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 12 includes four 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 University of Denver maintains our own Linux cluster for in-house high-performance computational needs.

**Doctor of Philosophy in Physics**

**Application Deadlines**
- Fall 2018 Priority Deadline: February 1, 2018
- Fall 2018 Final Submission Deadline: August 31, 2018

**Admission Requirements**
- Online admission application
- $65.00 Application Fee
- University Minimum Degree and GPA Requirements
- GRE (http://bulletin.du.edu/graduate/admission-and-enrollment-policies/admission-process-and-standards-for-all-applicants/university-admission-criteria): The Graduate Record Examination (GRE) is required. Scores must be received directly from the appropriate testing agency by the deadline. The institution code for the University of Denver is 4842.
- Letters of Recommendation: Three (3) letters of recommendation are required. Letters should be submitted by recommenders through the online application.
- Essay: Seven essay questions are provided on the online application. Please answer each question in the text box provided.

**Additional Standards for Non-Native English Speakers**

Official scores from the Test of English as a Foreign Language (TOEFL), International English Language Testing System (IELTS) or Cambridge English: Advanced (CAE) 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. The minimum TOEFL/IELTS/CAE test score requirements for the degree program are:

- Minimum TOEFL Score (paper-based test): 550
- Minimum TOEFL Score (internet-based test): 80
- Minimum IELTS Score: 6.5
- Minimum CAE Score: 169

**English Conditional Admission Offered:** No, this program does not offer English Conditional Admission.

Read the English Language Proficiency (http://bulletin.du.edu/graduate/admission-and-enrollment-policies/additional-standards-for-non-native-english-speakers/english-language-proficiency-toefl) policy for more details.

Physics and Astronomy

Read the Required Tests for GTA Eligibility (http://bulletin.du.edu/graduate/admission-and-enrollment-policies/additional-standards-for-non-native-english-speakers/required-tests-for-gta-eligibility) policy for more details.

Additional Standards for International Applicants
Per Student & Exchange Visitor Program (SEVP) regulation, international applicants must meet all standards for admission before an I-20 or DS-2019 is issued, [per U.S. Federal Register: 8 CFR § 214.3(k)] or is academically eligible for admission and is admitted [per 22 C.F.R. §62]. Read the Additional Standards For International Applicants (http://bulletin.du.edu/graduate/admission-and-enrollment-policies/additional-standards-for-international-applicants) policy for more details.

Financial Aid
There are many different options available to finance your education. Most University of Denver graduate students are granted some type of financial support. Our Office of Financial Aid is committed to helping you explore your options.

Master of Science in Physics

Application Deadlines
• Fall 2018 Priority Deadline: February 1, 2018
• Fall 2018 Final Submission Deadline: August 31, 2018

Admission Requirements
• Online admission application
• $65.00 Application Fee
• University Minimum Degree and GPA Requirements
• GRE (http://bulletin.du.edu/graduate/admission-and-enrollment-policies/admission-process-and-standards-for-all-applicants/university-admission-criteria): The Graduate Record Examination (GRE) is required. Scores must be received directly from the appropriate testing agency by the deadline. The institution code for the University of Denver is 4842.
• Letters of Recommendation: Three (3) letters of recommendation are required. Letters should be submitted by Recommenders through the online application.
• Essay: Seven essay questions are provided on the online application. Please answer each question in the text box provided.

Additional Standards for Non-Native English Speakers
Official scores from the Test of English as a Foreign Language (TOEFL), International English Language Testing System (IELTS) or Cambridge English: Advanced (CAE) 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. The minimum TOEFL/IELTS/CAE test score requirements for the degree program are:

• Minimum TOEFL Score (paper-based test): 550
• Minimum TOEFL Score (internet-based test): 80
• Minimum IELTS Score: 6.5
• Minimum CAE Score: 169
• English Conditional Admission Offered: No, this program does not offer English Conditional Admission.

Additional Standards for International Applicants
Per Student & Exchange Visitor Program (SEVP) regulation, international applicants must meet all standards for admission before an I-20 or DS-2019 is issued, [per U.S. Federal Register: 8 CFR § 214.3(k)] or is academically eligible for admission and is admitted [per 22 C.F.R. §62]. Read the Additional Standards For International Applicants (http://bulletin.du.edu/graduate/admission-and-enrollment-policies/additional-standards-for-international-applicants) policy for more details.
Financial Aid
There are many different options available to finance your education. Most University of Denver graduate students are granted some type of financial support. Our Office of Financial Aid is committed to helping you explore your options.

Master of Arts in Physics

Application Deadlines
• Fall 2018 Priority Deadline: February 1, 2018
• Fall 2018 Final Submission Deadline: August 31, 2018

Admission Requirements
• Online admission application
• $65.00 Application Fee
• University Minimum Degree and GPA Requirements
• GRE (http://bulletin.du.edu/graduate/admission-and-enrollment-policies/admission-process-and-standards-for-all-applicants/university-admission-criteria): The Graduate Record Examination (GRE) is required. Scores must be received directly from the appropriate testing agency by the deadline. The institution code for the University of Denver is 4842.
• Letters of Recommendation: Three (3) letters of recommendation are required. Letters should be submitted by recommenders through the online application.
• Essay: Seven essay questions are provided on the online application. Please answer each question in the text box provided.

Additional Standards for Non-Native English Speakers
Official scores from the Test of English as a Foreign Language (TOEFL), International English Language Testing System (IELTS) or Cambridge English: Advanced (CAE) 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. The minimum TOEFL/IELTS/CAE test score requirements for the degree program are:

• Minimum TOEFL Score (paper-based test): 550
• Minimum TOEFL Score (internet-based test): 80
• Minimum IELTS Score: 6.5
• Minimum CAE Score: 169
• English Conditional Admission Offered: No, this program does not offer English Conditional Admission.

Read the English Language Proficiency (http://bulletin.du.edu/graduate/admission-and-enrollment-policies/additional-standards-for-non-native-english-speakers/english-language-proficiency-ielts-toefl) policy for more details.


Additional Standards for International Applicants
Per Student & Exchange Visitor Program (SEVP) regulation, international applicants must meet all standards for admission before an I-20 or DS-2019 is issued, [per U.S. Federal Register, 8 CFR § 214.3(k)] or is academically eligible for admission and is admitted [per 22 C.F.R. §62]. Read the Additional Standards For International Applicants (http://bulletin.du.edu/graduate/admission-and-enrollment-policies/additional-standards-for-international-applicants) policy for more details.

Financial Aid
There are many different options available to finance your education. Most University of Denver graduate students are granted some type of financial support. Our Office of Financial Aid is committed to helping you explore your options.

Doctor of Philosophy in Physics
The Department of Physics and Astronomy offers PhD degree in physics that prepares students for careers across a spectrum of scientific pursuits. At the conclusion of your degree, you'll be equipped with the experience and knowledge necessary to build a career in the advancement of scientific
knowledge or education at the highest levels, which can open doors to careers in research and development in academia, government, and private industry.

Our department offers research opportunities in theoretical, experimental and computational astronomy and astrophysics, biophysics, and condensed matter and materials physics. PhD candidates in the program will work closely with faculty advisors to create a path of study that culminates in a dissertation defense based on independent research of a publishable quality.

**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.

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<td>PHYS 4003</td>
<td>Introduction to Research III</td>
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**Minimum credits required for the degree:** 90 of which a minimum of 60 must be in Physics and Astronomy including the Graduate Core Courses, which constitute 19-23 quarter hours.

**Non-Course Requirements**

- Regular attendance at the Physics and Astronomy colloquia;
- Annual presentation at the Physics and Astronomy colloquia;
- Passing Comprehensive Examination at the Ph.D. level;
- 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 ARTS in Physics**

The Department of Physics and Astronomy offers a Master of Arts (M.A.) in Physics that prepares the student for a wide variety of jobs. The M.A. degree is intended primarily for students who are seeking an advanced degree without a significant research component. For instance, the M.A degree is appropriate for students pursuing careers in pre-college or community college teaching, planetarium or museums, or as technical representatives of various organizations. With complementary courses in education, M.A. graduates are well qualified to teach at the secondary level. The main difference between the M.A. and M.S. degree is that a research thesis is not required for the M.A. degree. However, students pursuing the M.A. degree will get exposed to some research experience through Introduction to Research courses in their first year in the program.

**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.
### 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.

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Minimum credits required for degree: 45 including the Graduate Core Courses, which constitute 19-23 quarter hours

Non-Course 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.
Physics and Astronomy

- Advancement to M.S. Candidacy;
- Formation of the Master’s Committee;
- Thesis;
- Thesis Defense. Two 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;

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; electromagnetic 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. Students 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 discipline. 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 4720 Light-Matter Interaction (4 Credits)
This course will introduce the theory and applications of light-matter interactions. Fundamental theory will be explored from both semi-classical and quantum perspectives, and photon-carrier interactions will be studied in a variety of physical systems, including atoms, glasses, semiconductors, and metals. Experimental techniques will also be discussed, such as absorption, photoluminescence, and coherent spectroscopies, in addition to ultrafast nonlinear optical interactions. Students will also build their own demonstration and teaching module for elementary-age children, and will use their module to teach children at a local school.
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 4860 Numerical and Computational Methods in Physics (4 Credits)
The main goal of this course is to gain a better understanding of physical problems by solving them numerically; in the process, students learn about several numerical methods and computational techniques that have a very broad range of applications in many other scientific fields. Depending on the problem, students work with a software package (Mathematica), and also acquire coding experience in different programming languages. Graduate students carry out projects involving more complex simulation and numerical methods currently used in many areas of condensed matter physics, quantum chemistry and biophysics, such as Density Functional calculations, Monte Carlo and Molecular Dynamics methods.
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)