical coordinates; multipole expansion of the electric potential; electric fields in matter: polarization; the electric displacement vector; boundary conditions, linear dielectrics. Magnetostatics: magnetic fields and forces. Prerequisites: PHYS 1113, PHYS 1213, or PHYS 1214 and MATH 2070.

PHYS 3612 Electromagnetism II (4 Credits)
Second of a two-quarter sequence. Magnetic vector potential; magnetic fields in matter: magnetization; fields of magnetized objects; linear and nonlinear magnetic materials; electromotive force, Ohm's law; electromagnetic induction; Faraday's law; Maxwell's equations; the displacement current; boundary conditions; the Poynting theorem; momentum and energy density of the fields; the Maxwell stress tensor; the wave equation and electromagnetic waves in vacuum and matter; absorption and dispersion; wave guides; the potential formulation and gauge transformations; retarded potentials; dipole radiation. Prerequisite: PHYS 3611.

PHYS 3700 Advanced Topics: General (3 Credits)
Offered irregularly, depending on demand. May be taken more than once for credit. Prerequisite: instructor's permission.

PHYS 3711 Optics I (4 Credits)
First of a two-quarter sequence. Gaussian optics and ray tracing; matrix methods and application to optical design; elementary theory of aberrations; light as electromagnetic wave, diffraction and interference; interferometers and their applications. Elementary theory of coherence; selected topics. May include laboratory work as appropriate. Prerequisites: PHYS 1113, PHYS 1213 or PHYS 1214, and MATH 2070.

PHYS 3841 Thermal Physics I (4 Credits)
First of a two-quarter sequence. Laws of thermodynamics; thermal properties of gases and condensed matter; kinetic theory of gases, classical and quantum statistics. Prerequisites: PHYS 1113, PHYS 1213 or PHYS 1214 and MATH 2070.

PHYS 3991 Independent Study (1-8 Credits)
PHYS 3992 Directed Study (1-10 Credits)
PHYS 3995 Independent Research (1-10 Credits)
PHYS 4001 Introduction to Research I (1,2 Credit)
This course is the first of the 3-course sequence designed to provide the opportunity of learning fundamental skills to conduct independent research in any physical science discipline. In this course, students review essential material in mathematical physics, learn basic programming techniques and improve upon their skills in literature search and scientific writing, especially proposal writing. Special in-class seminars in collaboration with the Penrose Library and Writing and Research Center are scheduled. Student are introduced to research conducted by Physics and Astronomy faculty so that they can choose a faculty member with whom to take on a Winter Research Project during the winter interterm and winter quarter as part of Introduction to Research II. Students must prepare and submit a research proposal before the end of the fall quarter.
PHYS 4002 Introduction to Research II (1-3 Credits)
This is the second of the 3-course sequence to provide the opportunity of learning fundamental skills to conduct independent research in any physical science discipline. In this course, students conduct an independent research or study project that they have outlined in the research proposal they submitted as part of Introduction to Research I under supervision of a faculty advisor of their choosing. At the same time, students have time to review issues that we face as researchers. Prerequisites: PHYS 4001 and consent of a faculty research advisor.

PHYS 4003 Introduction to Research III (1,2 Credit)
This is the third of the 3-course sequence to provide students with the opportunity of learning fundamental skills to conduct independent research in any physical science disciplines. In this course, students complete their Winter research project conducted as part of Introduction to Research II and present the results in writing as a term paper and in oral presentation as part of the Departmental Colloquia. Special in-class sessions in collaboration with the Writing and Research Center are included. Prerequisite: PHYS 4002.

PHYS 4100 Foundations of Biophysics (3 Credits)
Focus of the course is on application of basic physics principles to the study of cells and macromolecules. Topics include diffusion, random processes, thermodynamics, reaction equilibriums and kinetics, computer modeling. Must be admitted to the MCB PhD program or related graduate program with instructor approval. Cross listed with BIOP 4100.

PHYS 4111 Quantum Mechanics I (3 Credits)

PHYS 4112 Quantum Mechanics II (3 Credits)

PHYS 4251 Intro to Astrophysics I (3 Credits)

PHYS 4252 Intro to Astrophysics II (3 Credits)

PHYS 4253 Intro to Astrophysics III (3 Credits)

PHYS 4411 Advanced Condensed Matter I (3 Credits)
Materials structure; structure analysis; elastic properties; defects; plastic mechanical properties; thermal properties and phonons; free electron gas; energy bands and Fermi surfaces; crystalline and amorphous semiconductors; quasiparticles and excitations; electrical properties and ferroelectrics; magnetic properties and ferromagnetics; classical and high-Tc superconductors; other advanced materials. Co-requisite: PHYS 4111.

PHYS 4412 Advanced Condensed Matter II (3 Credits)
Materials structure; structure analysis; elastic properties; defects; plastic mechanical properties; thermal properties and phonons; free electron gas; energy bands and Fermi surfaces; crystalline and amorphous semiconductors; quasiparticles and excitations; electrical properties and ferroelectrics; magnetic properties and ferromagnetics; classical and high-Tc superconductors; other advanced materials. Co-requisite: PHYS 4112.

PHYS 4413 Advanced Condensed Matter III (3 Credits)
Materials structure; structure analysis; elastic properties; defects; plastic mechanical properties; thermal properties and phonons; free electron gas; energy bands and Fermi surfaces; crystalline and amorphous semiconductors; quasiparticles and excitations; electrical properties and ferroelectrics; magnetic properties and ferromagnetics; classical and high-Tc superconductors; other advanced materials. Co-requisite: PHYS 4113.

PHYS 4511 Advanced Dynamics I (4 Credits)

PHYS 4611 Adv Electricity & Magnetism I (3 Credits)

PHYS 4612 Adv Electricity & Magnetism II (3 Credits)

PHYS 4750 Seminar in Physics (1 Credit)

PHYS 4811 Statistical Mechanics I (4 Credits)
Fundamentals of thermodynamics, microcanonical and canonical ensemble, quantum formulation noninteracting particle systems.

PHYS 4910 Special Topics Physics (1-5 Credits)

PHYS 4991 Independent Study (M.S.) (1-10 Credits)

PHYS 4992 Directed Study (M.S.) (1-10 Credits)

PHYS 4995 Independent Research (M.S.) (1-10 Credits)

PHYS 6991 Independent Study (PhD) (1-10 Credits)

PHYS 6995 Independent Research (PhD) (1-10 Credits)