Department of

Physics

Courses of Study:
Minor
Major (BA/BS)
Combined BA/MS
Master of Science
Doctor of Philosophy

Objectives

Undergraduate Major
A typical scenario for a physical explanation of a given situation is this: a small collection of basic physical principles relevant to the situation is used to create a mathematical model of it; computations are carried out using the model, leading to predictions that are checked experimentally; if there is agreement, the physical situation is deemed to have been explained. The objective of the program in physics is to make it possible for students to execute such a scenario for a wide range of physical situations. To that end, students are required to attain a firm grasp of the basic principles of classical physics and familiarity with those of quantum physics, to learn how to decide which principles are relevant to a given situation and how to construct the appropriate mathematical model, to develop the mathematical skills necessary to carry out the computations that generate predictions, and to strengthen the experimental skills used in exploring new phenomena and in carrying out the verification step of the typical scenario.

The ability to execute the typical scenario of physical explanation is useful not only to research physicists, but also to scientists in many other fields, especially interdisciplinary ones such as biophysics and environmental science; it is also useful to engineers, to members of the medical profession, and to architects. For that reason, the physics program has made special arrangements to integrate a physics major with study preparing for a career in any of the areas mentioned above. Students interested in combining biology and physics should see the Interdepartmental Program in Biological Physics elsewhere in this *Bulletin*.

Graduate Program in Physics
The graduate program in physics is designed to equip students with a broad understanding of major fields of physics and to train them to carry out independent, original research. This objective is to be attained by formal course work and supervised research projects. As the number of students who are accepted is limited, a close contact between students and faculty is maintained, permitting close supervision and guidance of each student.

Advanced degrees will be granted upon evidence of the student's knowledge, understanding, and proficiency in classical and modern physics. The satisfactory completion of advanced courses will constitute partial fulfillment of these requirements.

Research upon which theses may be based, with residence at Brandeis, may be carried out in the following areas:

1. *Theoretical Physics*
Quantum theory of fields; relativity; supergravity; string theory; condensed matter physics; statistical mechanics; quantum theory of the solid state; critical phenomena and phase transitions; biological physics; computational neuroscience.

2. *Experimental Physics*
High-energy experimental physics; condensed matter physics; radio astronomy; and biological physics.

Every graduate teaching fellow (TF) is supervised by a member of the faculty, who serves as a mentor to improve the quality of the TF's teaching. In recognition of this objective, each year the physics department awards the David Falkoff Prize to an outstanding teaching fellow. An additional goal of the department is to enable graduate students to present their research findings in a clear and effective manner. Each spring the department organizes the Stephan Berko Symposium, where students give short presentations of their research. These talks are prepared with the assistance of faculty research advisors. The best graduate student research project and the best undergraduate research project are recognized with Stephan Berko Prizes.

How to Become a Major

Since the sequence in which physics courses should be taken is tightly structured, and in most cases requires at least three years to complete, students contemplating a major in physics should consult the physics advising coordinator at the first opportunity. For most students, either such consultation should take place before enrolling in courses at the beginning of the first year, or PHYS 15a and 19a should be part of the first-semester program.

How to Be Admitted to the Graduate Program

The general requirements for admission to the Graduate School, given in an earlier section of this *Bulletin*, apply to candidates for admission to the graduate area in physics. Admission to advanced courses in physics will be granted following a conference with the student at entrance.

Faculty

Bulbul Chakraborty, Chair
Theoretical condensed matter physics.

James Bensinger
Experimental high-energy physics.

Craig Blocker
Experimental high-energy physics.

Zvonimir Dogic
Soft condensed matter physics. Biological physics.

Richard Fell
Theoretical quantum electrodynamics.

Seth Fraden
Physics of liquid crystals. Colloids. Macromolecules. Microfluidics.

Michael Hagan
Computation and theory in biological physics.

Lawrence Kirsch
Experimental high-energy physics.

Jané Kondev, Graduate Advising Head
Theoretical condensed matter physics. Biological physics.

Albion Lawrence
String theory and its applications to particle physics and cosmology.

Robert Meyer
Physics of liquid crystals, colloids, and polymer gels.

David Roberts, Undergraduate Advising Head
Theoretical astrophysics. Radio astronomy.

Azadeh Samadani
Experimental biological physics. Soft condensed matter physics.

Howard Schnitzer
Quantum theory of fields. String theory.

John Wardle
Radio astronomy. Cosmology.

Hermann Wellenstein
Experimental high-energy physics.

Requirements for the Majors

Degree of Bachelor of Arts
The requirement for the major in physics leading to the degree of Bachelor of Arts is the equivalent of eleven semester courses in physics and two semester courses in mathematics. There must be the equivalent of at least three semesters in laboratory courses (PHYS 19a and 19b together count as one semester, as do PHYS 18a and 18b). One must also take PHYS 30b. Mathematics and physics courses numbered under 10 may not be used to fulfill the requirement for the major in physics. A student not intending to pursue graduate study in physics may be permitted to substitute two advanced courses in other fields to meet the requirements for the major in physics, subject to the approval of the advising coordinator. A student with a major in physics and an interest in biophysics may want to take courses in biophysics, biology, biochemistry, chemistry, or neuroscience. With departmental approval, a student may use such courses to satisfy part of the requirements for the major in physics. No course with a grade of below C– can be used to satisfy the requirements of the major.

Degree of Bachelor of Science
To satisfy the requirements for the major in physics leading to the degree of Bachelor of Science, students must successfully complete the eleven physics courses required for the BA in physics and six additional courses. Two of the additional six courses should be chosen from the following: PHYS 25b, 32b, 39a, 40a, 100a, 104a, 105a, 110a. Another two courses must be selected from the following: NPHY 115a, NBIO 136b, CHEM 41a, 41b, any MATH course numbered 27 or higher (excluding courses used to fulfill the math requirement below), any COSI course numbered 21 or higher, or any other course approved by the physics department that is either listed or cross-listed in other departments within the School of Science. The final two courses must be chosen from one of the following pairs of courses: MATH 15a and MATH 20a, or MATH 21a and MATH 21b, or any two MATH courses numbered higher than 22. No course with a grade of below C– can be used to satisfy the requirements of the major.

Combined BA/MS Program

A student may be admitted to a special four-year BA/MS program upon recommendation of the department and the Graduate School by May 1 preceding the senior year. The student must successfully complete **at least** thirty-eight courses. All the regular requirements for the MA degree in physics must be met: successful completion of six graduate courses in physics numbered 160 or above, and satisfactory performance on the qualifying examination. No more than two of the graduate-level courses may be counted toward major requirements. Grades of B– or better are required in the six courses numbered 160 or above. The qualifying examination includes the final examinations in PHYS 161a, 161b, 162a and 162b, 163a and two oral examinations on all of physics through the first-year graduate level. The department will recommend admission to this program only if the student's record indicates that the student can successfully complete the requirements. Consultation with the physics advising coordinator before March 1 of the sophomore year is highly recommended for a student contemplating this program.

Requirements for the Minor

Six semester courses in physics at the level of PHYS 10 or above. Note that PHYS 18a,b and PHYS 19a,b each count as one semester course.

Special Notes Relating to Undergraduates

There are several natural tracks through the undergraduate physics courses. The first is: Year 1—PHYS 15a,b, PHYS 19a,b, MATH 10a,b; Year 2—PHYS 20a,b, 29a,b, MATH 22a,b or PHYS 110a; Year 3—PHYS 30a,b; Year 4—PHYS 40a, 100a.

The second, a premedical track, is: Year 1—PHYS 15a,b, 19a,b, MATH 10a,b; Year 2—PHYS 20a,b, 29a,b, CHEM 11a,b, 18a,b; Year 3—BIOL 22a (Formerly BIBC 22a), BIOL 22b, 18a,b, CHEM 25a,b, 29a,b; Year 4—PHYS 30a,b.

Students are encouraged to construct other tracks that might better suit their needs in consultation with their advisors.

Students considering a career in engineering should consult the description of the Columbia University School of Engineering Combined Degree Program in the special academic opportunities section of this *Bulletin.*

A student intending to pursue graduate work in physics will normally add to the tracks above PHYS 25b, 39a, 100a, 104a, and 105a or graduate courses dealing with previously treated subjects at a more advanced level, such as PHYS 161a,b (formerly 101a,b), and 162a,b (formerly 102a,b). Normally only two or three of the six courses PHYS 25b, 32b, 100a, 104a, 105a, and 110a will be offered in a given year; the others will normally be offered in the following year. Undergraduates are not permitted to enroll in physics courses numbered above 160 without the explicit approval of their appropriate major advisors.

A student who has attained a grade of 4 or 5 on the Advanced Placement Examination Physics B may obtain credit for PHYS 10a,b; a student who has attained a grade of 4 or 5 on the Advanced Placement Examination C: Mechanical may obtain credit for PHYS 15a while a grade of 4 or 5 on Advanced Placement Examination Physics C: Electrical may earn credit for PHYS 15a. A student who claims any of these advanced placement credits may not take the same or equivalent courses for credit: PHSC 9b, PHYS 10a,b, PHYS 15a,b.

In order to be a candidate for a degree with distinction in physics, one must take a departmentally approved honors program of either PHYS 99d or two semester courses in physics numbered above 160, and one must obtain honor grades. Students should have their honors programs approved by the departmental honors advisor before the beginning of the senior year.

Requirements for Advanced Degrees

Normally, first-year graduate students will elect courses from the 100 series, with at least four courses numbered above 160. The normally required first-year courses are PHYS 113a,b, 161a, 162a,b, and 163a. To obtain credit toward residence for a graduate course taken at Brandeis, a student must achieve a final grade of B– or better in that course. Students may obtain credit for advanced courses taken at another institution provided their level corresponds to the level of graduate courses at Brandeis and that an honor grade in those courses was obtained. To place out of PHYS 161a, 162a or b, or 163a, a student must pass an exemption exam before the end of the second week of the course.

Requirements for the Degree of Master of Science

Residence Requirement
For those accepted for full-time study, there is a one-year residency requirement. No transfer residence credit will be allowed toward the fulfillment of the master's requirements. Part-time students have no residency requirement.

Course Requirements
Six semester courses in physics numbered above 160. A thesis on an approved topic may be accepted in place of a semester course.

Language Requirement
There is no foreign language requirement for advanced degrees in physics.

Qualifying Examination
Satisfactory performance in the qualifying examination is required. The qualifying examination consists of a written and an oral part, and both parts are administered during the first year of the program. The written part of the qualifying examination is the final examinations in PHYS 161a, 162a,b, and 163a, unless these courses have been exempted by separate examination or credit has been given for equivalent courses taken elsewhere. There are two oral exams on general physics, the first at college physics level, the second at the first-year graduate level.

Requirements for the Degree of Doctor of Philosophy

All of the requirements for the master's degree and the following:

Residence Requirement
The minimum residence requirement is three years. A student may obtain up to one year's residence credit toward the PhD requirements for graduate studies taken at another institution.

Teaching Requirement
It is required that all PhD candidates participate in undergraduate teaching during the course of their studies.

Course Requirements
In addition to the normally required first-year courses listed above, PHYS 161b is required of all students in their second year. In addition, all students are required to take one laboratory course. After consultation with the graduate advisor, each student must also take two elective advanced physics courses, one of which is outside the student's intended area of research. A total of at least nine semester courses in physics numbered above 160 are required for the doctoral degree.

Qualifying Examination
PHYS 161a, 162a,b and 163a must be passed with grades of B or above, in addition to the requirements listed for the master's degree.

Advanced Examinations
Advanced examinations are in topics partitioned in the several areas of research interest of the faculty. Faculty members working in each general area function as a committee for this purpose and provide information about their work through informal discussions and seminars. The advanced examination requirement consists of a written paper and an oral examination. While no original research by the student is required, it is hoped that a proposal for a possible thesis topic will emerge. It is expected that the candidates will take the advanced examination in the field they wish to pursue for the PhD thesis by the middle of the fourth term in order to qualify for continued departmental support beyond the second year.

Thesis Research
After passing the advanced examination, the student begins work with an advisor, who guides his or her research program. The advisor should be a member of the Brandeis faculty but in special circumstances may be a scientist associated with another research institution. The graduate committee of the physics faculty will appoint a dissertation committee to supervise the student's research. The student's dissertation advisor will be the chair of the dissertation committee.

Dissertation and Final Oral Examination
The doctoral dissertation must represent research of a standard acceptable to the faculty committee appointed for each PhD candidate. The final oral examination, or defense, is an examination in which the student will be asked questions pertaining to the dissertation research.

Requirements for the Degree of Doctor of Philosophy in Physics with Specialization in Quantitative Biology

Program of Study
Students wishing to obtain the specialization must first gain approval of the graduate program chair. This should be done as early as possible, ideally during the first year of graduate studies. In order to receive the PhD in physics with additional specialization in quantitative biology, candidates must complete (a) the requirements for the PhD described above and (b) the course requirements for the quantitative biology specialization that are described in the quantitative biology section of this *Bulletin*.

Any alteration to the quantitative biology course requirements must be approved by the graduate program chair and by the quantitative biology program faculty advisory committee.

Courses of Instruction

(1–99) Primarily for Undergraduate Students

PHSC 2b Introductory Astronomy
[qr sn]
Does not meet requirements for the major in physics.
Elementary physical ideas will be used to discuss the life and death of stars, the structure of the galaxies, and the large-scale features and evolution of the universe. Usually offered every year.
Mr. Wardle

PHSC 8b Concept and Theories in Physics
[sn]
Does not meet the requirements for the major in physics.
An introductory study of key ideas in fundamental physical science and the philosophy it has helped to shape. General physics and topics in astronomy, cosmology, and relativity are explored utilizing basic quantitative methods and critical thinking techniques. Usually offered every year.
Mr. Farber

PHYS 10a Introduction to Physical Laws and Phenomena I
[sn qr]
Corequisite: MATH 10a or equivalent. Usually taken with PHYS 18a.
An introduction to Newtonian mechanics, kinetic theory, and thermodynamics. Usually offered every year.
Mr. Fell

PHYS 10b Introduction to Physical Laws and Phenomena II
[sn qr]
Prerequisite: PHYS 10a. Usually taken with PHYS 18b.
An introduction to electricity and magnetism, optics, special theory of relativity, and the structure of the atom. Usually offered every year.
Staff

PHYS 15a Advanced Introductory Physics I
[sn qr]
Corequisite: MATH 10a,b or the equivalent. Usually taken with PHYS 19a
An introduction to Newtonian mechanics, kinetic theory, and thermodynamics for students with advanced preparation. Usually offered every year.
Mr. Meyer

PHYS 15b Advanced Introductory Physics II
[qr sn]
Corequisite: MATH 10a,b or the equivalent. Prerequisite: PHYS 15a or the equivalent. Usually taken with PHYS 19b.
An introduction to electricity and magnetism and the special theory of relativity for students with advanced preparation. Usually offered every year.
Mr. Roberts

PHYS 18a Introductory Laboratory I
Corequisite: PHYS 10a. May yield half-course credit toward rate-of-work and graduation. Two semester-hour credits.
Laboratory course consisting of basic physics experiments designed to accompany PHYS 10a. One two-and-a-half-hour laboratory per week. One one-hour lecture per week. Usually offered every year.
Mr. Wellenstein

PHYS 18b Introductory Laboratory II
Corequisite: PHYS 10b. May yield half-course credit toward rate-of-work and graduation. Two semester-hour credits.
Laboratory course consisting of basic physics experiments designed to accompany PHYS 10b. One two-and-a-half-hour laboratory per week. One one-hour lecture per week. Usually offered every year.
Mr. Wellenstein

PHYS 19a Physics Laboratory I
May yield half-course credit toward rate-of-work and graduation. Two semester-hour credits.
Laboratory course designed to accompany PHYS 15a. Introductory statistics and data analysis including use of microcomputers and basic experiments in mechanics. One afternoon or evening of laboratory per week. One one-and-a-half-hour lecture per week. Usually offered every year.
Staff

PHYS 19b Physics Laboratory II
May yield half-course credit toward rate-of-work and graduation. Two semester-hour credits.
Laboratory course designed to accompany PHYS 15b. Basic experiments in electricity, magnetism, and optics. Basic electrical measurements. Determination of several fundamental physical constants. One afternoon or evening of laboratory per week. One one-and-a-half-hour lecture per week. Usually offered every year.
Staff

PHYS 20a Modern Physics I
[sn]
Prerequisites: PHYS 15a, PHYS 15b, or equivalent.
A survey of phenomena, ideas, and mathematics underlying modern physics—special relativity, waves and oscillations, optics, thermal and statistical physics, and introductory quantum mechanics—as well as a selection of topics such as nuclear physics and radioactivity, elementary particles, cosmology, and electronic properties of crystals, semiconductors, and metals. Usually offered every year.
Mr. Bensinger

PHYS 20b Modern Physics II
[sn]
Prerequisite: PHYS 20a.
Continuation of PHYS 20a. Usually offered every year.
Mr. Bensinger

PHYS 22a The Science in Science Teaching and Learning
[sn]
Does not meet requirements for the major in physics.
General science concepts and scientific inquiry will be studied in depth using direct instruction, student projects, and discovery learning. This laboratory-based course, especially relevant to future elementary school teachers, will be cotaught with school teachers and enlivened by children's visits. Usually offered every year.
Staff

PHYS 25b Astrophysics
[sn]
Prerequisites: PHYS 10a, PHYS 10b or PHYS 15a, 15b, and Math 10a, 10b.
Application of basic physical principles to the study of stars, galaxies, quasars, and the large-scale structure of the universe. Usually offered every second year.
Mr. Roberts or Mr. Wardle

PHYS 29a Electronics Laboratory I
[sn]
Prerequisites: PHYS 10a, 10b or 15a, 15b; and 18a, 18b or 19a, 19b.
Introductory laboratory in analog electronics. Topics to be covered are DC circuits, AC circuits, complex impedance analysis, diodes, transistors, and amplifiers. Usually offered every year.
Mr. Kirsch

PHYS 29b Electronics Laboratory II
[sn]
Prerequisite: PHYS 29a.
Introductory laboratory in digital electronics. Topics to be covered are Boolean algebra, combinational logic, sequential logic, state machines, digital-analog conversion, and microprocessors. The last part of the semester is spent on individual design projects. Usually offered every year.
Mr. Meyer

PHYS 30a Electromagnetism
[sn]
Prerequisite: PHYS 20b or permission of the instructor.
The fundamentals of electromagnetic theory. Includes electrostatics, magnetostatics, electric and magnetic circuits, and Maxwell's equations. Usually offered every year.
Ms. Samadani

PHYS 30b Quantum Theory
[sn]
Prerequisites: PHYS 15a,b and PHYS 20a,b or permission of the instructor.
Introduction to quantum mechanics: atomic models, Schrodinger equation, angular momentum, and hydrogen atom. Multielectron atoms and interaction of atoms with the electromagnetic field. Usually offered every year.
Staff

PHYS 32b Microprocessor Laboratory
[sn]
Prerequisite: PHYS 29a or 29b.
Study of microprocessor design and use as controller for other devices. Topics include architecture of microcomputers, interfacing, digital control, analog control, and software development. Usually offered every second year.
Mr. Kirsch

PHYS 33b Optics
[sn]
Prerequisites: PHYS 10a,b; PHYS 15a,b and PHYS 20a,b or permission of the instructor.
This mixed lecture and laboratory course gives an introduction to general optics and demonstrates its application in modern research experiments and engineering problems. Lecture topics include geometric optics, wave optics, and electromagnetic theory and its applications like lens and optical instrument design. In the lab first simple experiments in basic optics are presented, followed by advanced labs to build instruments such as microscopes and interferometers. Usually offered every year.
Mr. Fraden

PHYS 39a Advanced Physics Laboratory
[qr sn wi]
Prerequisite: PHYS 20a. This course may be repeated once for credit with permission of the instructor. This course is cotaught with PHYS 169b.
Experiments in a range of topics in physics, possibly including selections from the following: wave optics, light scattering, Nuclear Magnetic Resonance, X-ray diffraction, scanning tunnelling microscopy, numerical simulation and modeling, holography, electro-optics, phase transitions, rubber elasticity, laser tweezers, chaotic dynamics, and optical microscopy. Students work in depth on three or four experiments during the term. Usually offered every year.
Mr. Blocker

PHYS 40a Introduction to Thermodynamics and Statistical Mechanics
[sn]
Statistical approach to thermal properties of matter. Theoretical tools are developed for studying questions such as: "Why does a rubber band contract upon heating?" or "What is the size of a white dwarf star?" Usually offered every year.
Mr. Dogic

PHYS 97a Tutorial in Physics
Tutorial for students studying advanced material not covered in regular courses. Usually offered every year.
Staff

PHYS 97b Tutorial in Physics
Tutorial for students studying advanced material not covered in regular courses. Usually offered every year.
Staff

PHYS 98a Readings in Physics
Open to exceptional students who wish to study an area of physics not covered in the standard curriculum. Usually offered every year.
Staff

PHYS 98b Readings in Physics
Open to exceptional students who wish to study an area of physics not covered in the standard curriculum. Usually offered every year.
Staff

PHYS 99d Senior Research
Permission of the advising coordinator required.
Research assignments and preparation of a report under the direction of an instructor. Usually offered every year.
Staff

(100-199) For Both Undergraduate and Graduate Students

PHYS 100a Classical Mechanics
[sn]
Prerequisites: PHYS 20a and 20b or permission of the instructor.
Lagrangian dynamics, Hamiltonian mechanics, planetary motion, general theory of small vibrations. Introduction to continuum mechanics. Usually offered every second year.
Mr. Fell

PHYS 102a General Relativity
[sn]
Prerequisites: PHYS 10a and b, PHYS 15a and b, and PHYS 20a and b, or permission of the instructor.
An introduction to the basic principles of general relativity. Topics include a review of special relativity, tensor analysis in curved space-times, the principle of equivalence, the Einstein equations, the Schwarzschild solution, and experimental tests of general relativity. Usually offered every second year.
Mr. Fell

PHYS 104a Soft Condensed Matter
[sn]
Mechanical, thermal, and electronic properties of matter including fluids, solids, liquid crystals, and polymers. Simple models of matter are developed and used to discuss recent experimental findings. Usually offered every second year.
Staff

PHYS 105a Biological Physics
[sn]
Physical forces in living matter are studied from the perspective offered by statistical mechanics, elasticity theory, and fluid dynamics. Quantitative models for biological structure and function are developed and used to discuss recent experiments in single-molecule biology. Usually offered every second year.
Mr. Fraden

PHYS 107b Particle Physics
[sn]
Prerequisite: PHYS 30a or permission of the instructor. Corequisite: PHYS 30b or permission of the instructor.
The phenomenology of elementary particles and the strong, weak, and electromagnetic interactions are studied. Properties of particles, quarks, neutrinos, vector bosons, Higgs particles, supersymmetry, symmetries, and conservation laws are covered. This course is cotaught with the graduate course PHYS 167b, and the work load will be appropriate to each group. Usually offered every second year.
Mr. Bensinger or Mr. Blocker

PHYS 110a Mathematical Physics
[sn]
Prerequisite; PHYS 30a,b or instructor's permission.
Complex variables; Fourier and Laplace transforms; special functions; partial differential equations. This course is co-taught with PHYS 161a, and the work load will be appropriate to each group. Usually offered every year.
Mr. Schnitzer

PHYS 113a First-Year Tutorial I
[sn]
A review of physics from the most elementary topics to those treated in other first-year graduate courses. The environment of an oral qualifying examination is reproduced in the tutorial. Usually offered every year.
Staff

PHYS 113b First-Year Tutorial II
[sn]
Continuation of PHYS 113a. Usually offered every year.
Staff

NPHY 115a Dynamical Systems, Chaos, and Fractals
[sn]
Prerequisites: PHYS 10a or 15a, MATH 21a, or approved equivalents. This course may not be repeated for credit by students who have taken PHYS 115a in previous years.
Advanced introduction to the theory of nonlinear dynamical systems, bifurcations, chaotic behaviors, and fractal patterns. Concepts and analysis are illustrated by examples from physics, chemistry, and biology. The course will be complemented by a significant number of computer labs. Usually offered every second year.
Staff

PHYS 161a Electromagnetic Theory I
[sn]
Electrostatics, magnetostatics, boundary value problems. This course is cotaught with PHYS 110a, and the work load will be appropriate to each group. Usually offered every year.
Mr. Schnitzer

PHYS 161b Electromagnetic Theory II
[sn]
Maxwell's equations. Quasi-stationary phenomena. Radiation. Usually offered every year.
Mr. Schnitzer

PHYS 162a Quantum Mechanics I
[sn]
Nonrelativistic quantum theory and its application to simple systems; spin systems and the harmonic oscillator. Feynman diagram visualization of time-dependent perturbation theory. Usually offered every year.
Mr. Roberts

PHYS 162b Quantum Mechanics II
[sn]
Path integral formulation of quantum mechanics. Quantum treatment of identical particles. Approximate methods: variational, WKB, and perturbation theory. Applications to atoms, molecules, and solids. Usually offered every year.
Mr. Lawrence

PHYS 163a Statistical Physics and Thermodynamics
[sn]
The thermal properties of matter. Derivation of thermodynamics from statistical physics. Statistical theory of fluctuations. Usually offered every year.
Ms. Chakraborty

PHYS 167b Particle Phenomenology
[sn]
The phenomenology of elementary particles and the strong, weak, and electromagnetic interactions. Properties of particles, kinematics of scattering and decay, phase space, quark model, unitary symmetries, and conservation laws. This course is cotaught with PHYS 107b, and the work load will be appropriate to each group. Usually offered every second year.
Mr. Bensinger or Mr. Blocker

PHYS 168b Introduction to Astrophysics
[sn]
Bremsstrahlung, synchrotron radiation, inverse Compton scattering. Extended and compact radio sources, jets, superluminal motion. Quasars and active galactic nuclei, IR to X-ray continua, spectral line formation. Black holes and accretion disks. Usually offered irregularly as demand requires; consult department.
Mr. Wardle

PHYS 169b Advanced Laboratory
[sn]
Experiments in a range of topics in physics, possibly including selections from the following: wave optics, light scattering, Nuclear Magnetic Resonance, X-ray diffraction, scanning tunneling microscopy, numerical simulation and modeling, holography, electro-optics, phase transitions, rubber elasticity, laser tweezers, chaotic dynamics, and optical microscopy. Students work in depth on three or four experiments during the term. This course is cotaught with PHYS 39a. Usually offered every year.
Mr. Blocker

(200 and above) Primarily for Graduate Students

PHYS 202a Quantum Field Theory
Methods of statistical and quantum field theory including path integrals, second quantization, Feynman diagrams, renormalization group, epsilon expansions, effective field theory. Applications ranging from phase transitions and critical phenomena to gauge theories of particle physics. Usually offered every year.
Mr. Lawrence

PHYS 204a Condensed Matter II
Modern techniques such as effective field theory, scaling, and the renormalization group are introduced and used to study solids, magnets, liquid crystals, and macromolecules. Most of the theory is developed on simple models and applied experiments. Usually offered every second year.
Ms. Chakraborty

PHYS 210a High Energy Physics Seminar I
Analysis of important recent developments in particle physics. Usually offered every fourth year.
Mr. Lawrence

PHYS 213a Advanced Examination Tutorial I
Supervised preparation for the advanced examination. Specific sections for individual faculty members as requested. Usually offered every year.
Staff

PHYS 213b Advanced Examination Tutorial II
Supervised preparation for the advanced examination. Specific sections for individual faculty members as requested. Usually offered every year.
Staff

PHYS 280a Advanced Readings and Research
Specific sections for individual faculty members as requested. Usually offered every year.
Staff

PHYS 280b Advanced Readings and Research
Specific sections for individual faculty members as requested. Usually offered every year.
Staff

PHYS 401a Dissertation Research
Independent research for the PhD. Specific sections for individual faculty members as requested. Usually offered every semester.
Staff

PHYS 401b Dissertation Research
Independent research for the PhD. Specific sections for individual faculty members as requested. Usually offered every semester.
Staff

Cross-Listed Courses

QBIO 110a
Numerical Modeling of Biological Systems

QBIO 120b
Quantitative Biology Instrumentation Laboratory

BIOP 200b
Reading in Macromolecular Structure-Function Analysis