APPLIED PHYSICS

Courses offered by the Department of Applied Physics are listed under the subject code APPPHYS on the (http://explorecourses.stanford.edu/CourseSearch/search/?view=catalog&catalog=&page=0&q=APPPHYS&filter-catalognumber-APPPHYS=on) Stanford Bulletin's (http://explorecourses.stanford.edu/CourseSearch/search/?view=catalog&catalog=&page=0&q=APPPHYS&filter-catalognumber-APPPHYS=on) ExploreCourses web site (http://explorecourses.stanford.edu/CourseSearch/search/?view=catalog&catalog=&page=0&q=APPPHYS&filter-catalognumber-APPPHYS=on).

The Department of Applied Physics offers qualified students with backgrounds in physics or engineering the opportunity to do graduate course work and research in the physics relevant to technical applications and natural phenomena. These areas include accelerator physics, biophysics, condensed matter physics, nanostructured materials, quantum electronics and photonics, quantum optics and quantum information, space science and astrophysics, synchrotron radiation and applications.

Student research is supervised by the faculty members and also by various members of other departments such as Biology, Chemistry, Electrical Engineering, Materials Science and Engineering, Physics, the SLAC National Accelerator Laboratory, and faculty of the Medical School who are engaged in related research fields.

Research activities are carried out in laboratories including the Geballe Laboratory for Advanced Materials (GLAM), the Edward L. Ginzton Laboratory (GINZTON), the Hansen Experimental Physics Laboratory (HEPL), the SLAC National Accelerator Laboratory, the Center for Probing the Nanoscale, and the Stanford Institute for Materials and Energy Science (SIMES).

The number of graduate students admitted to Applied Physics is limited. Applications to the Master of Science and Ph.D. programs should be received by December 15, 2020. M.S. and PhD. students normally enter the department the following Autumn Quarter. Joint applicants for the Knight-Hennessy Scholars Program (http://knight-hennessy.stanford.edu/) must submit their Knight-Hennessy Scholars application by October 14, 2020 by 1:00pm Pacific Time and Applied Physics application by December 15, 2020. The general and subject GREs are optional for both the Ph.D. and master's programs. Applicants may submit scores, but they are not required.

Graduate Programs in Applied Physics

The Department of Applied Physics offers three types of advanced degrees:

- the Doctor of Philosophy
- the coterminal Master of Science in Applied and Engineering Physics
- the Master of Science in Applied Physics, either as a terminal degree or an en route degree to the Ph.D. for students already enrolled in the Applied Physics Ph.D. program.

Admission requirements for graduate work in the Master of Science and Ph.D. programs in Applied Physics include a bachelor's degree in Physics or an equivalent engineering degree. Students entering the program from an engineering curriculum should expect to spend at least an additional quarter of study acquiring the background to meet the requirements for the M.S. and Ph.D. degrees in Applied Physics.

Learning Outcomes (Graduate)

The purpose of the master's program is to further develop knowledge and skills in Applied Physics and to prepare students for a professional career or doctoral studies. This is achieved through completion of courses, in the primary field as well as related areas, and experience with independent work and specialization.

The Ph.D. is conferred upon candidates who have demonstrated substantial scholarship and the ability to conduct independent research and analysis in Applied Physics. Through completion of advanced course work and rigorous skills training, the doctoral program prepares students to make original contributions to the knowledge of Applied Physics and to interpret and present the results of such research.

The department offers an M.S. in Applied Physics as well as a coterminal M.S. in Applied Physics available, upon application and acceptance, to Stanford undergraduates. Both programs are described below.

Master of Science in Applied Physics

The University's basic requirements for the master's degree are discussed in the "Graduate Degrees (http://exploredegrees.stanford.edu/graduatedegrees/)" section of this bulletin. The minimum requirements for the degree are 45 units, of which at least 39 units must be graduate-level courses in applied physics, engineering, mathematics, and physics. The deadline for 2021-22 admissions is December 15, 2020. The required program consists of the following:

		Units
Advanced Mechanics		**3**
Select one of the following:		
PHYSICS 210	Advanced Mechanics	
PHYSICS 211	Continuum Mechanics	
Electrodynamics		**3**
Select one of the following:		
APPPHYS 201	Electrons and Photons	
PHYSICS 220	Classical Electrodynamics	
Quantum Mechanics		**6**
Select two of the following:		
APPPHYS 203	Atoms, Fields and Photons	
APPPHYS 204	Quantum Materials	
EE 222	Applied Quantum Mechanics I	
EE 223	Applied Quantum Mechanics II	
PHYSICS 230	Graduate Quantum Mechanics I	
PHYSICS 231	Graduate Quantum Mechanics II	
PHYSICS 234	Advanced Topics in Quantum Mechanics	
PHYSICS 330	Quantum Field Theory I	
PHYSICS 331	Quantum Field Theory II	
PHYSICS 332	Quantum Field Theory III	
Directed Studies		
APPPHYS 290	Directed Studies in Applied Physics	
1-unit Seminar Courses		
Examples of suitable courses include		
EE 222	Applied Quantum Mechanics I	3
EE 223	Applied Quantum Mechanics II	3
EE 236A	Modern Optics	3
EE 236C	Lasers	3
EE 332	Laser Dynamics	3
EE 346	Introduction to Nonlinear Optics	3

PHYSICS 372	Condensed Matter Theory I	3
PHYSICS 373	Condensed Matter Theory II	3

1. Courses in Physics and Mathematics to overcome deficiencies, if any, in undergraduate preparation.
2. Basic graduate courses (letter grade required):
   - 33 units of additional advanced courses in science and/or engineering. May be any combination of APPPHYS 290 Directed Studies in Applied Physics, any 1-unit course, and regular courses. At least 18 of these 33 units must be taken for a letter grade. 15 of these 18 units must be at the 200-level or above. Only 6 units below the 200-level are permitted without approval by the Applied Physics Graduate Study Committee.
3. A final overall grade point average (GPA) of 3.0 (B) is required for courses used to fulfill degree requirements.

There are no department nor University examinations. There is no thesis component. If a student is admitted to the M.S. program only, but later wishes to change to the Ph.D. program, the student must re-apply through the admissions portal.

Coterminal Master of Science in Applied and Engineering Physics

Stanford undergraduates, regardless of undergraduate major, who are interested in a M.S. degree at the intersection of applied physics and engineering may choose to apply for the coterminal Master of Science program in Applied and Engineering Physics. The program is designed to be completed in the fifth year at Stanford. Students with accelerated undergraduate programs may be able to complete their B.S. and coterminal M.S. in four years.

Application and Admission

Undergraduates must be admitted to the program and enrolled as a graduate student for at least one quarter prior to B.S. conferral. Applications are due on the last day of class of the Spring Quarter (June 10, 2020) for Autumn 2020 matriculation and at least four weeks before the last day of class in the previous quarter for Winter or Spring matriculation (October 20, 2020 for Winter matriculation, February 19, 2021 for Spring matriculation, and June 4, 2021 for Autumn 2021 matriculation). All application materials must be submitted directly to the Applied Physics department office by the deadlines. To apply for admission to the Applied and Engineering Physics coterminal M.S. program, students must submit the coterminal application which consists of the following:

- Application for Admission to Coterminal Master's Program (https://registrar.stanford.edu/students/coterminal-degree-programs/applying-coterm/)
- Statement of Purpose
- Unofficial Transcript
- Two Letters of Recommendation from members of the Stanford faculty

University Coterminal Requirements

Coterminal master's degree candidates are expected to complete all master's degree requirements as described in this bulletin. University requirements for the coterminal master's degree are described in the "Coterminal Master's Program (http://exploredegrees.stanford.edu/cotermdegrees/)" section. University requirements for the master's degree are described in the "Graduate Degrees (http://exploredegrees.stanford.edu/graduatedegrees/#masterstext)" section of this bulletin.

After accepting admission to this coterminal master's degree program, students may request transfer of courses from the undergraduate to the graduate career to satisfy requirements for the master's degree. Transfer of courses to the graduate career requires review and approval of both the undergraduate and graduate programs on a case by case basis.

In this master's program, courses taken three quarters prior to the first graduate quarter, or later, are eligible for consideration for transfer to the graduate career. No courses taken prior to the first quarter of the sophomore year may be used to meet master's degree requirements.

Course transfers are not possible after the bachelor's degree has been conferred.

The University requires that the graduate advisor be assigned in the student's first graduate quarter even though the undergraduate career may still be open. The University also requires that the Master's Degree Program Proposal be completed by the student and approved by the department by the end of the student's first graduate quarter.

Program Requirements

Coterminal M.S. students are required to take 45 units of course work during their graduate career. Of these 45 units, the following are required.

		Units
Four Breadth Courses (required)		
APPPHYS 201	Electrons and Photons	4
APPPHYS 203	Atoms, Fields and Photons	4
APPPHYS 204	Quantum Materials	4
APPPHYS 205	Introduction to Biophysics	4
Three Engineering Depth Courses		**9**
At least one must be at the 300 level and the other courses must be at the 200 level or above to provide depth in one area. To be approved by the Applied Physics academic adviser.		
One Laboratory or Methods Course		**3-4**
APPPHYS 207	Laboratory Electronics	
APPPHYS 208	Laboratory Electronics	
APPPHYS 215	Numerical Methods for Physicists and Engineers	
APPPHYS 217	Estimation and Control Methods for Applied Physics (by arrangement with the instructor)	
APPPHYS 232	Advanced Imaging Lab in Biophysics	
EE 234	Photonics Laboratory	
EE 251	High-Frequency Circuit Design Laboratory	
EE 312	Integrated Circuit Fabrication Laboratory	
ENGR 341	Micro/Nano Systems Design and Fabrication	
ENGR 342	MEMS Laboratory II	
MATSCI 322	Transmission Electron Microscopy Laboratory	
MATSCI 331	Atom-based computational methods for materials	
Seminar [1]		**3**
Examples of suitable seminars include:		
APPPHYS 470	Condensed Matter Seminar	
APPPHYS 483	Optics and Electronics Seminar	
BIOPHYS 250	Seminar in Biophysics	
EE 380	Colloquium on Computer Systems	
MATSCI 230	Materials Science Colloquium	
Approved Technical Electives [2]		**6-12**

6 units minimum that brings up the total units to 45	
Total Units	**45**

1 The seminar requirement can be fulfilled by either (i) taking one formal seminar course for credit each term, and/or (ii) enrolling in APPPHYS 290 and attending a minimum of eight informal talks or formal research seminars during each of the three terms. Students enrolling in APPPHYS 290 must submit with their final M.S. program proposal a list of the eight talks/seminars with a paragraph describing the content, signed by their academic adviser.

2 These include APPPHYS, CS, CME, EE, ME, BIOE, MATSCI, PHYSICS courses (see http://www.stanford.edu/dept/app-physics/cgi-bin/academic-programs/) as well as those courses that are formally approved by the Applied Physics Graduate Studies Committee through petition.

Any request for a course transfer from the undergraduate career is subject to approval of the undergraduate and graduate departments.

Doctor of Philosophy in Applied Physics

The University's basic requirements for the Ph.D. including residency, dissertation, and examinations are discussed in the "Graduate Degrees (http://exploredegrees.stanford.edu/graduatedegrees/)" section of this bulletin. The deadline for the 2021-22 admissions is December 15, 2020. Joint applicants for the Knight-Hennessy Scholars Program (http://knight-hennessy.stanford.edu/) must submit their Knight-Hennessy Scholars application by October 14, 2020 by 1:00pm Pacific Time and Applied Physics application by December 15, 2020. The program leading to a Ph.D. in Applied Physics consists of course work, research, qualifying for Ph.D. candidacy, a research progress report, a University oral examination, and a dissertation as follows:

1. *Course Work:*

		Units
Statistical Physics		**3-4**
Select one of the following: [1]		
APPPHYS 217	Estimation and Control Methods for Applied Physics (by arrangement with the instructor)	
APPPHYS 223	Stochastic and Nonlinear Dynamics	
PHYSICS 212	Statistical Mechanics	
Electrodynamics [1]		**3-4**
Select one of the following: [1]		
APPPHYS 201	Electrons and Photons	
PHYSICS 220	Classical Electrodynamics	
Quantum Mechanics		**3**
Select one of the following: [1]		
APPPHYS 203	Atoms, Fields and Photons	
APPPHYS 204	Quantum Materials	
EE 222	Applied Quantum Mechanics I	
EE 223	Applied Quantum Mechanics II	
PHYSICS 230	Graduate Quantum Mechanics I	
PHYSICS 231	Graduate Quantum Mechanics II	
PHYSICS 234	Advanced Topics in Quantum Mechanics	
PHYSICS 330	Quantum Field Theory I	
PHYSICS 331	Quantum Field Theory II	
PHYSICS 332	Quantum Field Theory III	
Laboratory		**3-4**
Select one of the following: [2]		
APPPHYS 207	Laboratory Electronics	
APPPHYS 208	Laboratory Electronics	
APPPHYS 232	Advanced Imaging Lab in Biophysics	
BIOE 370	Microfluidic Device Laboratory	
EE 234	Photonics Laboratory	
EE 235	Analytical Methods in Biotechnology	
EE 312	Integrated Circuit Fabrication Laboratory	
MATSCI 171	Energy Materials Laboratory	
MATSCI 172	X-Ray Diffraction Laboratory	
MATSCI 173	Mechanical Behavior Laboratory	
PHYSICS 301	Astrophysics Laboratory	

1 Additional courses to fulfill this requirement are being reviewed by the department curriculum committee and will be added here when they have been approved.

2 Students who took APPPHYS 304 or APPPHYS 305 in previous years may also count these courses towards this requirement.

a. Courses in Physics and Mathematics to overcome deficiencies, if any, in undergraduate preparation.
b. *Basic graduate courses:* These requirements may be totally or partly satisfied with equivalent courses taken elsewhere, pending the approval of the graduate study committee. Letter grades required for all courses.
c. 18 units of additional advanced courses in science and/or engineering. At least one course in each of two areas other than those of the student's research specialization is required. Only 3 units at the 300 or above level may be taken on a satisfactory/no credit basis. Units from APPPHYS 290, APPPHYS 390, and any 1-unit courses do not count towards this requirement. Examples of suitable courses include:

		Units
EE 222	Applied Quantum Mechanics I	3
EE 223	Applied Quantum Mechanics II	3
EE 236A	Modern Optics	3
EE 236C	Lasers	3
EE 332	Laser Dynamics	3
EE 346	Introduction to Nonlinear Optics	3
PHYSICS 372	Condensed Matter Theory I	3
PHYSICS 373	Condensed Matter Theory II	3

d. Additional units of courses as needed to meet the minimum residency requirement of 135. Directed study and research units as well as 1-unit seminar courses can be included.
e. A final average overall grade point average (GPA) of 3.0 (B) is required for courses used to fulfill degree requirements.
f. Students are normally expected to complete the specified course requirements by the end of their third year of graduate study.

2. *Research:* may be conducted in a science/engineering field under the supervision of a member of the Applied Physics faculty or appropriate faculty from other departments. If the primary adviser is from a department other than Applied Physics, the student must appoint a co-adviser from the Applied Physics department.
3. *Ph.D. Candidacy:* satisfactory progress in academic and research work, together with passing the Ph.D. candidacy qualifying examination, qualifies the student to apply for Ph.D. candidacy, and must be completed before the third year of graduate registration. The examination consists of a seminar on a suitable subject delivered by the student before a committee consisting of the chair (who is from the graduate studies committee), a faculty member from outside the department chosen by the student, and the third member is from the AP faculty (courtesy appointment is okay).
4. *Research Progress Report:* normally before the end of the Winter Quarter of the fourth year of enrollment in graduate study at Stanford,

the student arranges to give an oral research progress report, which could be last up to two hours.

5. *University Ph.D. Oral Examination*: consists of a public seminar in defense of the dissertation, followed by private questioning of the candidate by the University examining committee.
6. *Dissertation:* must be approved and signed by the Ph.D. reading committee.

COVID-19 Policies

On July 30, the Academic Senate adopted grading policies effective for all undergraduate and graduate programs, excepting the professional Graduate School of Business, School of Law, and the School of Medicine M.D. Program. For a complete list of those and other academic policies relating to the pandemic, see the "COVID-19 and Academic Continuity (http://exploredegrees.stanford.edu/covid-19-policy-changes/#tempdepttemplatetabtext)" section of this bulletin.

The Senate decided that all undergraduate and graduate courses offered for a letter grade must also offer students the option of taking the course for a “credit” or “no credit” grade and recommended that deans, departments, and programs consider adopting local policies to count courses taken for a “credit” or “satisfactory” grade toward the fulfillment of degree-program requirements and/or alter program requirements as appropriate.

Graduate Degree Requirements

Grading

The Department of Applied Physics counts all courses taken in academic year 2020-21 with a grade of 'CR' (credit) or 'S' (satisfactory) towards satisfaction of graduate degree requirements that otherwise require a letter grade provided that the instructor affirms that the work was done at a 'B' or better level.

Graduate Advising Expectations

The Department of Applied Physics is committed to providing academic advising in support of graduate student scholarly and professional development. When most effective, this advising relationship entails collaborative and sustained engagement by both the advisor and the advisee. As a best practice, advising expectations should be periodically discussed and reviewed to ensure mutual understanding. Both the advisor and the advisee are expected to maintain professionalism and integrity.

In addition, the Faculty Candidacy Chair, Professor Philip Bucksbaum, is available for consultation during the academic year by email and during office hours. The Applied Physics student services office is also an important part of the advising team. Staff in the office inform students and advisors about University and department requirements, procedures, and opportunities, and maintain the official records of advising assignments and approvals.

Faculty advisors guide students in key areas such as selecting courses, designing and conducting research, developing of teaching pedagogy, navigating policies and degree requirements, and exploring academic opportunities and professional pathways.

Graduate students are active contributors to the advising relationship, proactively seeking academic and professional guidance and taking responsibility for informing themselves of policies and degree requirements for their graduate program.

For a statement of University policy on graduate advising, see the "Graduate Advising (http://exploredegrees.stanford.edu/graduatedegrees/#advisingandcredentialstext)" section of this bulletin.

Master of Science Advising

At the start of graduate study, each student is assigned a master’s program advisor: a member of our faculty who provides guidance in course selection, course planning, and in exploring short and long term academic opportunities and professional pathways. The program advisor serves as the first resource for consultation and advice about a student's academic program. Usually, the same faculty member serves as program advisor for the duration of master’s study. In rare instances, a formal advisor change request may be considered. See the Applied Physics student services office for additional information on this process.

Ph.D. Advising

Academic advisors are assigned to incoming first year students by the graduate study committee based on their interest of studies. Faculty academic advisors guide students in key areas such as selecting courses, designing and conducting research, developing of teaching pedagogy, navigating policies and degree requirements, and exploring academic opportunities and professional pathways. Each individual program, designed by the student in consultation with the academic advisor, should represent a strong and cohesive program reflecting the student’s major field of interest. Based on the research interest, students and research advisors mutually agree to work on the research together and establish a collaborative relationship. When the research advisor is from outside the Applied Physics department, the student must also identify a co-advisor from departmental primary faculty to provide guidance on departmental requirements and opportunities.

Emeriti: (Professors) Malcolm R. Beasley, Arthur Bienenstock, Sebastian Doniach, Alexander L. Fetter, Theodore H. Geballe, Stephen E. Harris, Walter A. Harrison, Peter A. Sturrock, Yoshihisa Yamamoto; (Professors, Research) Helmut Wiedemann, Herman Winick; (Courtesy) Douglas D. Osheroff

Chair: Martin M. Fejer

Chair of Graduate Studies Committee: Philip H. Bucksbaum

Professors: Steven M. Block, Philip H. Bucksbaum, Robert L. Byer, Martin M. Fejer, Daniel S. Fisher, Ian R. Fisher, Tony F. Heinz, Harold Y. Hwang, Aharon Kapitulnik, Mark A. Kasevich, Young S. Lee, Hideo Mabuchi, Kathryn A. Moler, Vahé Petrosian, Stephen R. Quake, Zhi-Xun Shen, Yuri Suzuki

Associate Professors: Benjamin L. Lev, David A. Reis, Mark J. Schnitzer

Assistant Professors: Surya Ganguli, Amir H. Safavi-Naeini, Benjamin Good

Professor (Research): Michel J-F. Digonnet

Courtesy Professors: Mark L. Brongersma, Bruce M. Clemens, Shanhui Fan, David Goldhaber-Gordon, James S. Harris, Lambertus Hesselink, David A. B. Miller, W. E. Moerner, Jelena Vuckovic

Courtesy Associate Professors: Willliam J. Greenleaf, Zhirong Huang, Andrew J. Spakowitz

Adjunct Professors: Thomas M. Baer, Raymond G. Beausoleil, John D. Fox, Richard M. Martin

Courses

APPPHYS 61. Science as a Creative Process. 4 Units.
What is the process of science, and why does creativity matter? We'll delve deeply into the applicability of science in addressing a vast range of real-world problems. This course is designed to teach the scientific method as it's actually practiced by working scientists. It will cover how to ask a well-posed question, how to design a good experiment, how to collect and interpret quantitative data, how to recover from error, and how to communicate findings. Facts matter! Course topics will include experimental design, statistics and statistical significance, formulating appropriate controls, modeling, peer review, and more. The course will incorporate a significant hands-on component featuring device fabrication, testing, and measurement. Among other "Dorm Science" activities, we'll be distributing Arduino microcontroller kits and electronic sensors, then use these items, along with other materials, to complete a variety of group and individual projects outside the classroom. The final course assignment will be to develop and write a scientific grant proposal to test a student-selected myth or scientific controversy. Although helpful, no prior experience with electronics or computer programming is required. Recommended for freshmen.
Same as: BIO 61

APPPHYS 77N. Functional Materials and Devices. 3 Units.
Preference to freshmen. Exploration via case studies how functional materials have been developed and incorporated into modern devices. Particular emphasis is on magnetic and dielectric materials and devices. Recommended: high school physics course including electricity and magnetism.

APPPHYS 79N. Energy Options for the 21st Century. 3 Units.
Preference to frosh. Choices for meeting the future energy needs of the U.S. and the world. Basic physics of energy sources, technologies that might be employed, and related public policy issues. Trade-offs and societal impacts of different energy sources. Policy options for making rational choices for a sustainable world energy economy.

APPPHYS 100. The Questions of Clay: Craft, Creativity and Scientific Process. 5 Units.
Students will create individual studio portfolios of ceramic work and pursue technical investigations of clay properties and the firing process using modern scientific equipment. Emphasis on development of creative process; parallels between science and traditional craft; integration of creative expression with scientific method and analysis. Prior ceramics experience desirable but not necessary. Limited enrollment. Prerequisites: any level of background in physics, Instructor permission.
Same as: ARTSINST 100

APPPHYS 100B. The Questions of Cloth: Weaving, Pattern Complexity and Structures of Fabric. 4 Units.
Students will learn to weave on a table loom while examining textile structures from historic, artistic and scientific perspectives. Emphasis on analyzing patterns and structures generated by weaving, with elementary introductions to information-scientific notions of algorithmic complexity, image compression, and source coding. This class is primarily intended for non-STEM majors with little or no prior experience in working with textiles. Limited enrollment. Prerequisites: Instructor permission.
Same as: ARTSINST 100B

APPPHYS 100Q. INDIGO. 3 Units.
Preference to sophomores. Indigo as a plant, biomolecule, dye, ancient craft material, and organic semiconductor; the interest of natural dyes for both biomimetic engineering and indigenous artistic practices. Students will plant and tend an indigo crop, harvest and process indigo leaves for dyestuffs, and dye textiles using an organic vat process. Lectures, readings and discussions will focus on the biochemistry and physics of indigo dye, traditional indigo textile arts, environmental impacts of industrial-scale indigo dyeing of denim, roles of indigo in upcycling, craft-washing, and the aesthetics of indigo in western and non-western cultural frames.

APPPHYS 188. Matter and Mattering: Transdisciplinary Thinking about Things. 4-5 Units.
Things sit at the nexus of cross-cutting heterogeneous processes; tracing the entanglements of any prominent thing or class of things demands a transdisciplinary approach that recruits expertise from the natural sciences, social sciences and humanities. For example, carbon is a key factor in global warming for reasons that are as much socio-historical as bio-physical, and we could not begin to sketch the full significance of carbon without considering such diverse frames of reference. Our growing appreciation in the social sciences and humanities of the agency, polyvalence and catalytic role of things has given rise to The New Materialist and Post-Humanist movements, which in turn raise questions about intra-action and observational perspective that are echoed in the modern physical and life sciences. In this class we will explore these theoretical convergences in considering themes such as `things-in-themselves¿, networks and open systems, assemblages and entanglements. We will also examine specific examples such as oil, metal (guns), dams, viruses, electricity, mushrooms; each thing will be explored both in terms of its social and ethical entanglements and in terms of its material properties and affordances. There will also be hands-on encounters with objects in labs and a couple of local field trips. The key question throughout will be `why and how does matter matter in society today?.
Same as: ANTHRO 188, ANTHRO 288, ARCHLGY 188

APPPHYS 189. Physical Analysis of Artworks. 3 Units.
Students explore the use of Stanford Nano Shared Facilities (SNSF) for physical analysis of material samples of interest for art conservation, technical art history and archaeology. Weekly SNSF demonstrations will be supplemented by lectures on intellectual context by Stanford faculty/staff and conservators from the Fine Arts Museums of San Francisco (FAMSF). Students will complete the SNSF training sequence for electron microscopy and undertake analysis projects derived from ongoing conservation efforts at FAMSF.".

APPPHYS 201. Electrons and Photons. 4 Units.
Applied Physics Core course appropriate for graduate students and advanced undergraduate students with prior knowledge of elementary quantum mechanics, electricity and magnetism, and special relativity. Interaction of electrons with intense electromagnetic fields from microwaves to x- ray, including electron accelerators, x-ray lasers and synchrotron light sources, attosecond laser-atom interactions, and x-ray matter interactions. Mechanisms of radiation, free-electron lasing, and advanced techniques for generating ultrashort brilliant pulses. Characterization of electronic properties of advanced materials, prospects for single-molecule structure determination using x-ray lasers, and imaging attosecond molecular dynamics.
Same as: PHOTON 201

APPPHYS 203. Atoms, Fields and Photons. 4 Units.
Applied Physics Core course appropriate for graduate students and advanced undergraduate students with prior knowledge of elementary quantum mechanics, electricity and magnetism, and ordinary differential equations. Structure of single- and multi-electron atoms and molecules, and cold collisions. Phenomenology and quantitative modeling of atoms in strong fields, with modern applications. Introduction to quantum optical theory of atom-photon interactions, including quantum trajectory theory, mechanical effects of light on atoms, and fundamentals of laser spectroscopy and coherent control.

APPPHYS 204. Quantum Materials. 4 Units.
Applied Physics Core course appropriate for graduate students and advanced undergraduate students with prior knowledge of elementary quantum mechanics. Introduction to materials and topics of current interest. Topics include superconductivity, magnetism, charge and spin density waves, frustration, classical and quantum phase transitions, multiferroics, and interfaces. Prerequisite: elementary course in quantum mechanics.

APPPHYS 205. Introduction to Biophysics. 3-4 Units.
Core course appropriate for advanced undergraduate students and graduate students with prior knowledge of calculus and a college physics course. Introduction to how physical principles offer insights into modern biology, with regard to the structural, dynamical, and functional organization of biological systems. Topics include the roles of free energy, diffusion, electromotive forces, non-equilibrium dynamics, and information in fundamental biological processes.
Same as: BIO 126, BIO 226

APPPHYS 207. Laboratory Electronics. 4 Units.
Lecture/lab emphasizing analog and digital electronics for lab research. RC and diode circuits. Transistors. Feedback and operational amplifiers. Active filters and circuits. Pulsed circuits, voltage regulators, and power circuits. Precision circuits, low-noise measurement, and noise reduction techniques. Circuit simulation tools. Analog signal processing techniques and modulation/demodulation. Principles of synchronous detection and applications of lock-in amplifiers. Common laboratory measurements and techniques illustrated via topical applications. Prerequisites: undergraduate device and circuit exposure.

APPPHYS 208. Laboratory Electronics. 4 Units.
Lecture/lab emphasizing analog and digital electronics for lab research. Continuation of APPPHYS 207 with emphasis on applications of digital techniques. Combinatorial and synchronous digital circuits. Design using programmable logic. Analog/digital conversion. Microprocessors and real time programming, concepts and methods of digital signal processing techniques. Current lab interface protocols. Techniques commonly used for lab measurements. Development of student lab projects during the last three weeks. Prerequisites: undergraduate device and circuit exposure. Recommended: previous enrollment in APPPHYS 207.

APPPHYS 215. Numerical Methods for Physicists and Engineers. 4 Units.
Fundamentals of numerical methods applied to physical systems. Derivatives and integrals; interpolation; quadrature; FFT; singular value decomposition; optimization; linear and nonlinear least squares fitting; error estimation; deterministic and stochastic differential equations; Monte Carlo methods. Lectures will be accompanied by guided project work enabling each student to make rapid progress on a project of relevance to their interests.

APPPHYS 217. Estimation and Control Methods for Applied Physics. 4 Units.
Recursive filtering, parameter estimation, and feedback control methods based on linear and nonlinear state-space modeling. Topics in: dynamical systems theory; practical overview of stochastic differential equations; model reduction; and tradeoffs among performance, complexity, and robustness. Numerical implementations in MATLAB. Contemporary applications in systems biology and quantum precision measurement. Prerequisites: linear algebra and ordinary differential equations.

APPPHYS 219. Solid State Physics Problems in Energy Technology. 3 Units.
Technology issues for a secure energy future; role of solid state physics in energy technologies. Topics include the physics principles behind future technologies related to solar energy and solar cells, solid state lighting, superconductivity, solid state fuel cells and batteries, electrical energy storage, materials under extreme condition, nanomaterials.

APPPHYS 222. Principles of X-ray Scattering. 4 Units.
Provides a fundamental understanding of x-ray scattering and diffraction. Combines pedagogy with modern experimental methods for obtaining atomic-scale structural information on synchrotron and free-electon laser-based facilities. Topics include Fourier transforms, reciprocal space; scattering in the first Born approximation, comparison of x-ray, neutron and electron interactions with matter, kinematic theory of diffraction; dynamical theory of diffraction from perfect crystals, crystal optics, diffuse scattering from imperfect crystals, inelastic x-ray scattering in time and space, x-ray photon correlation spectroscopy. Laboratory experiments at the Stanford Synchrotron Radiation Lightsource.
Same as: PHOTON 222

APPPHYS 223. Stochastic and Nonlinear Dynamics. 3 Units.
Theoretical analysis of dynamical processes: dynamical systems, stochastic processes, and spatiotemporal dynamics. Motivations and applications from biology and physics. Emphasis is on methods including qualitative approaches, asymptotics, and multiple scale analysis. Prerequisites: ordinary and partial differential equations, complex analysis, and probability or statistical physics.
Same as: BIO 223, BIOE 213, PHYSICS 223

APPPHYS 225. Probability and Quantum Mechanics. 3 Units.
Structure of quantum theory emphasizing states, measurements, and probabilistic modeling. Generalized quantum measurement theory; parallels between classical and quantum probability; conditional expectation in the Schrödinger and Heisenberg pictures; covariance with respect to symmetry groups; reference frames and super-selection rules. Classical versus quantum correlations; nonlocal aspects of quantum probability; axiomatic approaches to interpretation. Prerequisites: undergraduate quantum mechanics, linear algebra, and basic probability and statistics.

APPPHYS 228. Quantum Hardware. 4 Units.
Review of the basics of quantum information. Quantum optics: photon counting, detection, and amplification. Quantum noise in parametric processes. Quantum sensing: standard quantum limits, squeezed light, and spin squeezing. Gaussian quantum information. Quantum theory of electric circuits, electromagnetic components, and nanomechanical devices. Integrated quantum systems: superconductivity and Josephson qubits, measurement-based quantum computing with photons, spin qubits, topological systems. Prerequisites: PHYSICS 134/234 and APPPHYS 203.

APPPHYS 232. Advanced Imaging Lab in Biophysics. 4 Units.
Laboratory and lectures. Advanced microscopy and imaging, emphasizing hands-on experience with state-of-the-art techniques. Students construct and operate working apparatus. Topics include microscope optics, Koehler illumination, contrast-generating mechanisms (bright/dark field, fluorescence, phase contrast, differential interference contrast), and resolution limits. Laboratory topics vary by year, but include single-molecule fluorescence, fluorescence resonance energy transfer, confocal microscopy, two-photon microscopy, microendoscopy, and optical trapping. Limited enrollment. Recommended: basic physics, basic cell biology, and consent of instructor.
Same as: BIO 132, BIO 232, BIOPHYS 232, GENE 232

APPPHYS 236. Biology by the Numbers. 3 Units.
For PhD students and advanced undergraduates. Students will develop skills in quantitative reasoning over a wide range of biological problems. Topics: biological size scales ranging from proteins to ecosystems; biological times time scales ranging from enzymatic catalysis and DNA replication to evolution; biological energy, motion and force from molecular to organismic scales; mechanisms of environmental sensing ranging from bacterial chemotaxis to vision.
Same as: BIOC 236

APPPHYS 237. Quantitative Evolutionary Dynamics and Genomics. 3 Units.
The genomics revolution has fueled a renewed push to model evolutionary processes in quantitative terms. This course will provide an introduction to quantitative evolutionary modeling through the lens of statistical physics. Topics will range from the foundations of theoretical population genetics to experimental evolution of laboratory microbes. Course work will involve a mixture of pencil-and-paper math, writing basic computer simulations, and downloading and manipulating DNA sequence data from published datasets. This course is intended for upper level physics and math students with no biology background, as well as biology students who are comfortable with differential equations and probability.
Same as: BIO 251

APPPHYS 270. Magnetism and Long Range Order in Solids. 3 Units.
Cooperative effects in solids. Topics include the origin of magnetism in solids, crystal electric field effects and anisotropy, exchange, phase transitions and long-range order, ferromagnetism, antiferromagnetism, metamagnetism, density waves and superconductivity. Emphasis is on archetypal materials. Prerequisite: PHYSICS 172 or MATSCI 209, or equivalent introductory condensed matter physics course.

APPPHYS 272. Solid State Physics. 3 Units.
Introduction to the properties of solids. Crystal structures and bonding in materials. Momentum-space analysis and diffraction probes. Lattice dynamics, phonon theory and measurements, thermal properties. Electronic structure theory, classical and quantum; free, nearly-free, and tight-binding limits. Electron dynamics and basic transport properties; quantum oscillations. Properties and applications of semiconductors. Reduced-dimensional systems. Undergraduates should register for PHYSICS 172 and graduate students for APPPHYS 272. Prerequisites: PHYSICS 170 and PHYSICS 171, or equivalents.
Same as: PHYSICS 172

APPPHYS 273. Solid State Physics II. 3 Units.
Introduction to the many-body aspects of crystalline solids. Second quantization of phonons, anharmonic effects, polaritons, and scattering theory. Second quantization of Fermi fields. Electrons in the Hartree-Fock and random phase approximation; electron screening and plasmons. Magnetic exchange interactions. Electron-phonon interaction in ionic/covalent semiconductors and metals; effective attractive electron-electron interactions, Cooper pairing, and BCS description of the superconducting state. Prerequisite: APPPHYS 272 or PHYSICS 172.

APPPHYS 280. Phenomenology of Superconductors. 3 Units.
Phenomenology of superconductivity viewed as a macroscopic quantum phenomenon. Topics include the superconducting pair wave function, London and Ginzburg-Landau theories, the Josephson effect, type I type II superconductivity, and the response of superconductors to currents, magnetic fields, and RF electromagnetic radiation. Introduction to thermal fluctuation effects in superconductors and quantum superconductivity.

APPPHYS 282. Quantum Gases. 3 Units.
Introduction to the physics of quantum gases and their use in quantum simulation and computation. Topics in modern atomic physics and quantum optics will be covered, including laser cooling and trapping, ultracold collisions, optical lattices, ion traps, cavity QED, quantum phase transitions in quantum gases and lattices, BEC and quantum degenerate Fermi gases, 1D and 2D quantum gases, dipolar gases, and quantum nonequilibrium dynamics and phase transitions. Prerequisites: undergraduate quantum and statistical mechanics courses. Applied Physics 203 strongly recommended but not required.
Same as: PHYSICS 182, PHYSICS 282

APPPHYS 290. Directed Studies in Applied Physics. 1-15 Unit.
Special studies under the direction of a faculty member for which academic credit may properly be allowed. May include lab work or directed reading.

APPPHYS 291. Practical Training. 1-3 Unit.
Opportunity for practical training in industrial labs. Arranged by student with research adviser's approval. Summary of activities required.

APPPHYS 293. Theoretical Neuroscience. 3 Units.
Survey of advances in the theory of neural networks, mainly (but not solely) focused on results of relevance to theoretical neuroscience.Synthesizing a variety of recent advances that potentially constitute the outlines of a theory for understanding when a given neural network architecture will work well on various classes of modern recognition and classification tasks, both from a representational expressivity and a learning efficiency point of view. Discussion of results in the neurally-plausible approximation of back propagation, theory of spiking neural networks, the relationship between network and task dimensionality, and network state coarse-graining. Exploration of estimation theory for various typical methods of mapping neural network models to neuroscience data, surveying and analyzing recent approaches from both sensory and motor areas in a variety of species. Prerequisites: calculus, linear algebra, and basic probability theory, or consent of instructor.
Same as: PSYCH 242

APPPHYS 294. Cellular Biophysics. 3 Units.
Physical biology of dynamical and mechanical processes in cells. Emphasis is on qualitative understanding of biological functions through quantitative analysis and simple mathematical models. Sensory transduction, signaling, adaptation, switches, molecular motors, actin and microtubules, motility, and circadian clocks. Prerequisites: differential equations and introductory statistical mechanics.
Same as: BIO 294, BIOPHYS 294

APPPHYS 302. Experimental Techniques in Condensed Matter Physics. 3 Units.
Cryogenics; low signal measurements and noise analysis; data collection and analysis; examples of current experiments. Prerequisites: PHYSICS 170, PHYSICS 171, and PHYSICS 172, or equivalents.

APPPHYS 315. Methods in Computational Biology. 3 Units.
Methods of bioinformatics and biomolecular modeling from the standpoint of biophysical chemistry. Methods of genome analysis; cluster analysis, phylogenetic trees, microarrays; protein, RNA and DNA structure and dynamics, structural and functional homology; protein-protein interactions and cellular networks; molecular dynamics methods using massively parallel algorithms.
Same as: BIOPHYS 315

APPPHYS 322. Advanced Topics in x-ray scattering. 3 Units.
This course covers advanced topics in x-ray scattering including: diffuse scattering from static and dynamic disorder such as from defects or phonons; inelastic methods such as x-ray Raman and Compton scattering for measuring electronic structure and elementary excitations; and inelastic scattering in the time and frequency domain. Course combines lectures on basic principles with a review of foundational and current literature. May be repeat for credit.
Same as: PHOTON 322

APPPHYS 324. Introduction to Accelerator Physics. 3 Units.
Physics of particle beams in linear and circular accelerators. Transverse and longitudinal beam dynamics, equilibrium emittances in electron storage rings, high-brightness electron sources, RF acceleration and emittance preservation, bunch compression and associated collective effects, accelerator physics design for x-ray FELs, advanced accelerator concepts.

APPPHYS 325. Synchrotron Radiation and Free Electron Lasers: Principles and Applications.. 3 Units.
Synchrotron radiation sources for scientific exploration, and x-ray FELs for studies of ultrafast processes at the atomic scale. Fundamental concepts in electron and photon beams, bending magnet and undulator radiation, one-dimensional and three-dimensional FEL theory and simulations, self-amplified spontaneous emission, seeding and other improvement schemes, x-ray methodology, techniques and instrumentation for the study of ultrafast phenomena. Includes selected laboratory tours of the Linac Coherent Light Source and/or Stanford Synchrotron Radiation Lightsource at SLAC. Prerequisite: graduate-level electrodynamics, or consent of instructor.
Same as: PHOTON 325

APPPHYS 345. Advanced Numerical Methods for Data Analysis and Simulation. 3 Units.
Gaussian and unit sphere quadrature, singular value decomposition and principal component analysis, Krylov methods, non-linear fitting and super-resolution, independent component analysis, 3d reconstruction, "shrink-wrap", hidden Markov methods, support vector machines, simulated annealing, molecular dynamics and parallel tempering, Markov state methods, Monte Carlo methods for constrained systems.

APPPHYS 376. Literature of Cavity QED and Cavity Optomechanics. 3 Units.
Cavity quantum electrodynamics and optomechanics in modern quantum optics, photonics and quantum engineering. Review of basic concepts and survey of key literature in seminar format. May be repeat for credit.

APPPHYS 383. Introduction to Atomic Processes. 3 Units.
Atomic spectroscopy, matrix elements using the Coulomb approximation, summary of Racah algebra, oscillator and line strengths, Einstein A coefficients. Radiative processes, Hamiltonian for two- and three-state systems, single- and multi-photon processes, linear and nonlinear susceptibilities, density matrix, brightness, detailed balance, and electromagnetically induced transparency. Inelastic collisions in the impact approximation, interaction potentials, Landau-Zener formulation. Continuum processes, Saha equilibrium, autoionization, and recombination.

APPPHYS 384. Advanced Topics in AMO Physics. 3 Units.
This course will develop the subject of Strong-Field QED. Topics to be covered include: The structure of the quantum vacuum;relativistic laser-vacuum interactions;linear and non-linear Compton and Breit-Wheeler pair-production processes;vacuum polarization and vacuum tunneling; the radiation reaction problem in strong fields;applications in astrophysics and cosmology. The course will also cover experimental methods, including petawatt lasers with focused intensities sufficient to destabilize the vacuum. Prerequisites: familiarity with quantum mechanics, electrodynamics, and special relativity.

APPPHYS 390. Dissertation Research. 1-15 Unit.
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APPPHYS 392. Topics in Molecular Biophysics: Biophysics of Functional RNA (BIOPHYS 392). 3 Units.
Survey of methods used to relate RNA sequences to the structure and function of transcribed RNA molecules. Computation of contributions of the counter-ion cloud to the dependence of free energy on conformation of the folded RNA. The relation of structure to function of ribozymes, riboswitches, and the formation of ribosomal proteins.
Same as: BIOPHYS 392

APPPHYS 393. Biophysics of Solvation. 3 Units.
Statistical mechanics of water-protein or water-DNA (or RNA) interactions; effects of coulomb forces on molecular hydration shells and ion clouds; limitations of the Poisson-Boltzmann equations; DNA collapse, DNA-protein interactions; structure-function relationships in ion channels.
Same as: BIOPHYS 393

APPPHYS 453A. Collective Instabilities in Accelerators. 3 Units.
A beam in an accelerator can become unstable if its intensity is too high. Topics include the physical mechanism causing these instabilities; establishing the framework by introducing the concepts of wakefield and impedance; various instability mechanisms with a special emphasis on the underlying physical principles; new types of instabilities encountered in modern high performance accelerators such as the fast ion and the electron cloud instabilities. Course may be repeated when a different course is offered as a Special Topics.
Same as: PHOTON 453A

APPPHYS 470. Condensed Matter Seminar. 1 Unit.
Current research and literature; offered by faculty, students, and outside specialists. May be repeated for credit.

APPPHYS 483. Optics and Electronics Seminar. 1 Unit.
Current research topics in lasers, quantum electronics, optics, and photonics by faculty, students, and invited outside speakers. May be repeated for credit.

APPPHYS 802. TGR PhD Dissertation. 0 Units.
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