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 intending 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; 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 advisor, 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 191–Physics 192 and Physics 191L–Physics 192L 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 191 Physics I 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.

Focused Physics: The Physics 193–Physics 194 and Physics 193L–Physics 194L sequence is an advanced calculus-based introduction to physics for students with previous or concurrent enrollment in Calculus II (Math 132). This sequence is particularly addressed to students considering a physics- or mathematics-heavy science or engineering major.

The department also 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

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Wayman Crow Professor of Physics
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Experimental high-energy astrophysics

Associate Chair

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Majors

The Major in Physics

Required introductory courses: Majors in physics are required to complete a series of introductory courses.

They may take either:

Code	Title	Units
Physics 191	Physics I	3
Physics 191L	Physics I Laboratory	1
Physics 192	Physics II	3
Physics 192L	Physics II Laboratory	1

or (recommended for majors):

Code	Title	Units
Physics 193	Focused Physics I	4
Physics 193L	Focused Physics I Laboratory	1
Physics 194	Focused Physics II	4
Physics 194L	Focused Physics II Laboratory	1

Required courses: In addition, majors in physics are required to complete the following courses:

Code	Title	Units
Physics 217	Introduction to Quantum Physics	3
Physics 322	Physical Measurement Laboratory	3
Physics 411	Mechanics	3
Physics 421	Electricity and Magnetism	3

One additional upper-level laboratory course, chosen from the following:

Code	Title	Units
Physics 316	Optics and Wave Physics Laboratory	3
Physics 321	Electronics Laboratory	3
Physics 360	Biophysics Laboratory	3
Physics 427	Introduction to Computational Physics	3
Physics 435	Nuclear and Radiochemistry Lab	3

Upper-level courses: Majors are required to complete a minimum of 21 units of advanced courses (300 level or higher) in Physics, excluding Physics 341, Physics 342, Physics 441, Physics 442, Physics 499 and Physics 500. These 21 units may include courses listed above and may also include *one* upper level engineering class chosen from the following:

Code	Title	Units
ESE 351	Signals and Systems	3
ESE 429	Basic Principles of Quantum Optics and Quantum Information	3
ESE 436	Semiconductor Devices	3
ESE 438	Applied Optics	3
ESE 441	Control Systems	3
ESE 482	Digital Signal Processing	3
ESE 531	Nano and Micro Photonics	3
ESE 532	Introduction to Nano-Photonic Devices	3
ESE 582	Fundamentals and Applications of Modern Optical Imaging	3
MEMS 3410	Fluid Mechanics	3

Students must receive letter grades for these advanced courses, and the course must be completed with a grade of at least a C-.

Math courses required for the physics major:

Code	Title	Units
Math 131	Calculus I	3
Math 132	Calculus II	3
Math 217	Differential Equations	3
Math 233	Calculus III	3

Students who have completed Math 203 Honors Mathematics I and Math 204 Honors Mathematics II will have fulfilled the requirement for Math 131 Calculus I, Math 132 Calculus II, and Math 233 Calculus III.

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 Electricity and Magnetism.)
- Math 309 Matrix Algebra (We recommend that this course precede Physics 474 Introduction to Particle Physics.)
- Physics 501 Theoretical Physics/Math 501C Theoretical Physics and Physics 502 Methods of Theoretical Physics II/Math 502C Methods of Theoretical Physics II 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 103 Advanced Placement Chemistry I, Chem 104 Advanced Placement Chemistry II, Chem 105 Introductory General Chemistry I, Chem 106 Introductory General Chemistry II, Chem 111A General Chemistry I, Chem 112A General Chemistry II, Chem 401 Physical Chemistry I or Chem 402 Physical Chemistry II.

Code	Title	Units
Biol 2960	Principles of Biology I	4
Biol 2970	Principles of Biology II	4
Chem 103	Advanced Placement Chemistry I	3
Chem 104	Advanced Placement Chemistry II	3
Chem 105	Introductory General Chemistry I	3
Chem 106	Introductory General Chemistry II	3
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
CSE 247	Data Structures and Algorithms	3
EEPS 202	Introduction to Earth, Environmental, and Planetary Science	3

Students who have received credit for Chem 103 Advanced Placement Chemistry I and Chem 104 Advanced Placement Chemistry II can use them toward the science-breadth requirement.

Biophysics Track

Physics majors may concentrate in the subfield of biophysics by taking the following (as part of their distribution requirement):

Physics requirement:

Code	Title	Units
Physics 463	Statistical Mechanics and Thermodynamics	3

One of the following:

Code	Title	Units
Physics 350	Physics of the Brain	3
or Physics 450	Physics of the Brain	
Physics 355	Physics of Vision	3
or Physics 455	Physics of Vision	

One of the following:

Code	Title	Units
Physics 354	Physics of Living Systems	3
or Physics 454	Physics of Living Systems	
Physics 453	Topics in Theoretical Biophysics	3
Physics 481	Critical Analysis of Scientific Data	3
Physics 509	Nonlinear Dynamics	3
Physics 563	Topics in Theoretical Biophysics	3

Biology requirements:

Code	Title	Units
Biol 2960	Principles of Biology I	4
Biol 2970	Principles of Biology II	4

Note: Students who want to have the biophysics track displayed on their transcript must inform the Department of Physics (https://physics.wustl.edu/biophysics-track-declaration-form/) at least one semester before their graduation date. Contact the Director of Undergraduate Studies (dus@physics.wustl.edu) with any questions.

The Major in Astrophysics

Required introductory courses: Majors in astrophysics are required to complete a series of introductory courses.

They may take either:

Code	Title	Units
Physics 191	Physics I	3
Physics 191L	Physics I Laboratory	1
Physics 192	Physics II	3
Physics 192L	Physics II Laboratory	1

or (recommended for majors):

Code	Title	Units
Physics 193	Focused Physics I	4
Physics 193L	Focused Physics I Laboratory	1
Physics 194	Focused Physics II	4
Physics 194L	Focused Physics II Laboratory	1

Required courses: In addition, majors in astrophysics are required to complete the following courses:

Code	Title	Units
Physics 217	Introduction to Quantum Physics	3
Physics 312	Introduction to Astrophysics	3
Physics 322	Physical Measurement Laboratory	3
Physics 411	Mechanics	3
Physics 421	Electricity and Magnetism	3

One additional laboratory course must be chosen from the following:

Code	Title	Units
Physics 316	Optics and Wave Physics Laboratory	3
Physics 321	Electronics Laboratory	3
Physics 427	Introduction to Computational Physics	3
Physics 435	Nuclear and Radiochemistry Lab	3

Required advanced courses: In addition to the above requirements, students who are earning the astrophysics major are required to complete three advanced electives (300 level and above). Students who declare an astrophysics major *and* who complete both Physics 125A Solar System Astronomy and Physics 126A Stars, Galaxies and Cosmology will be required to complete two advanced electives (300 level and above). They will choose courses from the following list. Students must receive letter grades for these advanced courses, and the course must be completed with a grade of at least a C-.

Code	Title	Units
Physics 446	Galactic Astrophysics	3
Physics 456	Stellar Astrophysics	3
Physics 460	X-Ray & Gamma-Ray Astrophysics	3
Physics 476	Astrophysics	3
Physics 478	From Black Holes to the Big Bang	3
Physics 3330	Planets and Life in the Universe	3

They must also complete one additional course from the preceding list of five courses or one from the following list of courses:

Code	Title	Units
EEPS 353	Earth Forces	4
EEPS 407	Remote Sensing	3
Physics 422	Electricity and Magnetism II	3
Physics 474	Introduction to Particle Physics	3
Physics 477	Physics of Finite and Infinite Nuclear Systems	3
Physics 547	Intro to Elementary Particle Physics	3
Physics 558	Relativistic Astrophysics	3
MEMS 3410	Fluid Mechanics	3

Math courses required for the astrophysics major:

Code	Title	Units
Math 131	Calculus I	3
Math 132	Calculus II	3
Math 217	Differential Equations	3
Math 233	Calculus III	3

Students who have completed Math 203 Honors Mathematics I and Math 204 Honors Mathematics II will have fulfilled the requirement for Math 131 Calculus I, Math 132 Calculus II, and Math 233 Calculus III.

Science-breadth requirement: Majors must select one of the following courses to satisfy the science-breadth requirement:

Code	Title	Units
Chem 105	Introductory General Chemistry I	3
Chem 106	Introductory General Chemistry II	3
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
CSE 247	Data Structures and Algorithms	3
EEPS 202	Introduction to Earth, Environmental, and Planetary Science	3

Students who have received credit for Chem 103 Advanced Placement Chemistry I and Chem 104 Advanced Placement Chemistry II may use them toward the science-breadth requirement.

Additional Information

Senior Honors: Students are encouraged to work toward Latin honors (http://bulletin.wustl.edu/undergrad/artsci/honors/) (i.e., cum laude, magna cum laude, and 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 of their 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 March deadline. 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 grade point average cutoffs as Latin honors (http://bulletin.wustl.edu/undergrad/artsci/honors/) but are calculated exclusively from the grades in physics courses (i.e., 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; these distinctions are limited to the top 15% (highest distinction) and the top 15% to 50% (high distinction) of the physics majors in their senior year as ranked by their GPA in the physics courses. Students who meet the GPA cutoff but who do not undertake undergraduate research and a senior thesis may only receive the third level of distinction.

Minors

The Minor in Physics

Required introductory courses: Minors in physics are required to complete a series of introductory courses.

They may take either:

Code	Title	Units
Physics 191	Physics I	3
Physics 191L	Physics I Laboratory	1
Physics 192	Physics II	3
Physics 192L	Physics II Laboratory	1

or:

Code	Title	Units
Physics 193	Focused Physics I	4
Physics 193L	Focused Physics I Laboratory	1
Physics 194	Focused Physics II	4
Physics 194L	Focused Physics II Laboratory	1

Required courses: In addition, minors in physics are required to complete the following courses:

Code	Title	Units
Physics 217	Introduction to Quantum Physics	3
Physics 318	Introduction to Quantum Physics II	3

Elective courses: Minors must take at least one additional course at the 300 level or above (with the exception of Physics 341 Selected Topics in Physics III, Physics 342 Selected Topics in Physics III, Physics 441 Selected Topics in Physics IV, Physics 442 Selected Topics in Physics IV, Physics 499 Honors Program and Physics 500 Independent Work) with a grade of C- or better.

The Minor in Astrophysics and Astroparticle Physics

Required introductory courses: Minors in astrophysics and astroparticle physics are required to complete a series of introductory courses.

They may take either:

Code	Title	Units
Physics 191	Physics I	3
Physics 191L	Physics I Laboratory	1
Physics 192	Physics II	3
Physics 192L	Physics II Laboratory	1

or:

Code	Title	Units
Physics 193	Focused Physics I	4
Physics 193L	Focused Physics I Laboratory	1
Physics 194	Focused Physics II	4
Physics 194L	Focused Physics II Laboratory	1

Required courses: In addition, minors in astrophysics and astroparticle physics are required to complete the following courses:

Code	Title	Units
Physics 217	Introduction to Quantum Physics	3
Physics 312	Introduction to Astrophysics	3

Minors must also take two of the following eight courses:

Code	Title	Units
Physics 319	Quantum Theory of Matter	3
Physics 446	Galactic Astrophysics	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
Physics 3330	Planets and Life in the Universe	3

The Minor in Biomedical Physics

This minor is for students interested in the discussion and application of methods and techniques from physics to topics in the areas of biology and medicine. The program may be of interest to the pre-medicine student or the research-oriented science major.

Required courses: Minors in biomedical physics are required to complete a series of introductory courses.

They may take either:

Code	Title	Units
Physics 191	Physics I	3
Physics 191L	Physics I Laboratory	1
Physics 192	Physics II	3
Physics 192L	Physics II Laboratory	1

or:

Code	Title	Units
Physics 193	Focused Physics I	4
Physics 193L	Focused Physics I Laboratory	1
Physics 194	Focused Physics II	4
Physics 194L	Focused Physics II Laboratory	1

Elective courses: Minors must take two of the following five courses:

Code	Title	Units
Physics 350	Physics of the Brain	3
Physics 354	Physics of Living Systems	3
Physics 355	Physics of Vision	3
Physics 453	Topics in Theoretical Biophysics	3
Physics 481	Critical Analysis of Scientific Data	3

They must also take one of 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

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 1001 First-Year Seminar: All About Black Holes
Black holes are the Universe's most extreme objects: they are so massive and compact that gravity bends space and time into a knot. The signature property of a black hole is that your can get in, but not out. In this first-year seminar, we discuss what is currently known about black holes, starting from Einstein's theories about space, time, and gravity, through the first observational evidence for black holes, to the latest images of the shadows cast by black holes taken with the largest telescopes on earth. This class is designed to bend your mind when figuring out why clocks run slower when approaching the edge of a black hole, what could be at the center of a black hole or even at the other side. At the same time, we will discuss the inner workings of the most advanced telescopes that astronomers have developed to study black holes, and the strategies astronomers employ to develop ever more sensitive instruments. Also expect a fair bit of astronomy in this class, when we discuss how black holes form, when and how they grow, and which roles they play in cosmic eco-systems such as the Milky Way Galaxy. This first-year seminar adopts a flipped class/socratic discussion structure. The students are asked to read a wide variety of texts, including texts from the current literature, and to present and to discuss some of the material in class. The class assumes no background in math; at the same time, we will discuss some of the math that brings Einstein's theories of space and time to life.
Credit 3 units. A&S: FYS A&S IQ: NSM, AN Art: NSM

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 Arch: NSM 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 130 Introduction to Mathematical and Computational Methods in Physics
This is a learning by doing course whose objective is for the students to learn practical methods for solving physics problems using mathematical and computational tools. The course gives an introduction to applied mathematics and basic computational tools and techniques used in contemporary scientific fields of research. The format of the course is highly interactive. Each course unit will be devoted to a specific activity, including a lecture from the instructor, working groups on solving analytical problems, and working groups on coding with Python. Prerequisite: Previous or concurrent Calculus I is recommended.
Credit 3 units. A&S IQ: NSM, AN Arch: NSM Art: NSM

L31 Physics 141 Selected Topics in Physics I
Topics of special interest (e.g., superconductivity, quasicrystals, neural networks, chaos) 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 apply for approval using the Physics independent study web form (https://physics.wustl.edu/independent-study/).
Credit variable, maximum 3 units. A&S IQ: NSM Arch: 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) 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 apply for approval using the Physics independent study web form (https://physics.wustl.edu/independent-study/).
Credit variable, maximum 3 units. A&S IQ: NSM Art: NSM BU: SCI

L31 Physics 173 Physics of Sustainable Energy
Introduction to the physics of climate change and sustainable energy. This course is intended for students with little previous exposure to science or math. We will learn about the value of rough estimates and simple calculations. We will apply this approach to energy and power; atoms and heat; the history and basic modeling of earth's climate; energy sources including fossil fuels, nuclear, and renewables. No prerequisites.
Credit 3 units. A&S IQ: NSM, AN Arch: NSM Art: NSM BU: SCI EN: SU

L31 Physics 191 Physics I
This is a calculus-based introduction to the concepts, laws, and structure of physics. Topics include kinematics, Newton's laws, energy, linear momentum, angular momentum, the conservation laws, gravitational force, harmonic motion, wave motion and interference, sound, 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. Prerequisite: Previous or concurrent enrollment in Calculus I (Math 131) is required; previous or concurrent enrollment in Calculus II (Math 132) us strongly recommended. Students may not receive credit for more than one of Physics 117A, Physics 191, and Physics 197.
Credit 3 units. A&S IQ: NSM, AN Arch: NSM Art: NSM BU: SCI

L31 Physics 191F Physics I — First-Years Only
This section of Physics 191 is for rising first-year students only. Any non-first-year students enrolled in this section will be removed from the course. Non-first-year students should enroll in Physics 191U. This is a calculus-based introduction to the concepts, laws, and structure of physics. Topics include kinematics, Newton's laws, energy, linear momentum, angular momentum, the conservation laws, gravitational force, harmonic motion, wave motion and interference, sound, and special relativity. Two evening exams are required, followed by a required final exam. Prerequisite: Previous or concurrent enrollment in Calculus I (Math 131) is required; previous or concurrent enrollment in Calculus II (Math 132) is strongly recommended. A combination of Physics 191 and Physics 191L is a replacement for Physics 197. Students may not receive credit for more than one of Physics 117A, Physics 191, and Physics 197.
Credit 3 units. A&S IQ: NSM, AN Arch: NSM Art: NSM BU: SCI

L31 Physics 191L Physics I Laboratory
Laboratory experience is an integral component of introductory physics. It is designed to provide a hands-on opportunity to explore concepts introduced in the lecture course and to develop careful measurement and documentation skills. Prerequisite/corequisite: Physics 191. Students may not receive credit for Physics 191L if they have already received credit for Physics 117A or 197.
Credit 1 unit. Arch: NSM

L31 Physics 191U Physics I — Sophomores, Juniors, and Seniors Only
This section of Physics 191 is for rising seniors, juniors, and sophomores only. Any first-year student enrolled in this section will be removed from the course. First-year students should enroll in Physics 191F. This is a calculus-based introduction to the concepts, laws, and structure of physics. Topics include kinematics, Newton's laws, energy, linear momentum, angular momentum, the conservation laws, gravitational force, harmonic motion, wave motion and interference, sound, and special relativity. Two evening exams are required, followed by a required final exam. Prerequisite: Previous or concurrent enrollment in Calculus I (Math 131) is required; previous or concurrent enrollment in Calculus II (Math 132) is strongly recommended. A combination of Physics 191 and Physics 191L is a replacement for Physics 197. Students may not receive credit for more than one of Physics 117A, Physics 191, and Physics 197.
Credit 3 units. A&S IQ: NSM, AN Arch: NSM Art: NSM BU: SCI

L31 Physics 192 Physics II
Continuation of Physics 191. Calculus-based introduction to concepts, laws, and structure of physics. Topics include electromagnetic forces and fields, direct current circuits, capacitance and inductance, electromagnetic radiation, light, physical optics, interference and diffraction, early quantum theory, and nuclear physics. 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. Prerequisite: Physics 191, Physics 193 and Calculus I (Math 131); previous or concurrent enrollment in Calculus II (Math 132) is very strongly recommended. Students may not receive credit for more than one of Physics 118A, Physics 192, and Physics 198.
Credit 3 units. A&S IQ: NSM, AN BU: SCI

L31 Physics 192L Physics II Laboratory
Laboratory experience is an integral component of Introductory Physics. It is designed to provide a hands-on opportunity to explore concepts introduced in the lecture course and to develop careful measurement and documentation skills. Prerequisite/Corequisite: Physics 192. Students who have taken Physics 118 or Physics 198 may not receive credit for Physics 192L.
Credit 1 unit.

L31 Physics 193 Focused Physics I
Physics 193 is the first part of a two-semester calculus-based introduction to physics. The course is an advanced first-year course in classical mechanics, taught at a more sophisticated level than Physics 191. The approach is that of an upper-division physics course, with more emphasis on underlying formal structure rather than breadth of topics. The main goal is to provide in-depth coverage of the physical laws that govern the motion of objects, forces, and forms of energy in mechanical systems as well as an introduction to special relativity. The course is particularly addressed to students considering a physics- or mathematics-heavy science or engineering major. Corequisite: Math 132 or equivalent.
Credit 4 units. A&S IQ: NSM, AN Arch: NSM Art: NSM BU: SCI

L31 Physics 193L Focused Physics I Laboratory
Laboratory experience is an integral component of Introductory Physics. It is designed to provide a hands-on opportunity to explore concepts introduced in the lecture course and to develop careful measurement and documentation skills. Required prerequisite or co-requisite: Physics 191. Students may not receive credit for Physics 191L if they have already received credit for 117A or 197
Same as L31 Physics 191L
Credit 1 unit. Arch: NSM

L31 Physics 194 Focused Physics II
Physics 194 is the second part of a two-semester calculus-based introduction to physics, with a co-requisite of Calculus III (Math 233 or its equivalent). The course is an advanced first-year course in electricity and magnetism, taught at a more sophisticated level than Physics 192. The approach is that of an upper-division physics course, with more emphasis on the underlying formal structure, rather than breadth of topics. The main goal is to provide an in-depth coverage of electromagnetism, DC and AC circuits using complex variables, and optics. The course is particularly addressed to students considering a physics or mathematics heavy science/engineering majors
Credit 4 units. A&S IQ: NSM, AN BU: SCI

L31 Physics 194L Focused Physics II Laboratory
Laboratory experience is an integral component of Introductory Physics. It is designed to provide a hands-on opportunity to explore concepts introduced in the lecture course and to develop careful measurement and documentation skills. Prerequisite/Corequisite: Physics 192. Students who have taken Physics 118 or Physics 198 may not receive credit for Physics 192L.
Same as L31 Physics 192L
Credit 1 unit.

L31 Physics 205 General Physics I
This course is the first semester of a two-semester, calculus-based introductory physics course. In this semester, we will study the principles of Newtonian mechanics and their application to various physical systems. The material we learn this semester will serve as a basis for topics we will study in the second semester, such as electromagnetism. The aim of this course is to give you a robust introduction to the fundamentals of physics. Studying physics will also give you a better insight into other subjects like chemistry. The analytic techniques we develop will have a wide range of availability. Prerequisite: previous or concurrent enrollment in Calculus I.
Credit 3 units. A&S IQ: AN BU: SCI

L31 Physics 205L General Physics I Lab
The laboratory experience is an integral component of Introductory Physics. It is designed to provide a hands-on opportunity to explore concepts introduced in the lecture course and to develop careful measurement and documentation skills. Prerequisite or Corequisite: Physics 205.
Credit 1 unit.

L31 Physics 206 General Physics II
Phys 206 is the second semester of a two semester, calculus-based introductory physics course. In this semester, we build on what we learned in the first semester to explore more advanced topics like electromagnetism and optics. A strong understanding of the topics covered in Phys 205 is essential for this semester. The aim of this course is to give you a robust introduction to the fundamentals of physics. Studying physics will also give you a better insight into other subjects like chemistry. The analytic techniques we develop will have a wide range of availability. Prerequisite - Physics 205. Previous or concurrent in Calc II is recommended.
Credit 3 units. A&S IQ: NSM, AN Arch: NSM Art: NSM BU: SCI

L31 Physics 206L General Physics II Lab
Laboratory experience is an integral component of Introductory Physics. It is designed to provide a hands-on opportunity to explore concepts introduced in the lecture course and to develop careful measurement and documentation skills. Required prerequisite or co-requisite: General Physics II.
Credit 1 unit. 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: Phys 191, Phys 193, Phys 197, or permission of 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: Phys 191-192 or Phys 193-194 or Phys 197-198 or Phys 205-206.
Credit 3 units. A&S IQ: NSM, AN Arch: 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) 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 apply for approval using the Physics independent study web form (https://physics.wustl.edu/independent-study/).

Credit variable, maximum 3 units. A&S IQ: NSM Arch: 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. Prerequisites: Physics 191 and 192 or Physics 193 and 194 or Physics 197 and 198 or permission of instructor.
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM BU: SCI

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 319 Quantum Theory of Matter
Students will learn how to apply quantum mechanics principles to atomic and molecular physics, solid-state physics, nuclear physics, and particle physics. A portion of the course will also be devoted to introducing Dirac notation and discussing its applications to simple systems.
Credit 3 units. A&S IQ: NSM, AN

L31 Physics 321 Electronics Laboratory
Elements of linear and nonlinear circuits, amplifiers, feedback, with applications in experimental physics. Prerequisite: Phys 192, Phys 194, Phys 198, Phys 206, or permission of instructor. Two three-hour laboratories and two one-hour lectures per week.
Credit 3 units. A&S IQ: NSM, AN Arch: NSM Art: NSM BU: SCI EN: BME T, 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 3330 Planets and Life in the Universe
In this course, we will explore the history, methods, outcomes, and broad impacts of exoplanet research and how these are connected to our search for life beyond planet Earth. Following an engaging contextual introduction at the beginning of the lectures, topics will be presented with an accessible mathematical treatment (e.g., geometrical derivations of the two-body transit problem). Prerequisite: Physics 191 and 192 or Physics 193 and 194.
Credit 3 units. A&S IQ: NSM, AN Art: NSM

L31 Physics 341 Selected Topics in Physics III
Topics of special interest (e.g., superconductivity, quasicrystals, neural networks, chaos) 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 apply for approval using the Physics independent study web form (https://physics.wustl.edu/independent-study/).
Credit variable, maximum 3 units. A&S IQ: NSM Arch: 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) 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 apply for approval using the Physics independent study web form (https://physics.wustl.edu/independent-study/).
Credit variable, maximum 3 units. A&S IQ: NSM Arch: NSM Art: NSM 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: Phys 191-192 or Phys 193-194 or Phys 197-198 or Phys 205-206, or permission of the instructor.
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM BU: SCI EN: BME T, 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. Prerequisites: Physics 191-192 or Phys 193-194 or Physics 197-198 or Phys 205-206.
Credit 3 units. Arch: NSM Art: NSM BU: SCI EN: BME T, 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: Prerequisites: Physics 191-192 or Phys 193-194 or Physics 197-198 or Phys 205-206. Some familiarity with thermodynamics and Chemistry 111A-112A recommended.
Credit 3 units. A&S IQ: NSM, AN Arch: NSM

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 191-192 or Phys 193-194 or Physics 197-198 or Phys 205-206, or Math 217 or Math 309, or permission of instructor.
Credit 3 units. A&S IQ: NSM Arch: NSM BU: SCI EN: BME T, TU

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 Arch: NSM Art: NSM BU: SCI EN: BME T, 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: Physics 191-192 or Phys 193-194 or Physics 197-198 or Phys 205-206 or permission of instructor.
Credit 3 units. A&S IQ: NSM, AN Arch: NSM Art: NSM

L31 Physics 400 Physical Science in 12 Problems
Exercises related to general chemistry, classical mechanics, quantum mechanics, statistical mechanics, thermodynamics, and kinetics, will be solved with numerical software. Each exercise will be accompanied by a lecture, a software template solving a problem and presenting a related take-home problem. The software will allow us to focus on, and treat in a transparent fashion, physical problems without the unworldly idealizations and contrivances found in textbooks. Prerequisites: General Chemistry and/or Physics, and prior or concurrent enrollment in either Chem 401 or Phys 217. The lectures will be in person; however, a complete set of taped lectures will also be available. A remote help session will be scheduled at a mutually agreed-upon time. There are no quizzes, exams or a final.
Same as L07 Chem 400
Credit 1 unit. A&S IQ: NSM Arch: NSM Art: NSM

L31 Physics 411 Mechanics
Motion of a point particle, rotational motion, oscillation, gravitation and central forces, Lagrangian and Hamiltonian formulation. Prerequisites: Physics 191-192 or Phys 193-194 or Physics 197-198 or Phys 205-206, 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 191-192 or Phys 193-194 or Physics 197-198 or Phys 205-206, Math 217, or permission of instructor.
Credit 3 units. A&S IQ: NSM, AN Arch: NSM Art: NSM BU: SCI EN: BME T, 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: BME T, DU, SU, TU

L31 Physics 427 Introduction to Computational Physics
What does it mean to solve a research problem using a computer? What is the difference between "someone ran a simulation" and an interesting research result? And what skills does it take? Familiarity with a programming language is, of course, essential, but that is only the beginning. This course will focus on the methodology of computational research, touching also on topics in numerical analysis, statistics and visualization. The format will combine lectures and hands-on experience, with emphasis on research-style small-group projects. Prerequisites: Physics 191-192 or Phys 193-194 or Physics 197-198 or Phys 205-206, Calculus, and familiarity with a programming language.
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L31 Physics 435 Nuclear and Radiochemistry Lab
Application of radiochemistry to problems in chemistry, physics, and nuclear medicine, with emphasis on particle detectors and experimental techniques. Prerequisites: 3 units of physical chemistry or quantum mechanics, or 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 interaction of radiation with mater, the production and decay of radioactive nuclides, the structure and properties of nuclei, and various applications of nuclear science (including nuclear power) are all presented. Prerequisites: General Chemistry and/or Physics, and prior or concurrent enrollment in either Chem 401 or Physics 217. Lectures will be in person (if allowed), but a complete set of taped lectures will also be available. A weekly (in-person or remote) help session will be scheduled at a mutually agreed-upon time. There will be about six timed quizzes, one midterm, and one final, all of which must be taken in person on mutually agreed-upon dates.
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) 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 apply for approval using the Physics independent study web form (https://physics.wustl.edu/independent-study/).
Credit variable, maximum 3 units. A&S IQ: NSM Arch: 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) 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 apply for approval using the Physics independent study web form (https://physics.wustl.edu/independent-study/).
Credit variable, maximum 3 units. A&S IQ: NSM Arch: NSM Art: NSM

L31 Physics 446 Galactic Astrophysics
In these lectures, the focus is on the dynamics and statistical mechanics of a collection of stars, which is 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, galaxy formation, and dark matter will constitute the final topics of discussion.
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM BU: SCI

L31 Physics 450 Physics of the Brain
Contents are the same as Phys 350. Also intended for graduate students. Includes a more sophisticated term project than Phys 350. Prerequisites: Physics 191-192 or Phys 193-194 or Physics 197-198 or Phys 205-206 or permission of instructor.
Credit 3 units. A&S IQ: NSM Arch: NSM Art: NSM BU: SCI EN: BME T, SU, TU

L31 Physics 453 Topics in Theoretical Biophysics
Application of a range of physical models to biological systems. Topics include protein folding, self-assembling molecular systems, and mechanical properties of biological materials. Background material will be provided, but some exposure to statistical mechanics or thermodynamics is necessary. Prerequisite: experience with ordinary differential equations (as in Mathematics 217).
Credit 3 units. A&S IQ: NSM BU: SCI

L31 Physics 454 Physics of Living Systems
Contents are the same as Phys 354. Graduate students will explore the subject in more depth. Prerequisites: Physics 191-192 or Phys 193-194 or Physics 197-198 or Phys 205-206, or Math 217 or Math 309, or permission of instructor.
Credit 3 units. A&S IQ: NSM Arch: NSM EN: TU

L31 Physics 455 Physics of Vision
Contents are the same as Phys 355. Also intended for graduate students. Includes a more sophisticated term project than Phys 355. Prerequisite: Physics 191, Phys 193, Phys 197, Phys 206, or permission of instructor.
Credit 3 units. A&S IQ: NSM Arch: 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 Arch: 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 Arch: NSM 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 Arch: NSM Art: NSM EN: BME T, 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 217.
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 Arch: 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. Prerequisite: Physics 318, Physics 471, or permission of instructor.
Credit 3 units. A&S IQ: NSM Arch: 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 Arch: NSM Art: NSM

L31 Physics 481 Critical Analysis of Scientific Data
Data science is most commonly associated with topics in computer science. However, efficient algorithms, specific software packages, neural nets, and so on are only tools, and they are easily misused. In a research setting, working with data is primarily an exercise in critical thinking. The purpose of this interactive, hands-on course is to learn from mistakes by making them in a safe environment. After covering/reviewing probability theory, Bayesian inference, elements of information theory, and random matrix theory, the course will focus on case studies of real-world biological data, such as quantitative imaging data, nextgeneration sequencing (metagenomics), and neural recordings. These modules will involve the critical reading of research papers and working through puzzle-based assignments. The primary modules will be supplemented by shorter presentations on topics chosen by students. Fair warning: This is explicitly not a course on "big data" or machine learning, although students may choose to explore some of these topics in their presentations (required for credit). Experience with MatLab or Python strongly encouraged or will need to be acquired during the course. Open to undergraduates with prior programming experience and a quantitative background (Phys 197/198, Math 203 or similar; contact instructor if unsure). Experience with data or statistics not required. Course mimics a research environment, and undergraduates considering an academic research track are especially encouraged.
Credit 3 units. Arch: NSM Art: NSM BU: SCI

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 Arch: NSM Art: NSM

L31 Physics 499 Honors Program
Prerequisites: junior standing, an average grade of B or better, and apply for approval using the Physics independent study web form https://physics.wustl.edu/independent-study. Program and credit to be determined; maximum 6 units.
Credit variable, maximum 3 units.