Physics

Physics is the discipline that deals with the most fundamental aspects of our universe, such as the properties of atoms, nuclei and elementary particles; the nature of the forces between them; and the collective behavior of atoms in solids, liquids and gases. It deals with the entire universe, from its birth to its ultimate fate. At the same time, physics provides the tools that help us to understand extremely complex everyday things, like the behavior of sand piles, the strength of materials, or processes in the brain. Physics seeks to discover and understand the mathematical rules that govern the behavior of things. Its early successes in comprehending motion, thermodynamics, electricity and magnetism provided a foundation upon which other physical sciences have grown.

For students planning a career in science and technology or planning to pursue graduate studies in physics, astronomy, earth sciences, environmental sciences, medical physics, meteorology or oceanography, a major in physics provides a solid foundation. The program is sufficiently flexible to allow students to combine a physics major with a second major in chemistry, mathematics or engineering, or with pre-medical studies, or with other disciplines in the humanities and social sciences. In addition to the fundamentals of physics, the program is designed to give students a broad range of skills in laboratory techniques, critical thinking, computer use and teamwork, which will serve them well in their chosen careers. In consultation with a faculty adviser, students may design a program of study to meet individual goals and interests. Physics majors are strongly encouraged to participate in physics research projects directed by faculty members.

Introductory Physics: The Physics 197–Physics 198 sequence is a calculus-based introduction to physics intended for adequately prepared students interested in majoring in science or engineering or undertaking pre-medical studies. Physics 197 fulfills the requirements for the Sam Fox School. The sequence uses interactive, active-learning techniques. Calculus I (Math 131) is a corequisite, although previous or concurrent enrollment in Calculus II (Math 132) is strongly recommended.

The department offers several other courses of general interest to the nonscience student. In most cases, these courses have no prerequisites.

Website: http://physics.wustl.edu

Faculty

Chair

Mark Alford (http://physics.wustl.edu/people/alford_mark-g)
Professor
PhD, Harvard University
Nuclear/particle physics

Endowed Professors

Ramanath Cowsik (http://www.physics.wustl.edu/people/cowsik_ramanath)
James S. McDonnell Professor of Space Sciences
PhD, University of Bombay
Astrophysics and space sciences

Kenneth F. Kelton (http://www.physics.wustl.edu/people/kelton_kenneth-f)
Arthur Holly Compton Professor of Physics
PhD, Harvard University
Condensed matter and materials physics

Professors

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Experimental high-energy astrophysics

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Biophysics

Joint Professors

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(Mechanical Engineering)

Lee G. Sobotka (http://www.physics.wustl.edu/people/sobotka_lee-g)
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(Chemistry)
Experimental nuclear physics

Associate Professors

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Condensed matter and materials science

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PhD, Massachusetts Institute of Technology/Harvard Medical School
Systems cell biology

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PhD, California Institute of Technology
Cosmochemistry, planetary science

Saori Pastore
PhD, Old Dominion University
Theoretical nuclear physics

Maria Piarulli
PhD, Old Dominion University
Theoretical nuclear physics

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PhD, Universitat Autonoma de Barcelona, Spain

Mairin Hynes (http://www.physics.wustl.edu/people/hynes_kathryn-mairin)
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PhD, Stanford University

Research Associate Professor

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PhD, Washington University

Professors Emeriti

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PhD, Harvard University

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Clifford Will (http://www.physics.wustl.edu/people/will_clifford-m)
PhD, California Institute of Technology

Majors

The Major in Physics

Total units required: 42-49

Prerequisites: As prerequisites for the major, students should complete Physics I and II (Physics 197 and Physics 198) during the first year. Majors should consider taking Physics 217, Physics 316 or Physics 321, Physics 318, and Physics 411 in the second year.

Required Physics courses: Students are required to complete a minimum program of 21 units of advanced courses (300-level or higher) in Physics. These 21 units must include:

Code	Title	Units
Physics 322	Physical Measurement Laboratory	3
Physics 411	Mechanics	3
Physics 421	Electricity and Magnetism	3

- One additional upper-level laboratory course. Choose from:

Code	Title	Units
Physics 316	Optics and Wave Physics Laboratory	3
Physics 321	Electronics Laboratory	3
Physics 360	Biophysics Laboratory	3
Physics 435	Nuclear and Radiochemistry Lab	3

- Students not taking Physics 217 must take either Physics 318 Introduction to Quantum Physics II or Physics 471 Quantum Mechanics.
- The remaining physics courses must be at the 300 level or above, excluding Physics 341, Physics 342, Physics 441, Physics 442, Physics 499 and Physics 500.

Recommended Physics courses: In addition to the above requirements, students who are preparing for graduate study in physics or astronomy should consider taking:

Code	Title	Units
Physics 422	Electricity and Magnetism II	3
Physics 463	Statistical Mechanics and Thermodynamics	3
Physics 471	Quantum Mechanics	3

As well as some of:

Code	Title	Units
Physics 472	Solid State Physics	3
Physics 474	Introduction to Particle Physics	3
Physics 476	Astrophysics	3
and additional lab courses		

Students also should consider taking Physics 501/Math 501–Physics 502/Math 502 and additional mathematics courses.

Students who are preparing for employment after the AB degree should take additional laboratory courses from the following choices:

Code	Title	Units
Physics 316	Optics and Wave Physics Laboratory	3
Physics 321	Electronics Laboratory	3
Physics 322	Physical Measurement Laboratory	3
Physics 360	Biophysics Laboratory	3
Physics 435	Nuclear and Radiochemistry Lab	3

Other relevant courses may include:

Code	Title	Units
Physics 350	Physics of the Brain	3
Physics 351	Introduction to Biomedical Physics	3
Physics 352	Physics of Biomolecules	3
Physics 355	Physics of Vision	3
Physics 422	Electricity and Magnetism II	3
Physics 463	Statistical Mechanics and Thermodynamics	3
Physics 471	Quantum Mechanics	3
Physics 472	Solid State Physics	3

Students also might consider:

Code	Title	Units
Chem 435	Nuclear and Radiochemistry Lab	3
Chem 436	Radioactivity and Its Applications	3

Students who are preparing for medical school should give special consideration to:

Code	Title	Units
Physics 314	Physics of the Heart	3
Physics 316	Optics and Wave Physics Laboratory	3
Physics 321	Electronics Laboratory	3
Physics 344	Energy and Environmental Physics	3
or Physics 444	Energy and Environmental Physics	
Physics 350	Physics of the Brain	3
Physics 351	Introduction to Biomedical Physics	3
Physics 352	Physics of Biomolecules	3
Physics 355	Physics of Vision	3
Physics 360	Biophysics Laboratory	3

Math courses required for the physics major:

Code	Title	Units
Math 131	Calculus I	3
Math 132	Calculus II	3
Math 233	Calculus III	3
Math 217	Differential Equations (We recommend that Math 217 precede Physics 411)	3
Total Units		12

Math courses recommended for the physics major:

- Math 308 Mathematics for the Physical Sciences or ESE 318 Engineering Mathematics A (We recommend that this course precede Physics 421.)
- Math 309 Matrix Algebra (We recommend that Math 309 precede Physics 471.)
- Physics 501/Math 501 and Physics 502/Math 502 also are recommended.

Science-breadth requirement: Majors must select three of the following courses to satisfy the science-breadth requirement. One of the three courses must be Chem 111A, Chem 112A, Chem 401 or Chem 402.

Code	Title	Units
Chem 111A	General Chemistry I	3
Chem 112A	General Chemistry II	3
Chem 151	General Chemistry Laboratory I	2
Chem 152	General Chemistry Laboratory II	2
Chem 401	Physical Chemistry I	3
Chem 402	Physical Chemistry II	3
Chem 445	Instrumental Methods: Physical Chemistry	3
CSE 131	Introduction to Computer Science	3
CSE 132	Introduction to Computer Engineering	3

Additional Information

Senior Honors: Students are encouraged to work toward Latin Honors (cum laude, magna cum laude, summa cum laude). To qualify, students must meet the academic requirements of the college and successfully complete a suitable project under the supervision of a faculty member in the department. The project, whether experimental or theoretical, should demonstrate the student's capacity for independent work. Honors candidates must apply to the Undergraduate Studies Committee no later than the the first day of classes senior year. The application should include a description of the proposed project, co-signed by the supervising professor. A written report of the completed work must be submitted to the committee by a deadline in March. By enrolling in Physics 499, students may earn up to 6 units of credit for the honors project.

The physics department also offers physics majors the possibility to earn departmental distinctions. These distinctions require the same GPA cutoff as Latin Honors (http://bulletin.wustl.edu/undergrad/artsci/honors) but are calculated exclusively from the grades in physics courses (all courses with the prefix L31). Three levels of distinction are offered: (1) highest distinction, (2) high

distinction, and (3) distinction. The highest and high distinctions require at least one semester of undergraduate research and a senior thesis describing the results, and are limited to the top 15 percent (highest distinction) and top 15-50 percent (high distinction) of the physics majors in their senior year ranked by their GPA in the physics courses. Students meeting the GPA cutoff but not undertaking undergraduate research and a senior thesis may only receive the third level of distinction.

Minors

The Minor in Physics

Units required: 17

Required courses:

Code	Title	Units
Physics 197	Physics I	4
Physics 198	Physics II	4
Physics 217	Introduction to Quantum Physics	3
Physics 318	Introduction to Quantum Physics II	3
Total Units		14

Elective courses:

At least one course at the 300 level or above (with the exception of Physics 303, Physics 304, Physics 341, Physics 342, Physics 441, Physics 442, Physics 499 and Physics 500) with a grade of C- or better.

Additional Information

For enrollment in Physics 197 Physics I, previous or concurrent enrollment in Math 131 Calculus I is required; previous or concurrent enrollment in Math 132 Calculus II is strongly recommended. Calculus II also is necessary to provide adequate preparation for Physics 217/318 Quantum Physics I, II. Note that for some advanced courses, Math 233 Calculus III and Math 217 Differential Equations are prerequisites.

The Minor in Astrophysics and Astroparticle Physics

Units required: 20

Required courses:

Code	Title	Units
Physics 197	Physics I	4
Physics 198	Physics II	4
Physics 217	Introduction to Quantum Physics	3
Physics 312	Introduction to Astrophysics	3
Total Units		14

Two courses from the following six courses:

Code	Title	Units
Physics 318	Introduction to Quantum Physics II	3
Physics 456	Stellar Astrophysics	3
Physics 460	X-Ray & Gamma-Ray Astrophysics	3
Physics 474	Introduction to Particle Physics	3
Physics 476	Astrophysics	3
Physics 478	From Black Holes to the Big Bang	3

The Minor in Biomedical Physics

Units required: 17

Required courses:

Code	Title	Units
Physics 197	Physics I	4
Physics 198	Physics II	4
Total Units		8

Elective courses:

Two courses from the following three:

Code	Title	Units
Physics 314	Physics of the Heart	3
Physics 350	Physics of the Brain	3
Physics 355	Physics of Vision	3

One course from the following four laboratory courses:

Code	Title	Units
Physics 316	Optics and Wave Physics Laboratory	3
Physics 321	Electronics Laboratory	3
Physics 322	Physical Measurement Laboratory	3
Physics 360	Biophysics Laboratory	3

Additional Information

This is a minor for students interested in the discussion and application of methods and techniques from physics to topics in the area of biology and medicine. The program may be of interest to the pre-medicine student or the research-oriented science major. New courses are being developed that also will satisfy these requirements.

Courses

Visit online course listings to view semester offerings for L31 Physics (https://courses.wustl.edu/CourseInfo.aspx?sch=L&dept=L31&crslvl=1:4).

L31 Physics 101A Basic Physical Science
An introduction to the concepts and modes of thought involved in understanding the physical world. The focus is not only on everyday phenomena (e.g., falling objects, skidding cars, the tides) but also on questions of cosmic significance (e.g., relativity, the Big Bang, black holes, the origin of the elements). Verbal reasoning is emphasized. No prerequisites.

Credit 3 units. A&S IQ: NSM, AN BU: SCI

L31 Physics 107A How Things Work
Why is the sky blue? How can a baseball curve? Natural and manmade phenomena can be understood by simple and basic ideas of physics. This course illustrates these underlying principles by using examples from everyday life as well as from physics and other fields. Because the phenomena are many and the principles are few we find that apparently very different events sometimes have similar explanations; we come to understand how the stretching of a rubber band is related to ice skating, and how the blue of the sky is related to the red of the sunset and the white color of milk. No prerequisites.
Credit 3 units. A&S IQ: NSM, AN Art: NSM BU: SCI

L31 Physics 110A Awesome Ideas in Physics
The ideas of physics that have revolutionized our perception of the world and reality. Emphasis is on understanding a selected set of crucial concepts without losing track of the numbers. Using the writings of Hawking, Feynman and Lightman, a study is made of such topics as energy and conservation laws, the relativity of time, the wave-particle duality, the modern picture of matter at the smallest and the largest distance scales, and the history of the universe. Must be taken for a letter grade. No prerequisites.
Credit 3 units. A&S IQ: NSM, AN Art: NSM BU: SCI

L31 Physics 111 Variational Calculus — A Mathematical Blade for Cutting-Edge Science
Variational calculus, a fancy generalization of ordinary calculus, is the study of functionals. In variational calculus one tries to find the special function that extremizes a functional. The applications of variational calculus are ubiquitous in modern science. Variational calculus is the mathematical setting for describing the physical world. In all areas of classical and quantum physics, the physical world is expressed in terms of functions that extremize specific functionals. In this seminar variational calculus is explained at an elementary level and many of its applications in science are examined. A good understanding of elementary first-year calculus is required to take this seminar.
Credit 3 units. A&S: FYS

L31 Physics 125A Solar System Astronomy
Designed for the nonscience major, this course deals with the planets, their moons and rings, comets, meteorites and interplanetary dust particles. In order to understand both classical astronomy and the results obtained from modern telescopes and the space program, basic scientific ideas (including optics and the laws of motion) are reviewed first. There also is some discussion of astronomical history to show how we have arrived at our present ideas of the structure and evolution of the solar system. Prerequisites: high school algebra and trigonometry or concurrent enrollment in Math 131.
Credit 3 units. A&S IQ: NSM, AN Art: NSM BU: SCI

L31 Physics 126A Stars, Galaxies and Cosmology
Intended as a general survey for the nonscience major. Topics include the structure and evolution of stars, such as red giants, white dwarfs, neutron stars, pulsars and black holes; galaxies and quasars; cosmology and the Big Bang theory. Prerequisites: high school algebra and trigonometry, or concurrent enrollment in Math 131.
Credit 3 units. A&S IQ: NSM, AN Arch: NSM Art: NSM BU: SCI

L31 Physics 141 Selected Topics in Physics I
Topics of special interest (e.g., superconductivity, quasicrystals, neural networks, chaos, etc.) may be studied under the supervision of a faculty member, variously by lectures, seminars or individual study or research. Students hoping to arrange such a course must prepare a proposal and secure consent to undertake direction of the course from a faculty member and finally secure approval of the department chair.
Credit variable, maximum 3 units. A&S IQ: NSM Art: NSM BU: SCI

L31 Physics 142 Selected Topics in Physics I
Topics of special interest (e.g., holography, relativity, nuclear power, computer applications in physics, etc.) may be studied under the supervision of a faculty member, variously by lectures, seminars or individual study or research. Students hoping to arrange such a course must prepare a proposal and secure the instructor's consent to undertake direction of the course from a faculty member and finally secure approval of the department chair.
Credit variable, maximum 3 units. A&S IQ: NSM Art: NSM BU: SCI

L31 Physics 171A Physics and Society
Introduction to physics: its goals, methods and relevance for society. Topics include energy as a unifying principle of physics and society's use of energy: resources and costs. Nuclear energy: history, technology, radiation, waste, weapons. Global climate change: the greenhouse effect, the hole in the ozone layer. Science and government. Bad science, pseudoscience, antiscience. Intended for science and nonscience majors. Must be taken for a letter grade.
Credit 3 units. A&S IQ: NSM, AN Art: NSM BU: SCI

L31 Physics 197 Physics I
Calculus-based introduction to the central concepts, laws, and structure of physics, presented in an active learning environment. The course is structured around three themes that are treated in-depth: conservation laws, Newtonian physics, and special relativity. A daily regimen of homework and reading, as well as weekly homework assignments, small-group problem-solving exercises, and active class participation are integral parts of this course. Concurrent registration in a Physics 197 lab section is required. Prerequisite: previous or concurrent enrollment in Calculus I (Math 131) is required; previous or concurrent enrollment in Calculus II (Math 132) strongly recommended. Credit may not be obtained for both Physics 117A and Physics 197, and students may not simultaneously enroll in both courses.
Credit 4 units. A&S IQ: NSM, AN Arch: NSM Art: NSM BU: SCI

L31 Physics 198 Physics II
Continuation of Physics 197. An advanced, calculus-based introduction to central concepts in physics for students who desire to major in physics or another physical science, or who have a special interest in physics. The course is structured around three themes that are treated in depth: electricity and magnetism, quantum physics, and statistical and thermal physics. A daily regimen of homework and reading as well as active class participation are integral parts of the course. Prerequisites: Physics 197 and Calculus II. Students who

have not taken Physics 197 may not register for Physics 198. Concurrent registration in a Physics 198 lab section is required. Credit may not be obtained for both Physics 118 and Physics 198.
Credit 4 units. A&S IQ: NSM, AN Arch: NSM Art: NSM BU: SCI

L31 Physics 216 Introduction to Relativity: The Special Theory
Introduction to the special and general theories of relativity. Einstein's postulates of the principle of relativity and the constancy of the speed of light. Simple kinematics and dynamics: simultaneity, time dilation, space-time diagrams, twin and other "paradoxes," $E=mc^2$, laws of motion. Elements of general relativity; curved spacetime, experimental tests, black holes, gravitational waves. Prerequisite: Physics 117A, Physics 197 or permission of the instructor.
Credit 1 unit. A&S IQ: NSM Arch: NSM Art: NSM BU: SCI

L31 Physics 217 Introduction to Quantum Physics
Theoretical and experimental basis for quantum mechanics, following the historical development of 20th-century physics. Failure of classical physics; the Bohr theory of the atom; the Heisenberg uncertainty principle; the Schroedinger equation; atomic and molecular structure. Prerequisites: Physics 117A and 118A or Physics 197 and 198.
Credit 3 units. A&S IQ: NSM, AN Art: NSM BU: SCI

L31 Physics 219 Energy and the Environment
Examination of the topic of energy from many human-relevant perspectives. Humans use an enormous amount of energy, at the rate of 18 terawatts. Where does this energy come from? How long will it last? What are the consequences? Examination of energy resources and consumption from scientific, social, economic and political viewpoints. Relationship of energy to concepts such as heat, work and power. Energy use by society. Energy sources, pros and cons of use, availability now and in the future. Types, abundance, advantages, challenges of renewable energy sources. Prerequisite: one year of high-school physics or chemistry.
Same as L19 EPSc 219
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM BU: SCI

L31 Physics 241 Select Topics in Physics II
Topics of special interest (e.g., superconductivity, quasicrystals, neural networks, chaos, etc.) may be studied under the supervision of a faculty member, variously by lectures, seminars or individual study or research. Students hoping to arrange such a course must prepare a proposal and secure consent to undertake direction of the course from a faculty member and finally secure approval of the department chair.
Credit variable, maximum 3 units. A&S IQ: NSM Art: NSM BU: SCI

L31 Physics 242 Selected Topics in Physics II
Topics of special interest (e.g., holography, relativity, nuclear power, computer applications in physics, etc.) may be studied under the supervision of a faculty member, variously by lectures, seminars or individual study or research. Students hoping to arrange such a course must prepare a proposal and secure the instructor's consent to undertake direction of the course from a faculty member and finally secure approval of the department chair.
Credit variable, maximum 3 units. A&S IQ: NSM Art: NSM BU: IS

L31 Physics 312 Introduction to Astrophysics
This course covers the physics needed for higher-level astrophysics courses, and is a requirement for those courses. Furthermore, it gives a first introduction to several topics in modern astrophysics, including stars (stellar structure and evolution), compact objects (neutron stars and black holes), galaxies (galactic structure), and cosmology. The course should be taken by everybody interested in astrophysics. Prerequisite: Physics 117A and 118A; or Physics 197 and 198; or permission of instructor.
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM BU: SCI

L31 Physics 314 Physics of the Heart
A lecture and demonstration course that may be of particular interest to premedical and life-science students. Basic physics of the human cardiovascular system. Elasticity of vessels: properties of elastin and collagen. Energetics of the circulation: arterial and venous blood pressure, total fluid energy, gravitational potential energy, kinetic energy. Streamline flow and turbulence: effects of stenosis. Static and dynamic energy consumption of the heart: cardiac efficiency, the tension-time integral, Laplace's law, Starling's law. Metabolism of cardiac muscle. Electrophysiology: the heartbeat and cardiac arrhythmias. The physics of phonocardiograms, echocardiograms and other non-invasive techniques for physical assessment of cardiac abnormalities, including ischemia and myocardial infarction. Models of mechanical properties: contractile element, series elastic and parallel elastic elements. Corequisite: Physics 118A, Physics 198 or permission of instructor.
Credit 3 units. A&S IQ: NSM, AN Arch: NSM Art: NSM BU: SCI EN: SU, TU

L31 Physics 316 Optics and Wave Physics Laboratory
Introduction to optics and to treatment of experimental data. Experiments and lectures on refraction, interference, diffraction, polarization and coherence properties of waves with emphasis on light. Data analysis using statistical methods. Prerequisites: Physics 117A–Physics 118A or Physics 197–Physics 198.
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM BU: SCI

L31 Physics 318 Introduction to Quantum Physics II
Application of elementary quantum principles to atomic and molecular physics, solid-state physics, and nuclear and particle physics. Prerequisite: Physics 217.
Credit 3 units. A&S IQ: NSM, AN Arch: NSM Art: NSM BU: SCI

L31 Physics 321 Electronics Laboratory
Elements of linear and nonlinear circuits, amplifiers, feedback, with applications in experimental physics. Prerequisite: Physics 118A, Physics 198 or permission of instructor. Two three-hour laboratories and two one-hour lectures a week.
Credit 3 units. A&S IQ: NSM, AN Art: NSM BU: SCI EN: DU, SU, TU

L31 Physics 322 Physical Measurement Laboratory
A variety of classical and modern experiments in physics, including five experiments in nuclear radiation. Use of computers in experiment control, data acquisition, and data analysis. Development of skills in writing lab notebooks and formal reports and giving short oral presentations on experiments. Two

laboratory periods each week. Prerequisites: Physics 217 or permission of instructor; junior- or senior-level standing.
Credit 3 units. A&S IQ: NSM, AN, WI Arch: NSM Art: NSM BU: SCI EN: TU

L31 Physics 341 Selected Topics in Physics III
Topics of special interest (e.g., superconductivity, quasicrystals, neural networks, chaos, etc.) may be studied under the supervision of a faculty member, variously by lectures, seminars or individual study or research. Students hoping to arrange such a course must prepare a proposal and secure consent to undertake direction of the course from a faculty member and finally secure approval of the department chair.
Credit variable, maximum 3 units. A&S IQ: NSM Art: NSM BU: SCI

L31 Physics 342 Selected Topics in Physics III
Topics of special interest (e.g., holography, relativity, nuclear power, computer application in physics, etc.) may be studied under the supervision of a faculty member, variously by lectures, seminars or individual study or research. Students hoping to arrange such a course must prepare a proposal and secure the instructor's consent to undertake direction of the course from a faculty member and finally secure approval of the department chair.
Credit variable, maximum 3 units. A&S IQ: NSM Art: NSM BU: SCI

L31 Physics 344 Energy and Environmental Physics
This intermediate-level course applies basic physics principles to this increasingly important area. It is designed for all science and engineering majors with an interest in energy and environmental issues. Topics covered include population trends, fossil fuel use, renewable energy sources, energy storage strategies and climate change. Particular emphasis is given to the use of the fundamental laws of physics, such as energy conservation, as well as more general concepts such as local and global stability, chaotic behavior, probability and risk. The aim of the course is the development of analytical skills and familiarity with important concepts, in order to enable an independent and informed view of environmental problems and possible solutions. A one-year introductory physics class on the level of Physics 117–118 or 197–198 is required. This course also may be taken as Physics 444, which requires an additional independent project.
Credit 3 units. A&S IQ: NSM, AN BU: SCI

L31 Physics 350 Physics of the Brain
Concepts and techniques of physics are applied to study the functioning of neurons and neuronal circuits in the brain. Neurons and neural systems are modeled at two levels: (1) at the physical level, in terms of the electrical and chemical signals that are generated and transmitted, and (2) at the information-processing level, in terms of the computational tasks performed. Specific topics include: neuronal electrophysiology, neural codes, neural plasticity, sensory processing, neural network architectures and learning algorithms, and neural networks as dynamical and statistical systems. Course grade is based primarily on an individualized term project. Prerequisites: Physics 117A–118A, Physics 197–198, or permission of the instructor.
Credit 3 units. A&S IQ: NSM Art: NSM BU: SCI EN: SU, TU

L31 Physics 351 Introduction to Biomedical Physics
Principles and application of key physical methods used in the diagnosis and treatment of diseases, and in biomedical research. Topics include interaction of radiation with living systems; fundamentals of optical and electron microscopy; imaging via X-rays, magnetic resonance and ultrasound; and electrical properties of organs and cells. Prerequisite: Physics 117A–118A or Physics 197–198.
Credit 3 units. Art: NSM BU: SCI EN: TU

L31 Physics 352 Physics of Biomolecules
This course emphasizes the application of physical laws and concepts in understanding biomolecules and their interactions, and in developing tools to investigate their biological properties and functionalities. Topics include (1) a general introduction to biomolecules and cells, (2) physics of biopolymers as modeled by stochastic analyses, (3) transport processes in biological systems including diffusion, reaction kinetics and "life at low Reynolds number," and (4) the physics of fluorescence and its contemporary applications to dynamics of biomolecules, such as optical tweezers. Prerequisite: Physics 117–118 or Physics 197–198. Some familiarity with thermodynamics; Chem 111A–112A recommended.
Credit 3 units. A&S IQ: NSM, AN

L31 Physics 354 Physics of Living Systems
One of the grand challenges in contemporary biophysics is placing our understanding of cellular systems on a firm quantitative footing. How does the collective activity of molecules enable the cell to sense its environment, make decisions, grow and develop? This course, aimed at physical and life science students, will serve as an introduction to the physical principles and mathematical techniques underlying the analysis of systems and synthetic biology. Topics will include modeling gene and signaling networks, the regulation of intracellular structures, and pattern formation in development. Students in this course can expect to learn both analytical and computer simulation approaches to fundamental problems in biology, biophysics, and biotechnology. Graduate students will explore the subject in more depth. Prerequisites: Physics 117A-118A or Physics 197-198 or Math 217 or Math 309, or permission of instructor.
Credit 3 units. A&S IQ: NSM

L31 Physics 355 Physics of Vision
How do the eyes capture an image and convert it to neural messages that ultimately result in visual experience? This lecture and demonstration course covers the physics of how we see. The course is addressed to physics, premedical and life-sciences students with an interest in biophysics. Topics include physical properties of light, evolution of the eyes, image formation in the eye, image sampling with an array of photoreceptors, transducing light into electrical signals, color coding, retinal organization, computing with nerve cells, compressing the 3-D world into optic nerve signals, inferring the 3-D world from optic nerve signals, biomechanics of eye movement, engineered vision in machines. The functional impact of biophysical mechanisms for visual experience is illustrated with psychophysical demonstrations. Corequisite: Physics 117A, Physics 197 or permission of instructor.
Credit 3 units. A&S IQ: NSM Art: NSM BU: SCI EN: SU, TU

L31 Physics 360 Biophysics Laboratory
This laboratory course consists of "table-top" experiments in biological physics that are designed to introduce the

student to concepts, methods and biological model systems in biophysics. Most experiments combine experimentation with computer simulations. The list of available experiments includes electrophysiology, human bioelectricity, optical tweezers, ultrasonic imaging, mass spectrometer and viscosity measurements. Prerequisites: prior completion of Physics 117A–118A, Physics 197–198 or permission of instructor.
Credit 3 units. A&S IQ: NSM, AN Art: NSM

L31 Physics 400 Physical Science in 12 Problems
Exercises related to general chemistry, classical mechanics, quantum mechanics, statistical mechanics, thermodynamics and kinetics, are solved with numerical software. Each exercise is accompanied by a lecture, a software template solving a problem and a related take-home problem. The software allows us to focus on, and treat in a transparent fashion, physical problems without the unworldly idealizations and contrivances found in textbooks. Prerequisites: General Chem, concurrent enrollment with Chem 401 and prior or concurrent enrollment in General Physics.
Same as L07 Chem 400
Credit 1 unit. A&S IQ: NSM Arch: NSM Art: NSM BU: SCI

L31 Physics 411 Mechanics
Motion of a point particle, rotational motion, oscillation, gravitation and central forces, Lagrangian and Hamiltonian formulation. Prerequisites: Physics 117A–118A or Physics 197–198, Math 217 or permission of instructor.
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L31 Physics 421 Electricity and Magnetism
Starting from Coulomb's law, the Biot-Savart law and Faraday's law, the electrical and magnetic fields are defined and applied. Maxwell's equations are derived and their consequences, such as electromagnetic waves and relativity, are explored. Prerequisites: Physics 117A–118A or Physics 197–198, Math 217 or permission of instructor.
Credit 3 units. A&S IQ: NSM, AN Art: NSM BU: SCI EN: DU, SU, TU

L31 Physics 422 Electricity and Magnetism II
The second course in a two-part series covering the classical theory of electricity and magnetism leading to the derivation and application of Maxwell's equation. Topics in electrodynamics including Faraday's law, the displacement current and Maxwell's equations in vacuum and in matter are covered. Electromagnetic waves and radiation, special relativity and relativistic electrodynamics also are discussed. Prerequisite: Physics 421 or permission of instructor.
Credit 3 units. A&S IQ: NSM, AN Arch: NSM Art: NSM EN: DU, SU, TU

L31 Physics 427 Introduction to Computational Physics
Lectures and hands-on experience in computational physics combining topics in numerical analysis, algorithms, statistics, visualization and computer algebra with projects in contemporary areas of physics. Prerequisites: Physics 217 or equivalent and familiarity with a programming language.
Credit 3 units. A&S IQ: NSM Art: NSM

L31 Physics 435 Nuclear and Radiochemistry Lab
Application of radiochemical techniques to problems in chemistry, physics, and nuclear medicine. Prerequisites: 3 units of physical chemistry and permission of instructor. One lecture hour and five hours of laboratory a week.
Same as L07 Chem 435
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L31 Physics 436 Introduction to the Atomic Nucleus
Introduction to the production and decay of radioactive nuclides, the structure and properties of nuclei, and the applications of nuclear and radiochemical techniques to current scientific problems. Prerequisites: one year each of chemistry, mathematics and physics.
Same as L07 Chem 436
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L31 Physics 441 Selected Topics in Physics IV
Topics of special interest (e.g., holography, relativity, nuclear power, computer applications in physics, etc.) may be studied under the supervision of a faculty member, variously by lectures, seminars or individual study or research. Students hoping to arrange such a course must prepare a proposal and secure the instructor's consent to undertake direction of the course from a faculty member and finally secure approval of the department chair.
Credit variable, maximum 3 units. A&S IQ: NSM Art: NSM BU: SCI

L31 Physics 442 Selected Topics in Physics IV
Topics of special interest (e.g., holography, relativity, nuclear power, computer applications in physics, etc.) may be studied under the supervision of a faculty member, variously by lectures, seminars or individual study or research. Students hoping to arrange such a course must prepare a proposal and secure the instructor's consent to undertake direction of the course from a faculty member and finally secure approval of the department chair.
Credit variable, maximum 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L31 Physics 444 Energy and Environmental Physics
This intermediate-level course applies basic physics principles to this increasingly important area. It is designed for all science and engineering majors with an interest in energy and environmental issues. Topics covered include population trends, fossil fuel use, renewable energy sources, energy storage strategies and climate change. Particular emphasis is given to the use of the fundamental laws of physics, such as energy conservation, as well as more general concepts such as local and global stability, chaotic behavior, probability and risk. The aim of the course is the development of analytical skills and familiarity with important concepts, in order to enable an independent and informed view of environmental problems and possible solutions. A one-year introductory physics class on the level of Physics 117-118 or Physics 197-198 is required. This course may also be taken as Physics 344. Physics 444 requires an additional independent project.
Same as L31 Physics 344
Credit 3 units. A&S IQ: NSM, AN BU: SCI

L31 Physics 446 Galactic Astrophysics
This course discusses the motion of stars, gas, and dark matter in galaxies with the aim to gain a deep understanding of the morphologies and the kinematics of galaxies and galaxy clusters. The lectures focus on the dynamics and statistical mechanics of a collection of stars — treated as a collisionless system. The course begins with a discussion of potential theory and proceeds to discuss the density and phase distributions of stars in star clusters and galaxies, thus leading to an understanding of the equilibria and stability of these systems. Topics such as Chandrasekhar's dynamical friction, cosmology, the growth of density perturbations, galaxy formation, and dark matter constitute the final topics of discussion. This course is available for advanced undergraduates. Prerequisites: Physics 312, 411, and 463, or permission by the instructor, and graduate students. Same as L31 Physics 546
Credit 3 units.

L31 Physics 450 Physics of the Brain
Contents are the same as Physics 350. Also intended for graduate students. Includes a more sophisticated term project than Physics 350. Prerequisites: Physics 117A–118A or Physics 197–198, or permission of instructor.
Credit 3 units. A&S IQ: NSM Art: NSM BU: SCI EN: SU, TU

L31 Physics 454 Physics of Living Systems
Contents are the same as Physics 354. Graduate students will explore the subject in more depth. Prerequisites: Physics 117A-118A or Physics 197-198 or Math 217 or Math 309, or permission of instructor.
Credit 3 units. A&S IQ: NSM

L31 Physics 455 Physics of Vision
Contents are the same as Physics 355. Also intended for graduate students. Includes a more sophisticated term project than Physics 355. Corequisite: Physics 117A , Physics 197 or permission of instructor.
Credit 3 units. A&S IQ: NSM Art: NSM

L31 Physics 456 Stellar Astrophysics
The course Stellar Astrophysics discusses the physical processes that play a role inside stars. Relevant physical processes include emissions and absorption processes, radiation transfer, convective transfer, the weak and strong interactions, nuclear processes and nuclear burning, and the thermodynamics of equilibrium and non-equilibrium processes in stellar interiors. Subsequently, these processes are used to explain the structure and evolution of stars of different mass ranges. Finally, the course discusses endpoints of stellar evolution including white dwarfs, neutron stars, black holes, supernova explosions and gamma-ray burst. Prerequisites: Physics 312, Physics 318, or permission of instructor.
Same as L31 Physics 556
Credit 3 units.

L31 Physics 460 X-Ray & Gamma-Ray Astrophysics
Observers started to use X-ray and gamma-rays in the '60s and '70s to explore the cosmos with high-energy photons. The sky looks dramatically different at these energies with bright flares from mass accreting black holes and gamma-ray bursts and large diffuse emission from supernova remnants and cosmic rays interacting with galactic matter and magnetic fields dominating the emission. This course gives a comprehensive overview of the underlying physics and observable phenomenology. Topics covered include the history of X-ray and gamma-ray astronomy, high-energy radiation processes, particle heating and acceleration, accretion physics, blast waves and shocks, black holes, neutron stars, supernova remnants, gamma-ray bursts, and galaxy clusters. Prerequisite: L31 Physics 312.
Credit 3 units. A&S IQ: NSM

L31 Physics 463 Statistical Mechanics and Thermodynamics
Basic methods of classical and quantum statistical mechanics, thermodynamics and transport theory. Prerequisite: Physics 217 or permission of instructor.
Credit 3 units. A&S IQ: NSM, AN Art: NSM

L31 Physics 471 Quantum Mechanics
Origins of quantum theory, wave packets and uncertainty relations, Schroedinger's equation in one dimension, step potentials and harmonic oscillators, eigenfunctions and eigenvalues, Schroedinger's equation in three dimensions, the hydrogen atom, symmetry, spin and the periodic table, approximation methods for time independent problems, quantum statistics. Prerequisite: Math 217, Physics 217, or permission of instructor.
Credit 3 units. A&S IQ: NSM Art: NSM EN: SU, TU

L31 Physics 472 Solid State Physics
Crystal structures, binding energies, thermal properties, dielectrics, magnetism, free electron theory of metals, band theory, semiconductors, defects in solids. Prerequisite: Physics 471.
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L31 Physics 474 Introduction to Particle Physics
Introduction to the standard model of particle physics, including symmetries, conservation laws, the weak interaction, the strong interaction, quark confinement and some more exotic ideas such as grand unified theories. Prerequisite: Physics 471.
Credit 3 units. A&S IQ: NSM, AN Arch: NSM Art: NSM

L31 Physics 476 Astrophysics
This Astrophysics course focuses on cosmic rays.Victor Hess discovered in 1912 that ionizing radiation impinges on the top of Earth's atmosphere. Even though physicists have been studying cosmic rays (the ionizing radiation) for more than 100 years now with a fantastic repertoire of experimental and theoretical tools, cosmic rays never stop to surprise us, and cosmic ray physicists are still pushing the frontier of cosmic exploration in many ways. This course gives an introduction into this exciting topic covering historical and recent cosmic ray measurements at all energies, particle and antiparticle observations, and neutrino observations. The presently favored models of cosmic ray acceleration and transport are discussed in detail, and some topics of current interest are highlighted (including the production of particles and antiparticles by dark matter). The course also covers radio astronomy and highlights the clues about the origin of the cosmic rays that can be obtained from radio observations. Prerequisite: Physics 312 or permission of instructor.
Credit 3 units. A&S IQ: NSM Art: NSM

L31 Physics 477 Physics of Finite and Infinite Nuclear Systems

Quantum mechanics of finite and infinite systems of protons and neutrons. Interaction between nucleons. Independent-particle model of nuclei and shell structure. Contrast with atomic shell model. Isospin symmetry. Information from weakly and strongly interacting probes of nuclei. Nuclear decay properties and some historical context. Many-particle description of nuclear systems. Single-particle versus collective phenomena. Properties of excited states. Bulk properties of nuclei. Nuclear and neutron matter. Role of different energy scales in determining nuclear properties: influence of long-range, short-range, and medium-induced interactions. Pairing correlations in nuclear systems. Relevance of nuclear phenomena and experiments for astrophysics and particle physics. Prerequisites: Physics 318 or Physics 471, or permission of instructor

Credit 3 units. A&S IQ: NSM

L31 Physics 478 From Black Holes to the Big Bang

An introduction to general relativity. The goal is to illustrate important features of general relativity without the full-blown mathematics of Einstein's equations by restricting attention to spherically symmetric spacetimes. Topics include: principle of equivalence; curved spacetime; spherical stars and black holes; the Big Bang model, observational cosmology. Prerequisite: Physics 411 or permission of instructor.

Credit 3 units. A&S IQ: NSM Art: NSM

L31 Physics 482 Research Seminar

Designed to introduce students to current developments in physics and to research carried out by faculty. Topics vary each year. Each member of the department addresses their particular specialty. Interested undergraduates may take this seminar in their junior or senior year. Must be taken pass/fail.

Credit 1 unit. A&S IQ: NSM Art: NSM

L31 Physics 499 Honors Program

Prerequisites: junior standing, an average grade of B or better, and permission of the chair of the department. Program and credit to be determined; maximum 6 units.

Credit variable, maximum 3 units. Art: NSM
