

PHYSICS AND ASTRONOMY

<http://physics-astronomy.jhu.edu/>

Johns Hopkins is the nation's first research university. That emphasis on research continues to this day and forms the backbone of the undergraduate and graduate programs in the Department of Physics and Astronomy. The department's research program is focused into four areas of excellence:

- Astrophysics
- Condensed Matter Physics
- Elementary Particle Physics
- Plasma Physics

For graduate students interested in these fields, the department offers world-class research opportunities in a friendly and supportive setting. For undergraduates, JHU offers exposure to cutting-edge research combined with a level of personal attention that is typically found only in liberal arts colleges. Nearly all physics majors at JHU work on research projects and many begin as freshmen or sophomores.

All research builds upon an established body of knowledge. To be effective researchers, teachers, or professionals, both undergraduate and graduate students must acquire a core knowledge of physics. Our undergraduate and graduate courses are designed to cover the core subjects at the appropriate levels, leading to advanced courses on a variety of specialized topics. As a consequence, students having different backgrounds or different ultimate objectives can select those parts that are most appropriate for them. The selections are made under the guidance of a faculty advisor. The advisor aids the student in making the most efficient use of their time and ensures that their program contains a reasonable balance among classroom and laboratory, mathematics, seminars, and introduction to research.

Donald E. Kerr Memorial Prize

In recognition of Dr. Kerr's work in microwave physics, the department awards the Donald E. Kerr Memorial Prize each year to the most outstanding undergraduate major graduating in physics.

Facilities

The Department of Physics and Astronomy's first facility was Rowland's measuring engine for determining the solar spectrum in the 1880s. Ever since that time the Department has maintained a long and continuous history in instrumentation. In recent decades this has extended to instrumentation for space missions. The Department maintains a Class-1000 clean room for microfabrication and nanofabrication, a high bay lab, professional and student machine shops, and supports a world-renowned Instrument Development Group (IDG) with six full-time engineers and three full-time machinists.

Among the diverse techniques used for studying condensed matter physics are magnetometry/susceptometry, specific heat and transport measurements, atomic force and magnetic force microscopy, X-ray and electron diffraction, terahertz spectroscopy, and neutron scattering at the nearby NIST Center for Neutron Research and at the Spallation Neutron Source, ORNL. A variety of cryostats, He3 refrigerators, and He3-He4 dilution refrigerators together with high temperature ovens, electromagnets, and superconducting magnets allow measurements to be made from 0.05 K to 1100 K and in magnetic fields up to 14 Tesla. Apparatus for the preparation of samples includes two image furnaces

for floating zone growth, single-crystal growth vacuum furnaces, box and tube furnaces, arc furnaces, several high vacuum and ultra-high vacuum chambers for thin film fabrication using evaporation, MBE, pulsed laser deposition, sputtering, and focused ion beam (FIB) milling. Also available on campus are cutting-edge transmission electron microscopes and scanning electron microscopes.

In astrophysics, research groups have state-of-the-art laboratories for testing cryogenic transition-edge bolometer detectors with SQUID read-out electronics, and closed-cycle helium cryogenics. Recent instrumentation advances include the design and manufacture of large free-standing polarization grids and novel high-bandwidth smooth-wall feed horns. Current activities include development of microwave and millimeter-wave instruments for far-infrared and microwave astronomy and cosmology.

The research groups in the department have a wide range of state-of-the-art computer facilities including high performance clusters with over a thousand processors and the largest database at a university—over a petabyte. All undergraduate majors and graduate students have access to high performance workstations.

Financial Aid

Graduate students in good standing are normally supported by a combination of fellowships, research assistantships and teaching assistantships. The financial package covers full tuition, individual health insurance, and an academic year salary commensurate with that of other leading research institutions. Teaching assistantship is a common mode of financial support; experience in teaching is a valuable part of the Ph.D. program. A teaching assistantship supports the student during the academic year and is supplemented by a research assistantship during the summer. The assistant is expected to help in the teaching of the general physics course and other introductory and major courses. The typical teaching duties include leading a problem-solving section or laboratory exercises and homework grading. Research assistantships are based on the availability of funding to the research advisor and are arranged directly with them. Research assistantships provide an opportunity for deep engagement in ongoing experimental or theoretical research. In addition, the department and the University offer several fellowships on a competitive basis, some covering travel, supplies or research expenses and some covering a semester's or a year's worth of the entire financial package. Some students are supported by external fellowships, such as the pre-doctoral fellowship of the National Science Foundation.

All fellows and teaching and research assistants in the Department of Physics and Astronomy register as full-time students and thus fulfill their residence requirements while holding appointments. Loans and work-study arrangements are available from the Office of Financial Aid.

Graduate Programs

Graduate study in physics and astronomy at JHU is intended primarily to prepare Ph.D. graduates for careers in teaching and research in physics and astronomy, or in applications such as biophysics, space physics, and industrial research. Entering students may elect to work toward a Ph.D. in physics or a Ph.D. in astronomy and astrophysics. The two programs are similar in structure but have somewhat different course requirements (see the programs tab). A wide range of research projects—both theoretical and experimental—are available for graduate students in Astrophysics (<http://physics-astronomy.jhu.edu/groups/astro/>), Condensed Matter Physics (<http://physics-astronomy.jhu.edu/research/>)

condensed-matter-physics/), Particle Physics (http://www.pha.jhu.edu/~morris/jhu_hep/jhu_hep.html), and Plasma Spectroscopy.

Programs

- Astronomy and Astrophysics, PhD (<https://e-catalogue.jhu.edu/arts-sciences/full-time-residential-programs/degree-programs/physics-astronomy/astronomy-astrophysics-phd/>)
- Physics, Bachelor of Arts (<https://e-catalogue.jhu.edu/arts-sciences/full-time-residential-programs/degree-programs/physics-astronomy/physics-astronomy-bachelor-arts/>)
- Physics, Bachelor of Science (<https://e-catalogue.jhu.edu/arts-sciences/full-time-residential-programs/degree-programs/physics-astronomy/physics-bachelor-science/>)
- Physics, Bachelor of Science/Master of Science (<https://e-catalogue.jhu.edu/arts-sciences/full-time-residential-programs/degree-programs/physics-astronomy/physics-bachelor-science-master-science/>)
- Physics, Minor (<https://e-catalogue.jhu.edu/arts-sciences/full-time-residential-programs/degree-programs/physics-astronomy/physics-minor/>)
- Physics, PhD (<https://e-catalogue.jhu.edu/arts-sciences/full-time-residential-programs/degree-programs/physics-astronomy/physics-phd/>)

For current course information and registration go to <https://sis.jhu.edu/classes/>

Courses

AS.171.101. General Physics: Physical Science Major I. 4 Credits.

First semester of a two-semester sequence in calculus-based general physics. In this term, the topics covered include the basic principles of classical mechanics and fluids as well as an introduction to wave motion. 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 Co-requisite: AS.110.108 or AS.110.113 AND AS.173.111
Area: Engineering, Natural Sciences

AS.171.102. General Physics: Physical Science Major II. 4 Credits.

Second semester of two-semester sequence in calculus-based general physics. In this term, the topics covered include wave motion, electricity and magnetism, optics, and modern physics. Recommended Corequisites: (AS.173.112) AND Calculus (AS.110.107 or AS.110.109 or AS.110.113).

Prerequisite(s): Prerequisites: 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.530.123

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 or AS.171.105 or AS.171.107; Corequisite: AS.110.109, AS.173.112 or OR EN.530.123.

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 or AS.171.310. Recommended Co-requisites: 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 calculus-based 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.

Second semester of a two-semester sequence in calculus-based general physics 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.530.123)

Prerequisite(s): Can be taken concurrently or as a prerequisite: (AS.110.107 OR AS.110.109 OR AS.110.211 OR AS.110.113)

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.171.114. Powering the world: the science of energy. 3 Credits.

We all know that the energy we use on a daily basis can come from a variety of sources, but a discussion of the merits and drawbacks to those sources more often leads to political argument than fact-based scientific dialogue. This course, meant for science and non-science students alike, explores the principles behind how energy from fossil fuels, solar, wind, nuclear, and other resources is produced, how efficiently the energy can be harnessed, and what effect the process has and will have on our environment and society today and in the future. Students will apply this fundamental understanding to compare and understand how each source could be used in real world scenarios. Ultimately, the course is intended to help students use a scientific perspective to shape their opinions when faced with these controversial topics.

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.171.135. Exploring the Universe with Space Telescopes. 1 Credit.

Through a mix of lectures and hands-on activities, you will learn how astronomers study objects in space using different types of light, observatories, and instrumental techniques. You will also hear from active researchers about the big, open questions in astronomy and how we use space telescopes such as Hubble and Webb to answer those questions. Building on this knowledge, you will work with a small group to design your own space telescope and present that design to your peers. No prior knowledge of astronomy, physics, or mathematics is assumed.

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.171.301. 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.171.310. 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). 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. Recommended Course Background: AS.110.108-AS.110.109, AS.171.202
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. Learn to Think Statistically. 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 analyze data, 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. The course will occasionally involve some coding. Junior, senior and graduate students only. More at <https://bit.ly/3iJ90ps>
Area: Natural Sciences

AS.171.402. Applied Quantum Information. 3 Credits.

This course will provide a basic introduction to quantum computing and quantum algorithms. It will cover celebrated quantum algorithms that are of interest in the long term in addition to having a particular focus on near-term quantum algorithms for specific applications (e.g., material simulation and approximate optimization) that can be readily studied on currently available hardware. Lastly, we will discuss critical techniques for managing noise in quantum systems (e.g., quantum error correction). Course attendees will also receive hands-on experience in near-term quantum algorithm implementation on the IBM Quantum Experience (IBMQE), a publicly available quantum computing platform. Recommended Background : Calculus, Python (Basic), Linear Algebra, Basic Quantum Mechanics
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.171.621 Recommended 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.

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.
Area: Natural Sciences, Quantitative and Mathematical Sciences

AS.171.418. Introduction to Topics in Contemporary Physics. 3 Credits.

Course is intended to give broad perspective on many aspects of modern physics: Astrophysics, Condensed Matter Physics, Particle Physics, Biological Physics.

Prerequisite(s): AS.171.303 AND AS.171.301 AND AS.171.312

Area: Natural 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.171.449. Astrophysical Plasmas. 3 Credits.

This course is for both graduate students and undergraduate students. There is no prerequisite although reading for introductory texts will be supplied where useful. Postdocs are also welcome to attend. Topics that will be discussed include: 1. Gravitational Wave Astronomy (related to cosmic plasmas), 2. Ultra-High Energy Cosmic Rays, 3. Black Hole Electrodynamics, 4. the Intergalactic, Interstellar and Intra-Cluster Medium, 5. Pulsars, 6. Magnetars, 7. Stellar and Galactic Dynamos, 8. Solar Flares and CMEs, 9. Gamma Ray Bursts, 10. Supernovae and their Remnants, 11. Radio Sources and Jets and, 12. the universal cosmic plasma from earliest times. Finally the detailed dusty plasmas around protostellar and protoplanetary disks including debris components of comets, asteroids planetesimals and interstellar intruders. We will spend roughly one week on each topic. In class, we will combine the lectures with reading interesting new papers from the current literature and it is expected that students will be sufficiently fluent in this field by the end of the semester to critically discuss and analyze such papers as experts. 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. 1 - 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.171.597. 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. 3 Credits.

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. 4 Credits.

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. 4 Credits.

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. 4 Credits.

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. 3 Credits.

Basic physics of stellar structure and evolution will be discussed with emphasis on current research.

AS.171.612. Interstellar Medium and Astrophysical Fluid Dynamics. 3 Credits.**AS.171.613. Radiative Astrophysics. 3 Credits.**

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. 3 Credits.

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 type of 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.171.620. Soft Matter Physics. 3 Credits.

This course is aimed at both graduate students and upper level undergraduate students. It will cover a range of topics going from the traditional areas of soft matter (polymers, liquid crystals, membranes) to newer areas at the intersection with biological physics and condensed matter. In class, we will combine lectures with reading and discussing papers from the current literature. In the second part of the course, students will at turn lead the paper discussions.

Area: Natural Sciences

AS.171.621. Condensed Matter Physics. 3 Credits.

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. 3 Credits.

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. 3 Credits.

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. 3 Credits.

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

AS.171.639. 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.

Area: Natural Sciences

AS.171.644. Exoplanets and Planet Formation. 3 Credits.

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. 3 Credits.

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. 3 Credits.

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.171.649. Astrophysical Plasmas. 3 Credits.

This course is for both graduate students and undergraduate students. There is no prerequisite although reading for introductory texts will be supplied where useful. Postdocs are also welcome to attend. Topics that will be discussed include: 1. Gravitational Wave Astronomy (related to cosmic plasmas), 2. Ultra-High Energy Cosmic Rays, 3. Black Hole Electrodynamics, 4. the Intergalactic, Interstellar and Intra-Cluster Medium, 5. Pulsars, 6. Magnetars, 7. Stellar and Galactic Dynamos, 8. Solar Flares and CMEs, 9. Gamma Ray Bursts, 10. Supernovae and their Remnants, 11. Radio Sources and Jets and, 12. the universal cosmic plasma from earliest times. 13. Finally the detailed dusty plasmas around protostellar and protoplanetary disks including debris components of comets, asteroids planetesimals and interstellar intruders. We will spend roughly one week on each topic. In class, we will combine the lectures with reading interesting new papers from the current literature and it is expected that students will be sufficiently fluent in this field by the end of the semester to critically discuss and analyze such papers as experts.

Area: Natural Sciences

AS.171.698. Physics Beyond the Standard Model. 3 Credits.

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. 3 Credits.

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. 3 Credits.

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. 3 Credits.

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. 3 Credits.

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. 3 Credits.

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. 3 Credits.

Description TBA

AS.171.749. Machine Learning for Scientists. 3 Credits.

Artificial Intelligence is penetrating the world at many levels. Neural networks have changed the ways we interact with data and think about statistics. For scientists, it is important to understand the fundamental concepts behind these systems, why they work, what are their potential and limitations. This course will provide an introduction to the subject, including aspects of statistics, information theory, optimization, and neural network architectures. We will alternate between theory and applications in python. More at <https://bit.ly/3LEAg7D>

Area: Natural Sciences

AS.171.750. Cosmology. 3 Credits.

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. 3 Credits.

Black holes are the central engines for a wide variety of astrophysical objects: Galactic X-ray sources, active galactic nuclei, gamma-ray bursts, stellar tidal disruptions, and black hole mergers. Although the mass distribution of astrophysical black holes spans ten orders of magnitude and their circumstances can vary tremendously, the physical processes relevant to them are often closely related. The class will begin with an overview of astrophysical black hole phenomenology and then review the most important physical mechanisms responsible for their observed properties: relativistic orbits for both matter and photons; accretion dynamics and radiation; relativistic jet launching, propagation, and radiation; binary black hole dynamics and gravitational wave emission; and lastly, black hole creation.

AS.171.755. Fourier Optics and Interferometry in Astronomy. 3 Credits.

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. 3 Credits.

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.171.764. Experimental Techniques in Condensed Matter Physics. 3 Credits.

This course will be a survey of modern techniques in experimental condensed matter physics and is intended for graduate students interested in this area, but others interested in this topic (especially condensed matter theory students) are encouraged to enroll. Topics include low temperature techniques, transport, the SQUID and other magnetic probes, digital and analog signal processing, scattering (neutron, X-ray, and light), EPR, NMR, data analysis, and Monte Carlo. Sample preparation, including crystal and film growth and lithography will also be covered.

AS.171.781. Symmetry and anomalies in quantum systems. 3 Credits.

This course will cover various aspects of gauge symmetries and anomaly cancellations, Anomaly matching and EFT, phases of matter, topological states, SPT phases, edge mode, discrete symmetries, aspect of quantum gravity and anomaly cancellations, QCD at low energies and chiral symmetry. A background in quantum mechanics and quantum field theory is recommended for the course.

Area: Natural Sciences

AS.171.782. Advanced Particle Theory: Quantum Gravity. 3 Credits.

Advanced course on the AdS/CFT correspondence and its relationship with contemporary research topics.

Area: Natural Sciences

AS.171.783. Black Hole Physics. 3 Credits.

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.171.785. Advanced Particle Theory: Dark Matter. 3 Credits.

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. 10 - 20 Credits.**AS.171.802. Independent Research-Graduate. 9 - 20 Credits.****AS.171.803. Independent Research-Graduate. 9 - 15 Credits.**

Area: Natural Sciences

AS.171.805. First Year Research - Graduates. 6 - 9 Credits.

Independent Research

AS.171.807. Second Year Research - Graduates. 6 - 9 Credits.

Independent Research

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, AS.171.105-AS.171.106 or AS.171.107-AS.171.108.

Area: Natural Sciences

AS.172.604. Joint JHU/STScI Colloquium. 2 Credits.

A joint JHU Department of Physics and Astronomy and Space Telescope Science Institute Colloquium Series.

AS.172.633. Language Of Astrophysics. 1 Credit.

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.173.111. General Physics Laboratory I. 1 Credit.

Experiments performed in the lab provide further illustration of the principles discussed in General Physics I. Students are required to take this course concurrently with General Physics I (AS.171.101 OR AS.171.103 OR AS.171.105 OR AS.171.107) unless they already have received credit for one of the mentioned courses. Note: First and second terms must be taken in sequence.

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

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.;The following courses can be taken concurrently or as a prerequisite: AS.171.102 OR AS.171.104 OR AS.171.106 OR AS.171.108 OR EN.530.123

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

Cross Listed Courses**Applied Mathematics & Statistics****EN.553.793. Turbulence Theory. 3 Credits.**

An advanced introduction to turbulence theory for graduate students in the physical sciences, engineering and mathematics. Both intuitive understanding and exact analysis of the fluid equations will be stressed. Previous familiarity with fluid mechanics is not required, although it could be helpful.

Chemistry**AS.030.691. Hardware, Software and Materials Chemistry. 3 Credits.**

The course is designed to provide the essential principles and concepts underlying the modern study of the structure and properties of solids in bulk crystals, thin films, and nanoscale objects. Topics include basic crystallography, structure determination by x-ray, neutron, and electron diffraction, fundamental concepts of bonding in solids, lattice dynamics, electronic band structure, magnetism, and strongly correlated electron behavior. Particular emphasis is placed on the impact of the structure, dimensionality, and electron count on electrical and magnetic properties (electric conduction, superconductivity, thermoelectricity, etc). More course info available at <http://occamy.chemistry.jhu.edu>. Cross-listed with Physics and Astronomy

Comparative Thought and Literature**AS.300.307. The Theory of Everything. 3 Credits.**

Most physicists and cosmologists still dream of a final theory for the cosmos, the one-inch mathematical formula that will explain... everything. From atoms to galaxies, from morals to daydreams. Is this possible? Can a single theory account for everything we see? Some physicists, such as Don Lincoln and Steven Weinberg believe so. Others, such as Lisa Randall and Carlo Rovelli are skeptical. In this course we will examine arguments for and against the existence of an all-encompassing theory from the point of view of philosophy and cosmology. We will read from a wide variety of sources, including popular science books, scientific articles, and classical texts in the philosophy of science. We will also trace the intellectual history of the notion of an all-encompassing theory in Western philosophy and in physics.

Area: Humanities

First Year Seminars**AS.001.105. FYS: The Science Behind the Fiction. 3 Credits.**

In this First-Year Seminar, we will seek to answer questions including: could you forge Beskar? What would it take to make a light saber? Is "Image, enhance" really possible? What is possible today? What might be possible in the future? And, what may never be possible, as it violates the laws of nature as we know them? We will take an empiricist approach, gathering data on the needed properties via screenings and related research, and then applying physical principles to reveal feasibility.

Area: Natural Sciences, Social and Behavioral Sciences

AS.001.140. FYS: What Everyone Should Know about How Science Works. 3 Credits.

Science and scientists often bear the brunt of public displeasure over current events. Recent debates over CoVID (the safety and effectiveness of vaccines, masks, and isolation), climate change, and many other controversies raise questions about the reliability of scientific results and what it means to conduct research. What is and what is not scientific? How can non-scientists determine whether a scientific result is "right?" In this First-Year Seminar, we will explore what scientists do – the practices of science – and how they set standards of knowledge. Discussions will be organized around current pressing topics, including: What does it mean to "follow the science" or "do your own research" in the age of COVID? Will science save us from the ravages of climate change? Who or what has ultimate authority over the direction of scientific advances? When are new scientific announcements important new results and when are they just click bait hype? Who pays for science and should we care? What is meant by replication and is it bad if it doesn't happen? How does scientific publication work and what issues have arisen? Why do scientists often get bad press, and is it fair?

Area: Natural Sciences

AS.001.142. FYS: The Physics of Democracy. 3 Credits.

This First-Year Seminar considers what we can learn about democratic societies by thinking of them as complex physical systems. We will discuss voting and social choice theories and their relationship to renormalization and emergence; organization and segregation in complex systems: power laws, inequality, and polarization; and the dynamics of information and opinions: networks, bubbles, filters, and phase transitions.

Area: Humanities, Natural Sciences

AS.001.185. FYS: Why We Science?. 3 Credits.

This First-Year Seminar will explore how some important results in physics and astronomy are discovered, their transformative implications to the basic understanding of nature and their impact on the progress of society. Students will explore how simple rules obtained from the lab or in idealized settings imply the complex behaviors and dynamics observed in the natural world, and how they back-reaction on society. The seminar will explore the motivations for doing scientific research in various context, and how they relate to the application of scientific discoveries. An example of topic that will be explored is General Relativity, a subject that emerged purely from theoretical considerations by Einstein which have revolutionized our basic understanding of the physical world and have reshaped the fields of physics and astronomy. On the other hand, General Relativity is necessary for satellite timing which revolutionized communication in human society. Another example is the basic physics experiments and research that lead to the invention of the transistor and the ensuing revolution of the information age. The students will explore the value of scientific thinking and its necessity in building a more robust society that can effectively serve its citizens. We will have regular visits and talks from leading researchers throughout the Hopkins ecosphere. This will help guide the in-class discussions.

Area: Natural Sciences

AS.001.194. FYS: The Arrow of Time. 3 Credits.

This First-year Seminar will study the direction of time, pointing from past to future. It will primarily be based on the physics of entropy and the Second Law of Thermodynamics, covering aspects of statistical mechanics, probability, and cosmology. But it will also touch on how time's arrow manifests itself in the macroscopic world, including questions of memory, prediction, aging, and causality.

Area: Humanities, Natural Sciences

AS.001.201. FYS: The Four Great Cosmic Questions: Dark Matter, Dark Energy, Black Holes and the Origin of Life. 3 Credits.

This First-Year Seminar combines current state of the art issues in Cosmology, Astrophysics and Biology around the Scientific American level. Discusses the history of thought on these issues ranging from Aristotle, Lucretius, Galileo, Newton, Einstein...to the Hubble and JWST era. For the last part of the seminar, we will consider existential issues for humanity in our Universe. Excellent books to read to start thinking about this are by Toby Ord: Precipice and Martin Rees: (1) The Future of Humanity and (2) If Science is to Save us. Our discussions and investigations will likely lead us toward many interesting and innovative paths.

Area: Natural Sciences

Interdepartmental**AS.360.339. Planets, Life and the Universe. 3 Credits.**

This multidisciplinary course explores the origins of life, planet formation, Earth's evolution, extrasolar planets, habitable zones, life in extreme environments, the search for life in the Universe, space missions, and planetary protection. Recommended Course Background: Three upper level (300+) courses in sciences (Biophysics, Biology, Chemistry, Physics, Astronomy, Math, or Computer Science).

Prerequisite(s): Students may not register for this class if they have already received credit for AS.020.334 OR AS.020.616 OR AS.171.333 OR AS.171.699 OR AS.270.335 OR AS.360.671

Area: Natural Sciences

AS.360.671. Planets, Life and the Universe. 3 Credits.

This multidisciplinary course explores the origins of life, planet formation, Earth's evolution, extrasolar planets, habitable zones, life in extreme environments, the search for life in the Universe, space missions, and planetary protection. Recommended Course Background: Three upper level (300+) courses in sciences (Biophysics, Biology, Chemistry, Physics, Astronomy, Math, or Computer Science).

Prerequisite(s): Students may not register for this class if they have already received credit for AS.020.616 OR AS.020.334 OR AS.171.333 OR AS.171.699 OR AS.270.335 OR AS.360.339.

Area: Natural Sciences

Philosophy**AS.150.465. Topics in the Philosophy of Physics. 3 Credits.**

This course will consider some philosophical topics in the foundations of physics. Entropy and the arrow of time – why time has a direction, whether it can be explained in terms of entropy, and what role the arrow of time plays in causation and emergence. Anthropic and indexical uncertainty – approaches to probability, reference classes, the cosmological multiverse, Boltzmann brains, simulation and doomsday arguments. Foundations of quantum mechanics – the measurement problem, many-worlds, probability and structure, alternative approaches.

Area: Humanities

For current faculty and contact information go to <http://physics-astronomy.jhu.edu/people/>