# AS.171 (PHYSICS & ASTRONOMY)

**AS.171.101. General Physics: Physical Science Major I. 4 Credits.**
First semester of a two-semester sequence in general physics covers mechanics, heat, sound, electricity and magnetism, optics, and atomic physics. Midterm exams for every section are given during the 8 AM section time! Accordingly, students registering for sections at times other than 8 AM must retain availability for 8 AM sections as needed. Corequisite: AS.110.108-AS.110.109, AS.173.111-AS.173.112
Area: Engineering, Natural Sciences

**AS.171.102. General Physics: Physical Science Major II. 4 Credits.**
Second semester of a two-semester sequence in general physics covers mechanics, heat, sound, electricity and magnetism, optics, and atomic physics. Midterm exams for every section are given during the 8 AM section time! Accordingly, students registering for sections at times other than 8 AM must retain availability for 8 AM sections as needed. Recommended Course Background: A grade of C- or better in either Physics I or the first semester of Intro to Mechanics I ( AS.171.101 OR AS.171.103 OR AS.171.105 OR AS.171.107 OR EN.530.103 )
Area: Engineering, Natural Sciences

**AS.171.103. General Physics I for Biological Science Majors. 4 Credits.**
First-semester of two-semester sequence in calculus-based general physics, tailored to students majoring in one of the biological sciences. In this term, the topics covered include the basic principles of classical mechanics and fluids as well as an introduction to wave motion. Recommended Corequisites: (AS.173.111) AND (AS.110.106 or AS.110.108 or AS.110.113).Midterm exams are given at 8am Tuesdays, so students must leave their schedules open at this time in order to be able to take these exams
Area: Engineering, Natural Sciences

**AS.171.104. General Physics/Biology Majors II. 4 Credits.**
This two-semester sequence is designed to present a standard calculus-based physics preparation tailored to students majoring in one of the biological sciences. Topics in electricity & magnetism, optics, and modern physics will be covered in this semester. Midterm exams for every section are given during the 8 AM section time! Accordingly, students registering for sections at times other than 8 AM must retain availability for 8 AM sections as needed. Recommended Course Background: C- or better in AS.171.101 or AS.171.103; Corequisite: AS.110.109, AS 173.112.
Area: Engineering, Natural Sciences

**AS.171.105. Classical Mechanics I. 4 Credits.**
An in-depth introduction to classical mechanics intended for physics majors/minors and other students with a strong interest in physics. This course treats fewer topics than AS.171.101 and AS.171.103 but with greater mathematical sophistication. It is particularly recommended for students who intend to take AS.171.201-AS.171.202 or AS.171.309-AS.171.310. Recommended Corequisites: AS.173.115 and AS.110.108
Area: Engineering, Natural Sciences

**AS.171.106. Electricity and Magnetism I. 4 Credits.**
Classical electricity and magnetism with fewer topics than 171.101-103, but with greater mathematical sophistication. Particularly recommended for students who plan to take AS.171.201-AS.171.202. Recommended Course Background: C- or better in AS.171.105; Corequisite: AS.173.116, AS.110.109
Area: Engineering, Natural Sciences

**AS.171.107. General Physics for Physical Sciences Majors (AL). 4 Credits.**
This two-semester sequence in general physics is identical in subject matter to AS.171.101-AS.171.102, covering mechanics, heat, sound, electricity and magnetism, optics, and modern physics, but differs in instructional format. Rather than being presented via lectures and discussion sections, it is instead taught in an 'active learning' style with most class time given to small group problem-solving guided by instructors. Midterm exams for every section are given during the 8 AM section time! Accordingly, students registering for sections at times other than 8 AM must retain availability for 8 AM sections as needed. Recommended Corequisites: (AS.173.111) AND (AS.110.106 or AS.110.108 or AS.110.113)
Area: Engineering, Natural Sciences

**AS.171.108. General Physics for Physical Science Majors (AL). 4 Credits.**
This two-semester sequence in general physics is identical in subject matter to AS.171.101-AS.171.102, covering mechanics, heat, sound, electricity and magnetism, optics, and modern physics, but differs in instructional format. Rather than being presented via lectures and discussion sections, it is instead taught in an 'active learning' style with most class time given to small group problem-solving guided by instructors. Recommended Course Background: A grade of C- or better in either Physics I or the first semester of Engineering Mechanics ( AS.171.101 OR AS.171.103 OR AS.171.105 OR AS.171.107 OR EN.530.103 )
Area: Engineering, Natural Sciences

**AS.171.113. Subatomic World. 3 Credits.**
Introduction to the concepts of physics of the subatomic world: symmetries, relativity, quanta, neutrinos, particles and fields. The course traces the history of our description of the physical world from the Greeks through Faraday and Maxwell to quantum mechanics in the early 20th century and on through nuclear physics and particle physics. The emphasis is on the ideas of modern physics, not on the mathematics. Intended for non-science majors.
Area: Natural Sciences

**AS.171.118. Stars and the Universe: Cosmic Evolution. 3 Credits.**
This course looks at the evolution of the universe from its origin in a cosmic explosion to emergence of life on Earth and possibly other planets throughout the universe. Topics include big-bang cosmology; origin and evolution of galaxies, stars, planets, life, and intelligence; black holes; quasars; and relativity theory. The material is largely descriptive, based on insights from physics, astronomy, geology, chemistry, biology, and anthropology.
Area: Natural Sciences

**AS.171.125. It's not magic, it's physics: Extraordinary Experiments. 3 Credits.**
Students will learn key concepts of everyday physics through experimentation. They will design, build, and run experiments themselves. The course will be graded on participation and a graded final presentation.
Area: Natural Sciences

**AS.171.133. Black Holes and Other Compact Objects: For Non-Majors. 3 Credits.**
This is a lecture and discussion course aimed at undergraduate students who are not physics and astronomy majors. The topic of the lectures will be a basic overview of the qualitative properties of and historical work on compact astrophysical objects (such as black holes, neutron stars, white dwarfs) and related phenomena.
Area: Natural Sciences

**AS.171.201. Special Relativity/Waves. 4 Credits.**
Course continues introductory physics sequence (begins with AS.171.105-AS.171.106). Special theory of relativity, forced and damped oscillators, Fourier analysis, wave equation, reflection and transmission, diffraction and interference, dispersion. Meets with AS.171.207.
Area: Engineering, Natural Sciences

**AS.171.202. Modern Physics. 4 Credits.**
Course completes four-semester introductory sequence that includes AS.171.105-AS.171.106 and AS.171.201. Planck's hypothesis, de Broglie waves, Bohr atom, Schrodinger equation in one dimension, hydrogen atom, Pauli exclusion principle, conductors and semiconductors, nuclear physics, particle physics.
Area: Natural Sciences

**AS.171.204. Classical Mechanics II. 4 Credits.**
Principles of Newtonian and Lagrangian mechanics; application to central-force motion, rigid body motion, and the theory of small oscillations. Recommended Course Background: AS.110.108 and AS.110.109, AS.110.202, AS.171.201, or AS.171.309. AS.110.201 or equivalent is strongly recommended.
Area: Natural Sciences

**AS.171.205. Introduction to Practical Data Science: Beautiful Data. 3 Credits.**
The class will provide an overview of data science, with an introduction to basic statistical principles, databases, fundamentals of algorithms and data structures, followed by practical problems in data analytics. Recommend Course Background: Familiarity with principles of computing.
Area: Natural Sciences, Quantitative and Mathematical Sciences

**AS.171.207. Special Relativity. 1 Credit.**
Three-week introduction to special relativity for students who elect to take AS.171.209 in place of AS.171.201.
Area: Natural Sciences

**AS.171.301. Electromagnetic Theory II. 4 Credits.**
Static electric and magnetic fields in free space and matter; boundary value problems; electromagnetic induction; Maxwell's equations; and an introduction to electrodynamics.
Area: Natural Sciences

**AS.171.303. Quantum Mechanics I. 4 Credits.**
Fundamental aspects of quantum mechanics. Uncertainty relations, Schrodinger equation in one and three dimensions, tunneling, harmonic oscillator, angular momentum, hydrogen atom, spin, Pauli principle, perturbation theory (time-independent and time-dependent), transition probabilities and selection rules, atomic structure, scattering theory. Recommended Course Background: AS.110.302 or AS.110.306.
**Prerequisite(s):** (AS.171.204 ) AND ( AS.110.201 OR AS.110.212 ) AND ( AS.110.202 OR AS.110.211 )
Area: Natural Sciences

**AS.171.304. Quantum Mechanics II. 4 Credits.**
Fundamental aspects of quantum mechanics. Uncertainty relations, Schrodinger equation in one and three dimensions, tunneling, harmonic oscillator, angular momentum, hydrogen atom, spin, Pauli principle, perturbation theory, transition probabilities and selection rules, atomic structure, scattering theory. Recommended Course Background: AS.171.303, AS.171.202, AS.171.204, AS.110.202.
Area: Natural Sciences

**AS.171.309. Wave Phenomena with Biophysical Application. 4 Credits.**
Introduction to wave phenomena, primarily through study of biophysical probes that depend on the interaction of electromagnetic radiation with matter. Topics include Fourier Analysis; standing waves; sound and hearing; diffraction and crystallography; geometrical and physical optics – the physics of modern light microscopy; quantum mechanics – how living things absorb light; NMR and MRI. Occasional laboratory exercises are included.
Area: Natural Sciences

**AS.171.310. Biological Physics. 4 Credits.**
Introduces topics of classical statistical mechanics. Additional topics include low-Reynolds number hydrodynamics and E&M of ionic solutions, via biologically relevant examples.
Area: Natural Sciences

**AS.171.312. Statistical Physics/Thermodynamics. 4 Credits.**
Undergraduate course that develops the laws and general theorems of thermodynamics from a statistical framework.
**Prerequisite(s):** Calculus II ( AS.110.107 or AS.110.109 or AS.110.113 ). It is recommended that students have also taken Quantum Mechanics (AS.171.303), Linear Algebra (AS.110.201 or AS.110.212) and Calculus III (AS.110.202 or AS.110.211)
Area: Natural Sciences

**AS.171.313. Introduction to Stellar Physics. 3 Credits.**
Survey of stellar astrophysics. Topics include stellar atmospheres, stellar interiors, nucleosynthesis, stellar evolution, supernovae, white dwarfs, neutron stars, pulsars, black holes, binary stars, accretion disks, protostars, and extrasolar planetary systems. Recommended Course Background: AS.110.108-AS.110.109, AS.171.202
Area: Natural Sciences

**AS.171.314. Introduction to Galaxies and Active Galactic Nuclei. 3 Credits.**
This course will introduce student to the physics of galaxies and their constituents: stars, gas, dust, dark matter and a supermassive black hole in the central regions.
Area: Natural Sciences

**AS.171.321. Introduction to Space, Science, and Technology. 3 Credits.**
Topics include space astronomy, remote observing of the earth, space physics, planetary exploration, human space flight, space environment, orbits, propulsion, spacecraft design, attitude control and communication. Crosslisted by Departments of Earth and Planetary Sciences, Materials Science and Engineering and Mechanical Engineering. Recommended Course Background: AS.171.101-AS.171.102 or similar; AS.110.108-AS.110.109.
Area: Engineering, Natural Sciences

**AS.171.324. Statistical thinking and data analysis. 3 Credits.**
We live in a data-rich world where the flux of information increases exponentially. We will learn how to think statistically and see patterns and structure in many systems around us: news reports, images, cities, social networks, etc. We will learn how to use this knowledge to make decisions and predictions. We will explore correlations, patterns, entropy, fractals. This course will allow students to better understand the complex world we live in. It involves some python coding. Junior, senior and graduate students only
Area: Natural Sciences

**AS.171.405. Condensed Matter Physics. 3 Credits.**
Undergraduate course covering basic concepts of condensed matter physics: crystal structure, diffraction and reciprocal lattices, electronic and optical properties, band structure, phonons, superconductivity and magnetism. Co-listed with AS.171.621Recommended Course Background: AS.171.304, AS.110.201-AS.110.202.
Area: Natural Sciences

**AS.171.406. Condensed Matter Physics. 3 Credits.**
Area: Natural Sciences

**AS.171.408. Nuclear and Particle Physics. 3 Credits.**
Basic properties of nuclei, masses, spins, parity. Nuclear scattering, interaction with electromagnetic radiation, radioactivity, Pions, muons, and elementary particles, including resonances. Recommended Course Background: AS.171.303
Area: Natural Sciences

**AS.171.410. Physical Cosmology. 3 Credits.**
This course provides an overview of modern physical cosmology. Topics covered include: the contents, shape, and history of the universe; the big bang theory; dark matter; dark energy; the cosmic microwave background; Hubble's law; the Friedmann equation; and inflation. Recommended Course Background: (AS.171.101-AS.171.102), or (AS.171.103-AS.171.104), or (AS.171.105-AS.171.106), or (AS.171.107-AS.171.108), or equivalent.
Area: Natural Sciences

**AS.171.411. Light and Optics. 3 Credits.**
What is light? How does it propagate and interact with matter? How do we use it to transmit information? How does technology make use of light? This course is designed for majors in physics as well as other science and engineering departments.
Area: Engineering, Natural Sciences

**AS.171.416. Numerical Methods for Physicists. 4 Credits.**
Area: Natural Sciences, Quantitative and Mathematical Sciences

**AS.171.425. Group Theory in Physics. 3 Credits.**
Introduction to finite and Lie groups, representations and applications to quantum mechanics, condensed matter physics, and other fields of physics; selected topics from differential geometry and algebraic topology.Recommended Prerequisite: AS.171.304
Area: Natural Sciences

**AS.171.430. Introduction to Quantum Field Theory. 3 Credits.**
Quantum Field Theory marries the principles of special relativity with quantum mechanics and provides a remarkably consistent description of a wide variety of phenomena, ranging from the theory of elementary particles to processes in condensed matter physics. It is an essential element in the toolkit of every physicist. In this course, we provide an introduction to this vast topic and aim to provide an intuitive understanding of this field. We will start by learning how to think about quantum mechanics in a manner consistent with special relativity (the Klein Gordon and Dirac equations), learn how to estimate relativistic quantum processes (Feynman diagrams), analyze nonsensical infinities that arise in these theories (Renormalization) and conclude with an overview of the Standard Model of Particle Physics (QCD and Electroweak theory). The course is aimed at introducing the student to how physicists think about these issues and it is a stepping stone to graduate study in this topic.
**Prerequisite(s):** AS.171.304
Area: Natural Sciences

**AS.171.501. Independent Research- Undergraduate. 3 Credits.**
Students may register for independent research with a faculty member in the Department of Physics and Astronomy. A research plan should be sent to the Director of Undergraduate Study before the add/drop date that includes project details, the number of hours of effort each week and the number of credits. This course may not be used for one of the two electives required for a BA, but one semester of research may be used as one of four focused electives in a BS program.
**Prerequisite(s):** You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.

**AS.171.502. Undergraduate Independent Research. 0 - 3 Credits.**
Research done in senior year in conjunction with experimental equipment of intermediate laboratory or as special project in research group. Credit for independent study given to junior and senior students who act as tutors.
**Prerequisite(s):** You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.

**AS.171.503. Senior Thesis. 3 Credits.**
Preparation of a substantial thesis based upon independent student research, supervised by at least one faculty member in Physics and Astronomy. This course may only be taken for credit during one semester. However, students are expected to have engaged in their research project during previous semesters through 171.501-502, summer research, etc. This course may not be used as one of the two electives required for a BA, but can be used as one of the four focused electives in a BS program. Open to senior department majors only.
**Prerequisite(s):** You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.
Writing Intensive

**AS.171.504. Senior Thesis. 0 - 3 Credits.**
Preparation of a substantial thesis based upon independent student research, supervised by at least one faculty member in Physics and Astronomy.
**Prerequisite(s):** You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.
Writing Intensive

**AS.171.597. Independent Research. 3 Credits.**
**Prerequisite(s):** You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.

**AS.171.603. Electromagnetic Theory.**
Classical field theory, relativistic dynamics, Maxwell's equations with static and dynamic applications, boundary-value problems, radiation and propagation of electromagnetic waves, advanced topics in electrodynamics in media and plasmas

**AS.171.605. Quantum Mechanics.**
Review of wave mechanics and the Schrodinger equation, Hilbert space, harmonic oscillator, the WKB approximation, central forces and angular momentum, scattering, electron spin, density matrix, perturbation theory (time-independent and time-dependent), quantized radiation field, absorption and emission of radiation, identical particles, second quantization, Dirac equation.

**AS.171.606. Quantum Mechanics.**
Review of wave mechanics and the Schrodinger equation, Hilbert space, harmonic oscillator, the WKB approximation, central forces and angular momentum, scattering, electron spin, density matrix, perturbation theory (time -independent and time - dependent), quantized radiation field, absorption and emission of radiation, identical particles, second quantization, Dirac equation. Recommended Course Background: AS.171.303 and AS.171.304

**AS.171.610. Numerical Methods for Physicists.**
Topics in applied mathematics used by physicists, covering numerical methods: linear problems, numerical integration, pseudo-random numbers, finding roots of nonlinear equations, function minimization, eigenvalue problems, fast Fourier transforms, solution of both ordinary and partial differential equations. Undergraduate students may register online for this course and will be assigned 3 credits during the add/drop period.

**AS.171.611. Stellar Structure and Evolution.**
Basic physics of stellar structure and evolution will be discussed with emphasis on current research.

**AS.171.612. Interstellar Medium and Astrophysical Fluid Dynamics.**

**AS.171.613. Radiative Astrophysics.**
A one-term survey of the processes that generate radiation of astrophysical importance. Topics include radiative transfer, the theory of radiation fields, polarization and Stokes parameters, radiation from accelerating charges, bremsstrahlung, synchrotron radiation, thermal dust emission, Compton scattering, properties of plasmas, atomic and molecular quantum transitions, and applications to astrophysical observations.

**AS.171.618. Observational Astronomy.**
How do we observe the Universe at each wavelength and what do we see? This course will present the knowledge required for astronomical observations across the entire spectrum. For each wavelength range (gamma rays, X-rays, UV, visible, IR, radio) we will discuss the typeof detector used, the range of possible observations and current open questions. We will also discuss the dominant astronomical and terrestrial sources across the spectrum, and study the differences between ground- and space-based observations.

**AS.171.619. Molecular Astrophysics.**
An advanced graduate level course that emphasizes the importance of molecules in astrophysical environments as diverse as interstellar clouds, circumstellar outflows, cometary comae, and active galactic nuclei. Topics will include the chemistry and photochemistry of astrophysical molecules; molecular excitation; astrophysical masers; interstellar molecular clouds; interstellar shock waves; circumstellar outflows; cometary comae; molecular accretion disks.

**AS.171.621. Condensed Matter Physics.**
This sequence is intended for graduate students in physics and related fields. Topics include: metals and insulators, diffraction and crystallography, phonons, electrons in a periodic potential, transport. Co-listed with AS.171.405

**AS.171.622. Condensed Matter Physics.**
This sequence is intended for graduate students in physics and related fields. Topics include superconductivity, magnetism, metal-insulator transitions, low dimensional materials, quantized hall effect.

**AS.171.625. Experimental Particle Physics.**
For graduate students interested in experimental particle physics, or theory students, or students from other specialties. Subjects covered: experimental techniques, including particle beams, targets, electronics, and various particle detectors; and a broad description of high energy physics problems. Undergraduate students may register online for this course and will be assigned 3 credits during the add/drop period.

**AS.171.627. Astrophysical Dynamics.**
This is a graduate course that covers the fundamentals of galaxy formation, galactic structure and stellar dynamics and includes topics in current research.

**AS.171.629. First Year Research.**

**AS.171.630. First Year Research.**

**AS.171.639. Group Theory in Physics.**
Introduction to finite and Lie groups, representations and applications to quantum mechanics, condensed matter physics, and other fields of physics; selected topics from differential geometry and algebraic topology.
Area: Natural Sciences

**AS.171.641. Second Year Research.**

**AS.171.642. Second Year Research.**

**AS.171.644. Exoplanets and Planet Formation.**
A graduate-level introduction to the properties of the solar system, the known exoplanet systems, and the astrophysics of planet formation and evolution. Topics also include the fundamentals of star formation, protoplanetary disk structure and evolution, exoplanet detection techniques, and the status of the search for other Earths in the Galaxy. Upper-level undergraduates may enroll with the permission of the instructor.

**AS.171.646. General Relativity.**
An introduction to the physics of general relativity. Principal topics are: physics in curved spacetimes; the Equivalence Principle; the Einstein Field Equations; the post-Newtonian approximation and Solar System tests; the Schwarzschild and Kerr solutions of the Field Equations and properties of black holes; Friedmann solutions and cosmology; and gravitational wave propagation and generation.
Area: Natural Sciences

**AS.171.648. Physics of Cell Biology: From Mechanics to Information.**
Cells are actively-driven soft materials – but also efficient sensors and information processors. This course will cover the physics of those cellular functions, from the mechanics of DNA to the sensing of chemical signals. Questions answered include: How does polymer physics limit how quickly chromosomes move? Why do cells use long, thin flagella to swim? What limits the accuracy of a cell's chemotaxis?Some experience with partial differential equations required. No biology knowledge beyond the high school level necessary. Some problem sets will require minimal programming.
Area: Natural Sciences

**AS.171.652. Exoplanets and their Atmospheres.**
This course covers the basic theory of planetary atmospheres as applied to extrasolar planets. The fundamental physical processes related to the structure, composition, radiative transfer, chemistry and dynamics of planetary atmospheres are covered, with an emphasis on those related to observable exoplanet properties. We also provide an overview of the observational techniques of exoplanetary atmospheres and discuss the habitability of exoplanets.
Area: Natural Sciences

**AS.171.697. Astro-Particle Physics.**
Topics include: Dark matter, dark energy, ultra-high energy cosmic rays, neutrino astrophysics, black holes, WIMPS, sterile neutrinos, axions, gamma ray bursts, particle acceleration, cosmic backgrounds, dark energy equation- of- state. Senior undergraduates with permission.

**AS.171.698. Physics Beyond the Standard Model.**
The Standard Model of particle physics has withstood every direct experimental test, explaining physics from sub nuclear to cosmological length scales. But, we know that it is not a complete theory. It fails to explain observational facts such as the nature of dark matter and dark energy. The theory is also beset by theoretical problems such as the hierarchy, strong CP, cosmological constant and the black hole information problem. Attempts to explain these puzzles have not been successful. In this course, we will highlight the main obstacles towards solving these problems and discuss new approaches to these problems, both from the experimental and theoretical point of view.
Area: Natural Sciences

**AS.171.701. Quantum Field Theory.**
Introduction to relativistic quantum mechanics and quantum field theory. Canonical quantization; scalar, spinor, and vector fields; scattering theory; renormalization; functional integration; spontaneous symmetry breaking; Standard Model of particle physics.

**AS.171.702. Quantum Field Theory II.**
Introduction to relativistic quantum mechanics and quantum field theory. Recommended Course Background: AS.171.605-AS.171.606 or equivalent.

**AS.171.703. Advanced Statistical Mechanics.**
Brief review of basic statistical mechanics and thermodynamics. Then hydrodynamic theory is derived from statistical mechanics and classical treatments of phase transitions, including Ginzburg-Landau theory.

**AS.171.704. Phase Transitions and Critical Phenomena.**
Course covers phase transitions and critical phenomena. Building on the ideas of spontaneous symmetry breaking and scale invariance at a critical point we develop Landau's theory of phase transitions and the apparatus of renormalization group using both analytic and numerical techniques for studying interacting systems.

**AS.171.708. Gravitational Waves.**
In September 2015, one hundred years after Einstein's prediction of the existence of gravitational waves, the LIGO/Virgo collaboration detected the gravitational radiation produced by the merger of two black holes, marking the beginning of a new era in astronomy. This course will review the theory of gravitational waves, the main astrophysical and cosmological sources of gravitational radiation, and the modeling of these sources through numerical and analytical techniques. We will discuss how present and future gravitational wave detections on Earth and in space can be used to study the astrophysics of compact objects (such as black holes and neutron stars) and to test Einstein's theory of general relativity.
Area: Natural Sciences

**AS.171.732. Elementary Particle Physics.**
Description TBA

**AS.171.749. Contemporary Machine Learning for Physicists.**
In the past decade there's been an explosion of progress in machine learning, using models with billions of parameters that learn from enormous datasets. These models present an exciting opportunity for physicists interested in investigating how and why they work. This course will provide an introduction to the subject, including aspects of learning theory, neural network architectures, optimization, statistics, and information theory.
Area: Natural Sciences

**AS.171.750. Cosmology.**
Review of special relativity and an introduction to general relativity, Robertson-Walker metric, and Friedmann equation and solutions. Key transitions in the thermal evolution of the universe, including big bang nucleosynthesis, recombination, and reionization. The early universe (inflation), dark energy, dark matter, and the cosmic microwave background. Development of density perturbations, galaxy formation, and large-scale structure.

**AS.171.752. Black Hole Astrophysics.**
Black holes are the central engines for a wide variety of astrophysical objects: Galactic X-ray sources, active galactic nuclei, stellar tidal disruptions, and the black hole mergers that are the only directly-detected gravitational wave sources (as of this writing). Although the mass distribution of astrophysical black holes spans at least eight orders of magnitude and their circumstances can vary tremendously, the physical processes relevant to them are often closely related. This class will present the most important of them: relativistic orbits; accretion dynamics, the structure of accretion flows, and their radiation mechanisms; relativistic jet launching; binary black hole dynamics and gravitational wave radiation.

**AS.171.753. String Theory.**
Area: Natural Sciences

**AS.171.755. Fourier Optics and Interferometry in Astronomy.**
A course for advanced undergraduate and beginning graduate students covering the principles of optics and image formation using Fourier Transforms, and a discussion of interferometry and other applications both in radio and optical astronomy.

**AS.171.762. Advanced Condensed Matter.**
This course is designed for graduate students interested in learning the language, techniques, and problematic of modern quantum many-body theory as applied to condensed matter physics.

**AS.171.782. Advanced Particle Theory: Quantum Gravity.**
Advanced course on the AdS/CFT correspondence and its relationship with contemporary research topics.
Area: Natural Sciences

**AS.171.783. Black Hole Physics.**
General Relativity predicts its own demise in the existence of singular black hole solutions. There have been mounting astrophysical evidence that black holes do exist in nature. Thus they are not just pathologies of the theory but fundamental objects in gravity that require understanding. Theoretically, they serve as 'laboratories' for studies in quantum gravity; indeed, most of the research in the field aims to resolve various paradoxes and puzzles that emerge when one tries to understand physics inside or outside black holes. The goal of this course is to elucidate these paradoxes and puzzles. First, we will study the classical properties of black holes in general relativity such as horizons, causal history, singularity theorems, area theorems and black hole mining. Next, we will study semi-quantum and quantum properties such as black hole thermodynamics, Hawking radiation, black hole evaporation. We will also explore modern results and perspectives on the fundamental physics of black holes that are necessary for current research. A background in general relativity and quantum field theory is recommended for the course.

**AS.171.784. Advanced Particle Theory: 'What to Expect at the LHC'.**
The course will focus on scenarios and principles for new particle physics that can be tested at the CERN Large Hadron Collider and other particle experiments.

**AS.171.785. Advanced Particle Theory: Dark Matter.**
The overwhelming evidence that dark matter exists and that it is not part of the fundamental theory of matter (the standard model) suggests the need for a graduate course. I will cover what is known and not known about dark matter, being specific enough to open lines of inquiry. I will cover what the rules of quantum field theory would allow it to be and how it could interact with us. I will go over possible mechanisms that explain the generation of dark matter in our universe in the first place. In addition, I will go over the ways to potentially discover (interact with) it directly.The first half or more of the course should be mostly accessible to advanced graduate students in astrophysics and high-energy particle experimentalists. The last half/third will be more field-theory oriented
Area: Natural Sciences

**AS.171.801. Independent Research- Graduates.**

**AS.171.802. Independent Research-Graduate.**

**AS.172.203. Contemporary Physics Seminar. 1 Credit.**
This seminar exposes physics majors to a broad variety of contemporary experimental and theoretical issues in the field. Students read and discuss reviews from the current literature, and are expected to make an oral or written presentation. Recommended Course Background: AS.171.101-AS.171.102, AS.171.103-AS.171.104, or AS.171.105-AS.171.106.
Area: Natural Sciences

**AS.172.601. Department Colloquium.**

**AS.172.604. Joint JHU/STScI Colloquium.**
A joint JHU Department of Physics and Astronomy and Space Telescope Science Institute Colloquium Series.

**AS.172.633. Language Of Astrophysics.**
Survey of the basic concepts, ideas, and areas of research in astrophysics, discussing general astrophysical topics while highlighting specialized terms often used compared to physics.

**AS.172.722. Hot Topics in Astrophysics.**

**AS.172.732. CAS Research Seminar.**

**AS.172.751. Elementary Particle Physics Seminar.**

**AS.172.752. Elementary Particle Physics Seminar.**

**AS.172.753. Advanced Particle Theory Seminar.**

**AS.172.754. Advanced Particle Theory Seminar.**

**AS.172.763. Condensed Matter Physics Seminar.**

**AS.172.764. Condensed Matter.**

**AS.173.111. General Physics Laboratory I. 1 Credit.**
Experiments are chosen from both physical and biological sciences and are designed to give students background in experimental techniques as well as to reinforce physical principles. Corequisite: AS.171.101, AS.171.103, or AS.171.105.
**Prerequisite(s):** Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Area: Natural Sciences

**AS.173.112. General Physics Laboratory II. 1 Credit.**
Experiments are chosen from both physical and biological sciences and are designed to give students background in experimental techniques as well as to reinforce physical principles. Recommended Course Background: AS.173.111; Corequisite: AS.171.102.
**Prerequisite(s):** Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.;AS.171.101 OR AS.171.102 OR AS.171.104 OR AS.171.106 OR AS.171.108
Area: Natural Sciences

**AS.173.115. Classical Mechanics Laboratory. 1 Credit.**
Experiments chosen to complement the lecture course Classical Mechanics I, II AS.171.105-AS.171.106 and introduce students to experimental techniques and statistical analysis. Corequisite: AS.171.105.
**Prerequisite(s):** Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Area: Natural Sciences

**AS.173.116. Electricity and Magnetism Laboratory. 1 Credit.**
Experiments chosen to complement Electricity and Magnetism AS.171.106 and introduce students to experimental techniques and statistical analysis.
**Prerequisite(s):** Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Area: Natural Sciences

**AS.173.308. Advanced Physics Laboratory. 3 Credits.**
A broad exposure to modern laboratory procedures such as holography, chaos, and atomic, molecular, and particle physics.
**Prerequisite(s):** Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.
Area: Natural Sciences
Writing Intensive