

# DEPARTMENT OF PHYSICS

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Department Website: <http://physics.uchicago.edu>

Chair

- Peter Littlewood

Professors

- David C. Awschalom, PME
- Edward C. Blucher
- Marcela Carena
- John Eric Carlstrom, Astronomy & Astrophysics
- Cheng Chin
- Juan Collar
- David DeMille
- Bonnie Fleming
- Henry J. Frisch
- Margaret Gardel
- Philippe M. Guyot Sionnest, Chemistry
- Jeffrey A. Harvey
- Daniel Holz
- William Irvine
- Heinrich Martin Jaeger
- Woowon Kang
- Young Kee Kim
- David Kutasov
- Kathryn Levin
- Michael Levin
- Peter Littlewood
- Emil J. Martinec
- Jeffrey McMahon
- Sidney R. Nagel
- Paolo Privitera, Astronomy & Astrophysics
- Robert Rosner, Astronomy & Astrophysics
- Michael Rust, Molecular Genetics and Cell Biology
- Guy Savard
- Savdeep Sethi
- Dam T. Son
- Abigail Viereggs
- Vincenzo Vitelli
- Carlos E.M. Wagner
- Yau Wai Wah
- Scott Wakely
- Robert M. Wald
- LianTao Wang
- Paul B. Wiegmann
- Linda Young

Associate Professors

- Luca Grandi
- David Miller
- Arvind Murugan
- Stephanie Palmer, Organismal Biology and Anatomy

- David Schmitz
- Wendy Zhang

## Assistant Professors

- Clay Cordova
- Luca Delacretaz
- Karri DiPetrillo
- Keisuke Harigaya
- Andrew Higginbotham
- Elizabeth Jerison
- Zoe Yan

## Associate Senior Instructional Professor

- Zosia Krusberg

## Assistant Instructional Professor

- Savan Kharel

## Senior Lecturer

- Stuart Gazes

## Emeritus Faculty

- Robert P. Geroch
- Gene F. Mazenko
- Frank S. Merritt
- Mark J. Oreglia
- James E. Pilcher
- Jonathan L. Rosner
- Melvyn J. Shochet
- Michael S. Turner
- Thomas A. Witten

The Department of Physics (<http://physics.uchicago.edu/>) offers advanced degree opportunities in many areas of experimental and theoretical physics, supervised by a distinguished group of research faculty. Applications are accepted from students of diverse backgrounds and institutions: graduates of research universities or four year colleges, from the U.S. and worldwide. Most applicants, but not all, have undergraduate degrees in physics; many have had significant research experience. Seeking to identify the most qualified students who show promise of excellence in research and teaching, the admissions process is highly selective and very competitive.

## DOCTOR OF PHILOSOPHY

During the first year of the doctoral program, a student takes introductory graduate physics courses and usually serves as a teaching assistant assigned to one of the introductory or intermediate undergraduate physics courses. Students are encouraged to explore research opportunities during their first year. Students are strongly encouraged to take the graduate diagnostic examination prior to their first quarter in the program. The results of this examination will determine which of the introductory graduate courses the student must take to achieve candidacy. After achieving candidacy and identifying a research sponsor, the student begins dissertation research while completing course requirements. Within a year after research begins, a PhD committee is formed with the sponsor as chairman. The student continues research, from time to time consulting with the members of the committee, until completion of the dissertation. The average length of time for completion of the PhD program in physics is about six years.

In addition to fulfilling University and divisional requirements, a candidate for the degree of Doctor of Philosophy in physics must:

- Achieve Candidacy.
- Fulfill the experimental physics requirement by completing PHYS 33400 Adv Experimental Physics or PHYS 33500 Adv Experimental Physics Project.
- Pass four post candidacy advanced graduate courses devoted to the broad physics research areas of (A) Condensed Matter Physics, (B) Particle Physics, (C) Large Scale Physics (i.e. Astrophysics and/or Cosmology related), and (D) Intermediate Electives. The four courses selected must include at least one from each of the categories (A), (B), and (C).

- Pass two other advanced (40000 level) courses either in physics or in a field related to the student's Ph.D. research. The latter requires department approval.
- Within the first year after beginning research, convene a first meeting of the Ph.D. committee to review plans for the proposed thesis research and for fulfilling the remaining Ph.D. requirements.
- Attend annual meetings with the thesis committee.
- One to two quarters prior to the defense of the dissertation, hold a pre-oral meeting at which the student and the Ph.D. committee discuss the research project.
- Defend the dissertation before the Ph.D. committee.
- Submit for publication to a refereed scientific journal the thesis which has been approved by the Ph.D. committee or a paper based on the thesis. A letter from the editor acknowledging receipt of the thesis must be provided to the department office.

Acquire further information about our doctoral program with Zosia Krusberg (<https://physics.uchicago.edu/people/profile/zosia-krusberg/>), Director of Graduate Studies.

### MASTER OF SCIENCE

The graduate program of the Department of Physics is oriented toward students who intend to earn a Ph.D. degree in physics. Therefore, the department does not offer admission to students whose goal is the Master of Science degree. However, the department does offer a master's degree to students who are already in the physics Ph.D. program or other approved graduate programs in the University. Normally it takes one and a half years for a student to complete the master's program. A master's degree is not required for continued study toward the doctorate.

In addition to fulfilling University and Divisional requirements, a candidate for the degree of Master of Science in physics must demonstrate a satisfactory level of understanding of the fundamental principles of physics by passing nine approved courses with a minimum grade point average of 2.5. Six of the nine courses must be:

PHYS 31600	Adv Classical Mechanics	100
PHYS 33000	Math Methods Of Physics-1	100
PHYS 34100	Graduate Quantum Mechanics-1	100
PHYS 32200	Advanced Electrodynamics I	100
PHYS 35200	Statistical Mechanics	100
PHYS 33400	Adv Experimental Physics	100
PHYS 33500	Adv Experimental Physics Project	100

The experimental physics requirement can be fulfilled either through PHYS 33400 Adv Experimental Physics or PHYS 33500 Adv Experimental Physics Project.

Testing out of certain courses (PHYS 31600, 32200, 32300, 34100, 34200, and 35200) on the Graduate Diagnostic Exam can be applied toward the Master's degree in place of taking the course. The 2.5 GPA minimum applies only to courses taken in addition to those credited by performance on the Graduate Diagnostic Exam.

The Department may approve substitutions to this list where warranted.

### TEACHING OPPORTUNITIES

Part of the training of graduate students is dedicated to obtaining experience and facility in teaching. Most first year students are supported by teaching assistantships, which provide the opportunity for them to engage in a variety of teaching related activities. These may include supervising undergraduate laboratory sections, conducting discussion and problem sessions, holding office hours, and grading written work for specific courses. Fellowship holders are invited to participate in these activities at reduced levels of commitment to gain experience in the teaching of physics. During the Autumn quarter first year graduate students attend the weekly workshop, Teaching and Learning of Physics, which is an important element in their training as teachers of physics.

### TEACHING FACILITIES

All formal class work takes place in the modern lecture halls and classrooms and instructional laboratories of the Kersten Physics Teaching Center. This building also houses special equipment and support facilities for student experimental projects, departmental administrative offices, and meeting rooms. The center is situated on the science quadrangle near the John Crerar Science Library, which holds over 1,000,000 volumes and provides modern literature search and data retrieval systems.

### RESEARCH FACILITIES

Most of the experimental and theoretical research of Physics faculty and graduate students is carried out within the Enrico Fermi Institute (<http://efi.uchicago.edu/>), the James Franck Institute (<http://jfi.uchicago.edu/>) and the Institute for Biophysical Dynamics (<http://ibd.uchicago.edu/>). These research institutes provide close

interdisciplinary contact, crossing the traditional boundaries between departments. This broad scientific endeavor is reflected in students' activities and contributes to their outlook toward research.

In the Enrico Fermi Institute, members of the Department of Physics carry out theoretical research in particle theory, string theory, field theory, general relativity, and theoretical astrophysics and cosmology. There are active experimental groups in high energy physics, nuclear physics, astrophysics and space physics, infrared and optical astronomy, and microwave background observations. Some of this research is conducted at the Fermi National Accelerator Laboratory, at Argonne National Laboratory (both of these are near Chicago), and at the European Organization for Nuclear Research (CERN) in Geneva, Switzerland.

Physics faculty in the James Franck Institute study chemical, solid state, condensed matter, and statistical physics. Fields of interest include chaos, chemical kinetics, critical phenomena, high T<sub>c</sub> superconductivity, nonlinear dynamics, low temperature, disordered and amorphous systems, the dynamics of glasses, fluid dynamics, surface and interface phenomena, nonlinear and nanoscale optics, unstable and metastable systems, laser cooling and trapping, atomic physics, and polymer physics. Much of the research utilizes specialized facilities operated by the institute, including a low temperature laboratory, a materials preparation laboratory, x-ray diffraction and analytical chemistry laboratories, laser equipment, a scanning tunneling microscope, and extensive shop facilities. Some members of the faculty are involved in research at Argonne National Laboratory.

The Institute for Biophysical Dynamics includes members of both the Physical Sciences and Biological Sciences Divisions, and focuses on the physical basis for molecular and cellular processes. This interface between the physical and biological sciences is an exciting area that is developing rapidly, with a bi-directional impact. Research topics include the creation of physical materials by biological self assembly, the molecular basis of macromolecular interactions and cellular signaling, the derivation of sequence structure function relationships by computational means, and structure function relationships in membranes.

In the areas of chemical and atomic physics, research toward the doctorate may be done in either the physics or the chemistry department. Facilities are available for research in crystal chemistry; molecular physics; molecular spectra from infrared to far ultraviolet, Bose Einstein condensation, and Raman spectra, both experimental and theoretical; surface physics; statistical mechanics; radio chemistry; and quantum electronics.

Interdisciplinary research leading to a Ph.D. degree in physics may be carried out under the guidance of faculty committees including members of other departments in the Division of the Physical Sciences, such as Astronomy & Astrophysics, Chemistry, Computer Science, Geophysical Sciences or Mathematics, or related departments in the Division of the Biological Sciences.

### ADMISSION AND STUDENT AID

Most students entering the graduate program of the Department of Physics of the University of Chicago hold a bachelor's or master's degree in physics from an accredited college or university.

December 15 is the deadline for applications for admission in the following autumn quarter. The Graduate Record Examination (GRE) given by the Educational Testing Service is required of all applicants. Applicants should submit recent scores on the verbal, quantitative, and analytic writing tests and on the advanced subject test in physics. Arrangements should be made to take the examination no later than September in order that the results be available in time for the department's consideration. Applicants from non-English speaking countries must provide the scores achieved on the TOEFL or the IELTS.

All full time physics graduate students in good standing receive financial aid. Most graduate students serve as teaching assistants in their first year.

The department has instituted a small bridge-to-Ph.D. program which does not require the Graduate Record Examination. The application deadline for this program varies but is expected to be mid to late spring.

For information including faculty research interests, application instructions, and other important program details please visit our department website <http://physics.uchicago.edu/>. You can also reach out to [physics@uchicago.edu](mailto:physics@uchicago.edu) with any questions or concerns regarding the admissions process.

### GRADING POLICY

The department's grading policy is available on the departmental website (<http://physics.uchicago.edu/>).

### COURSE REQUIREMENTS

Course requirements are available on the department's website (<http://physics.uchicago.edu/>).

### PHYSICS COURSES

#### **PHYS 30101. Analytical Methods of Physics I. 100 Units.**

This course focuses on analytical techniques used in physics. It is designed to have flexible topical coverage so that the course may be geared to the registered students. Enrollment is by instructor approval only.

Instructor(s): D. Reed Terms Offered: Autumn

Prerequisite(s): Permission of the instructor.

**PHYS 30102. Analytical Methods of Physics II. 100 Units.**

Course focuses on analytical techniques used in Physics. It is designed to have flexible topical coverage so that the course may be geared to registered students. Enrollment is by instructor approval only.

**PHYS 30103. Analytical Methods of Physics III. 100 Units.****PHYS 31600. Adv Classical Mechanics. 100 Units.**

This course begins with variational formulation of classical mechanics of point particles, including discussion of the principle of least action, Poisson brackets, and Hamilton-Jacobi theory. These concepts are generalized to continuous systems with infinite number of degrees of freedom, including a discussion of the transition to quantum mechanics.

Terms Offered: Autumn

Prerequisite(s): PHYS 18500

**PHYS 31700. Symplectic Methods of Classical Dynamics. 100 Units.**

This course covers advanced techniques in classical dynamics including Lagrangian mechanics on manifolds, differential forms, symplectic structures on manifolds, the Lie algebra of vector fields and Hamiltonian functions, and symplectic geometry.

Terms Offered: Spring

**PHYS 32200-32300. Advanced Electrodynamics I-II.**

This two-quarter sequence covers electromagnetic properties of continuous media, gauge transformations, electromagnetic waves, radiation, relativistic electrodynamics, Lorentz theory of electrons, and theoretical optics. There is considerable emphasis on the mathematical methods behind the development of the physics of these problems.

**PHYS 32200. Advanced Electrodynamics I. 100 Units.**

Terms Offered: Winter

Prerequisite(s): PHYS 22700 and 23500

**PHYS 32300. Advanced Electrodynamics II. 100 Units.**

Terms Offered: Spring

Prerequisite(s): PHYS 32200

**PHYS 33000. Math Methods Of Physics-1. 100 Units.**

Topics include complex analysis, linear algebra, differential equations, boundary value problems, and special functions.

Terms Offered: Autumn

Prerequisite(s): PHYS 22700

**PHYS 33400. Adv Experimental Physics. 100 Units.**

For course description contact Physics.

Terms Offered: Spring

**PHYS 33500. Adv Experimental Physics Project. 100 Units.**

For course description contact Physics.

**PHYS 34100-34200. Advanced Quantum Mechanics I-II.**

This two-quarter sequence covers wave functions and their physical content, one-dimensional systems, WKB method, operators and matrix mechanics, angular momentum and spin, two- and three-dimensional systems, the Pauli principle, perturbation theory, Born approximation, and scattering theory.

**PHYS 34100. Graduate Quantum Mechanics-1. 100 Units.**

This course is a two-quarter sequence that covers wave functions and their physical content, one dimensional systems, WKB method, operators and matrix mechanics, angular momentum and spin, two- and three dimensional systems, with Pauli principle, perturbation theory, Born approximation, and scattering theory.

Terms Offered: Autumn

Prerequisite(s): PHYS 23500

**PHYS 34200. Graduate Quantum Mechanics-2. 100 Units.**

This two-quarter sequence covers wave functions and their physical content, one-dimensional systems, WKB method, operators and matrix mechanics, angular momentum and spin, two- and three-dimensional systems, the Pauli principle, perturbation theory, Born approximation, and scattering theory

Terms Offered: Winter

Prerequisite(s): PHYS 34100

**PHYS 35200. Statistical Mechanics. 100 Units.**

This course covers principles of statistical mechanics and thermodynamics, as well as their applications to problems in physics and chemistry.

Terms Offered: Spring

Prerequisite(s): PHYS 19700 and 23500

**PHYS 35300. Advanced Statistical Mechanics. 100 Units.**

This course will cover advanced topics in collective behavior, mean field theory, fluctuations, scaling hypothesis. Perturbative renormalization group, series expansions, low-dimensional systems and topological defects, random systems and conformal symmetry.

**PHYS 36100. Solid State Physics. 100 Units.**

Topics include Properties of Insulators, Electronic Properties of Solids, Thermal Properties, Optical Properties of Solids, and Transport in Metals (conductivity, Hall effect, etc.)

Terms Offered: Autumn

Prerequisite(s): PHYS 23600, 34200, 35200

**PHYS 36300. Particle Physics. 100 Units.****PHYS 36400. General Relativity. 100 Units.**

This is advanced-level course on general relativity treats special relativity, manifolds, curvature, gravitation, the Schwarzschild solution and black holes.

Terms Offered: Winter 2014

**PHYS 36600. Adv Condensed Matter Physics. 100 Units.**

Phasetransitions, Magnetism, Superconductivity, Disorder, Quantum Hall Effect, Superfluidity, Physics of Low-dimensional systems, Fermi liquid theory, and Quasi-crystals.

Terms Offered: Winter

**PHYS 36700. Soft Condensed Matter Phys. 100 Units.**

This course will cover topics including granular and colloidal matter, jamming, fluids, instabilities and topological shapes and transitions between them.

**PHYS 37100. Introduction To Cosmology. 100 Units.****PHYS 37200. Particle Astrophysics. 100 Units.**

This course treats various topics in particle astrophysics.

Terms Offered: TBD

**PHYS 38500. Advanced Mathematical Methods. 100 Units.**

Course description unavailable.

Terms Offered: Winter

**PHYS 38520. Advanced Mathematical Methods: Topology. 100 Units.**

This course covers topology. It alternates years with PHYS 38510 (group theory).

Terms Offered: Winter

**PHYS 38600. Advanced Methods of Data Analysis. 100 Units.**

This course covers advanced methods of data analysis including probability distributions, propagation of errors, Bayesian approaches, maximum likelihood estimators, confidence intervals, and more.

Terms Offered: Spring

**PHYS 39000. PREP for Candidacy. 300.00 Units.**

Registration for students who have not yet reached Ph.D. candidacy.

**PHYS 39800. Research: Physics. 300.00 Units.**

Registration for students performing individually arranged research projects not related to a doctoral thesis.

**PHYS 39900. Prep For Candidacy Examination. 300.00 Units.****PHYS 40600. Nuclear Physics. 100 Units.**

No description Available

**PHYS 40700. X-ray Lasers and Applications. 100 Units.**

This course will introduce the basic concepts of accelerator-based x-ray light sources (XFELs and synchrotrons) and survey contemporary x-ray applications such as nonlinear multiphoton absorption, induced transparency/saturable absorption, and atomic x-ray lasing in systems ranging from atoms to clusters to solids.

**PHYS 41000. Accelerator Physics. 100 Units.**

The course begins with the historical development of accelerators and their applications. Following a brief review of special relativity, the bulk of the course will focus on acceleration methods and phase stability, basic concepts of magnet design, and transverse linear particle motion. Basic accelerator components such as bending and focusing magnets, electrostatic deflectors, beam diagnostics and radio frequency accelerating structures will be described. The basic concepts of magnet design will be introduced, along with a discussion of particle beam optics. An introduction to resonances, linear coupling, space charge, magnet errors, and synchrotron radiation will also be given. Topics in longitudinal and transverse beam dynamics will be explored, including synchrotron and betatron particle motion. Lastly, a number of additional topics will be reviewed, including synchrotron radiation sources, free electron lasers, high energy colliders, and accelerators for radiation therapy. Several laboratory sessions will provide hands-on experience with hardware and measurement instrumentation.

Terms Offered: Autumn

**PHYS 41100. Many Body Theory. 100 Units.**

The course will follow roughly the new textbook by Piers Coleman "Introduction to Many-Body Physics". The topics are: Second quantization, Path integral, Quantum fields, Green functions, Feynman diagrams, Landau Fermi Liquid theory, Phase transitions, BCS theory, more advanced topics.

**PHYS 41101. Entanglement in Many-Body Systems. 100 Units.**

This course starts with an introduction to quantum information theory: density operators, quantum channels and measurements, von Neumann entropy, mutual information, and entanglement. It continues with a discussion of topological quantum computation. The course then concludes with a discussion of entanglement in many-body ground states, including the area law, topological entanglement entropy, and entanglement in conformal field theories.

Terms Offered: Winter

Prerequisite(s): PHYS 342 or equivalent

**PHYS 41120. Topics in Many-Body Dynamics. 100 Units.**

Topics: 1. Non-variational Mechanics 2. Parity-violating Hydrodynamics 3. Dynamical Phase transitions

**PHYS 41200. Topological Quantum Matter. 100 Units.****PHYS 41300. Topological Phases in Condensed Matter. 100 Units.**

TBA

Terms Offered: Winter

Prerequisite(s): PHYS 36100

**PHYS 42100. Fractional Quantum Hall Effect. 100 Units.**

TBD

**PHYS 42600. Fluid Mechanics. 100 Units.**

Terms Offered: Spring

**PHYS 44000. Principles of Particle Detectors. 100 Units.****PHYS 44100. Advanced Particle Detectors. 100 Units.**

We will explore the development of modern detector types, and examine opportunities for developing new capabilities in a variety of fields.

Terms Offered: Spring

Prerequisite(s): PHYS 32300

**PHYS 44300. Quantum Field Theory I. 100 Units.**

Topics include Basic Field Theory, Scattering and Feynman Rules, and One Loop Effects.

Terms Offered: Autumn

Prerequisite(s): PHYS 34200

**PHYS 44400. Quantum Field Theory II. 100 Units.**

Topics include Path integral formulation of QFT, Renormalization, Non-Abelian gauge theory.

Terms Offered: Winter

**PHYS 44500. Quantum Field Theory-3. 100 Units.****PHYS 44800. Field Theory in Condensed Matter. 100 Units.**

Course description unavailable.

Terms Offered: Autumn

**PHYS 45700. Implementation of Quantum Information Processors. 100 Units.**

This course emphasizes the experimental aspects of quantum information focusing on implementations rather than algorithms. Several candidate quantum information systems will be discussed including ion traps, neutral atoms, superconducting circuits, semiconducting quantum dots, and linear optics.

**PHYS 45710. Physics of Superconducting Circuits. 100 Units.**

This course will give a brief introduction to superconductivity as it relates to building quantum circuits. Circuit quantization will be introduced and used to derive the Hamiltonians of several standard circuits including sensors such as single electron transistors and superconducting quantum interference devices as well as various flavors of superconducting qubit. We will study cavity QED and how such physics is realized with superconducting circuits. We will discuss the experiments used to characterize such quantum systems. The course will have a strong numerics component across all topics.

Terms Offered: Spring

Prerequisite(s): PHYS 34200 or MENG 31400 or consent of Instructor

**PHYS 45800. The Physics of Quantum Information. 100 Units.****PHYS 46000. Gravitational Waves. 100 Units.**

This course will provide a broad overview of gravitational waves, with a focus on current results from LIGO. We will cover the basics of gravitational wave theory, compact binary coalescence and sources of gravitational wave, ground-based gravitational wave detection, LIGO and the first detections, LIGO's black holes and how

the Universe might have made them, gravitational wave astrophysics, and the near future of gravitational wave science.

**PHYS 46200. Nuclear Astrophysics. 100 Units.**

Terms Offered: Autumn

**PHYS 46700. Quantum Field Theory in Curved Spacetime I. 100 Units.**

This course covers introductory topics in the study of quantum field theory in curved spacetime. These topics include QFT for a free scalar field and for globally hyperbolic curved spacetimes, and the Unruh effect.

**PHYS 46800. Quantum Field Theory in Curved Spacetime II. 100 Units.**

This course covers advanced topics in the study of quantum field theory in curved spacetime. These topics include the Hawking effect, quantum perturbations in cosmology, black hole evaporation and information loss, and other modern topics.

**PHYS 46900. Effective Field Theories. 100 Units.**

TBD

**PHYS 47100. Modern Atomic Physics. 100 Units.**

This course is an introduction to modern atomic physics, and focuses on phenomena revealed by new experimental techniques.

Terms Offered: Winter

**PHYS 48102. Neutrino Physics. 100 Units.**

This is an advanced course on neutrino phenomenology. The topics include neutrino flavor transformations, neutrino mass, sterile neutinos, non-standard interactions of neutrinos, and other topics of modern interest.

**PHYS 48103. Standard Model of Particle Physics and Beyond. 100 Units.**

This course provides an overview of the Standard Model of particle physics, the problems with it, and the candidates of physics beyond the Standard model that can solve those problems.

Terms Offered: Winter

**PHYS 48300. String Theory-I. 100 Units.**

First quarter of a two-quarter sequence on string theory.

Terms Offered: Winter

**PHYS 48400. String Theory-II. 100 Units.**

Second quarter of a two-quarter sequence on string theory.

**PHYS 49000. Basic Principles of Biophysics. 100 Units.**

This course is designed to expose graduate students in the physical sciences to conceptual and quantitative questions about biological systems. It will cover a broad range of biological examples from vision in flies and developing embryos to swimming bacteria and gene regulation. This course does not assume specialized biological knowledge or advanced mathematical skills.

**PHYS 49100. Biological Physics. 100 Units.**

Course will be structured around unifying problems and themes found across biology that benefit from a quantitative approach. No specialized biological knowledge assumed. Topics covered include: active solution to passive problems, self-replication: the origin of life and evolution, mass, energy and growth laws, biological behaviors as stable dynamical attractors.

Terms Offered: Spring

**PHYS 49900. Advanced Research: Physics. 300.00 Units.**

This course is for students performing research toward their doctoral thesis.

**PHYS 70000. Advanced Study: Physics. 300.00 Units.**

Advanced Study: Physics

