PHYSICS

Departmental Office: 704 Pupin; 212-854-3348
http://www.columbia.edu/cu/physics

Director of Undergraduate Studies: Dr. Jeremy Dodd, 924 Pupin; 212-854-3969; jeremy.dodd@columbia.edu

The physics major offers a rigorous preparation in the intellectual developments of modern physics, along with extensive exposure to the mathematical and experimental techniques required to conduct basic and applied research in physics.

For the major, the department offers a set of required courses well-suited to prepare students for the most rigorous course of graduate study. These can be supplemented by elective courses in a variety of advanced topics. Although most majors go on to graduate work in physics, the intellectual skills acquired in the study of physics can also provide the basis for work in a variety of other scientific and nonscientific areas.

The physics concentration is for students who are interested in physics but are uncertain about graduate study in physics; for those who want to explore other subjects along with physics; for those who want to find a physics- or technology-related job after graduation; or for those who are considering a professional school such as law or medicine. The department helps concentrators custom design programs to ensure maximum flexibility in meeting students’ intellectual needs and career goals. With appropriate selection of courses, the concentrator can explore other subjects yet maintain the option of graduate study in physics.

Research is an extremely important component of the Columbia physics experience. Because the department has a very small student-to-faculty ratio, essentially all physics majors and concentrators engage in experimental, computational, or theoretical research under the close supervision of a faculty member during part, if not all, of their time at Columbia.

Registration for Introductory Courses

The department offers a stand-alone one-semester course for nonscience majors, one introductory sequence in physics intended primarily for preprofessional students, and three introductory sequences in physics for engineering and physical science majors. Students are given credit for courses from only one of the different sequence groups.

Mixing courses across the sequences is strongly discouraged; however, physics majors who begin their studies with PHYS UN1401 INTRO TO MECHANICS # THERMO - PHYS UN1402 INTRO ELEC/MAGNETSM # OPTCS should take PHYS UN2601 PHYSICS III:CLASS/QUANTUM WAVE as the third-semester course.

Introductory Sequences

Non-science Majors:

| PHYS UN1001 | PHYSICS FOR POETS |

Preprofessional Students:

| PHYS UN1201 | GENERAL PHYSICS I |
| PHYS UN1202 | and GENERAL PHYSICS II |

Accompanying laboratory course:

| PHYS UN1291 | GENERAL PHYSICS I LAB |
| PHYS UN1292 | and GENERAL PHYSICS II LABORATORY |

Engineering and Physical Science Majors:

Select one of the following sequences with accompanying laboratory course:

| Sequence A: | | |
| PHYS UN1401 | INTRO TO MECHANICS # THERMO and INTRO ELEC/MAGNETSM # OPTCS |
| PHYS UN1402 | and INTRO-CLASSCL # QUANTUM WAVES |

| Sequence B: | | |
| PHYS UN1601 | PHYSICS I:MECHANICS/RELATIVITY and PHYSICS II: THERMO, ELEC # MAG |
| PHYS UN1602 | and PHYSICS III:CLASS/QUANTUM WAVE |

| Sequence C: | | |
| PHYS UN2801 | ACCELERATED PHYSICS I |
| PHYS UN2802 | and ACCELERATED PHYSICS II |

Sequence A is a self-contained group of three courses, while Sequences B and C anticipate more course work in the Physics Department. Students considering a physics major are strongly encouraged to begin one of these sequences in their first year.

Laboratory

Many of the introductory courses include a laboratory, as indicated. A $75 per term laboratory fee is charged for all 1000-level and 2000-level laboratories.

Advanced Placement

Students may earn a maximum of 6 credits in physics. The department grants 6 credits for a score of 4 or 5 on the AP Physics B exam, but the student is not entitled to any exemptions. The amount of credit is reduced to 3 if the student takes a 1000-level physics course.

The department grants 3 credits for a score of 4 or 5 on the AP Physics C/MECH exam, but the student is not entitled to any exemptions. The amount of credit is reduced to 0 if the student takes PHYS UN1001, PHYS UN1201, PHYS UN1401 or PHYS UN1601.

The department grants 3 credits for a score of 4 or 5 on the AP Physics C/E&M exam, but the student is not entitled to any exemptions. The amount of credit is reduced to 0 if the student takes PHYS UN1001, PHYS UN1202, PHYS UN1402 or PHYS UN1602.

Professors

Igor Aleiner
Boris Altshuler
Elena Aprile
Dmitri Bassov
Andrei Beloborodov
Allan Blaer (emeritus)
Gustaf Brooijmans
Norman Christ
Brian Cole
Frederik Denef
Richard Friedberg (Barnard emeritus)
Brian Greene (Mathematics)
Miklos Gyulassy (emeritus)
Charles J. Hailey
Timothy Halpin-Healy (Barnard)
Sven Hartmann (emeritus)
Tony Heinz (emeritus)
Emlyn Hughes
The department considers laboratory experience to be an essential part of the physics curriculum. Majors and concentrators can gain such experience in the intermediate-level laboratories, the electronics laboratory, and through experimental research in faculty research groups.

**Grading**

A grade of C- or better must be obtained for a course to count toward the majors or the concentration. The grade of P is not acceptable, but a course that was taken P/D/F may be counted if and only if the P is uncovered by the Registrar’s deadline.

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### Major in Physics

#### Physics Courses

The major in physics requires a minimum of 41 points in physics courses, including:

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<tr>
<th>Introductory Sequences</th>
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<tr>
<td>Sequence A: Students with a limited background in high school physics may elect to take:</td>
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<td>Sequence C: Students with advanced preparation in both physics and mathematics may be eligible to take:</td>
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<td>ACCELERATED PHYSICS I and ACCELERATED PHYSICS II</td>
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#### Core Physics Courses

| PHYS UN3003 |
| MECHANICS |
| PHYS UN3007 |
| ELECTRICITY-MAGNETISM |
| PHYS UN3008 |
| ELECTROMAGNETIC WAVES # OPTICS |
| PHYS GU4021 |
| QUANTUM MECHANICS I |
| PHYS GU4022 |
| QUANTUM MECHANICS II |
| PHYS GU4023 |
| THERMAL # STATISTICAL PHYSICS |

#### Elective Courses

Select at least six points of the following courses:

| PHYS UN3002 |
| From Quarks To the Cosmos: Applications of Modern Physics |
| PHYS GU4003 |
| ADVANCED MECHANICS |
| PHYS GU4011 |
| PARTICLE ASTROPHYS # COSMOLOGY |
| PHYS GU4018 |
| SOLID STATE PHYSICS |
| PHYS GU4019 |
| MATHEMATICAL METHODS OF PHYSICS |
| PHYS GU4040 |
| INTRO TO GENERAL RELATIVITY |
| PHYS GU4050 |
| Introduction to Particle Physics |

With the permission of the Director of Undergraduate Studies, 4000- or 6000-level courses offered in this or other science departments may be counted.

#### Laboratory Work at the Intermediate Level

Select one of the following options:

| PHYS UN3081 |
| INTERMEDIATE LABORATORY WORK (two semesters) |
PHYS UN3083 ELECTRONICS LABORATORY
Option 2:
PHYS UN3081 INTERMEDIATE LABORATORY WORK
(three semesters)

Senior Seminar
PHYS UN3072 SEM IN CURRENT RES. PROBLEMS

* Approved experimental work with a faculty research group may satisfy one semester of the laboratory requirement.

Mathematics Courses

Calculus through MATH UN1202 CALCULUS IV or MATH UN1208 HONORS MATHEMATICS B; and MATH UN3027 Ordinary Differential Equations or the equivalent.

Recommended cognate courses: MATH UN2010 LINEAR ALGEBRA, MATH UN3007 COMPLEX VARIABLES, and MATH UN3028 PARTIAL DIFFERENTIAL EQUATIONS.

Concentration in Physics

The concentration in physics requires a minimum of 24 points in physics, including one of the introductory sequences.

Interdisciplinary Major

It is also possible to major in astrophysics, biophysics, and chemical physics. Students interested in these areas should consult with the director of undergraduate studies and with cognate departments (astronomy, biological sciences, chemistry).

For astrophysics requirements please see:
http://bulletin.columbia.edu/columbia-college/departments-instruction/astronomy/#requirementstext

For biophysics requirements please see:
http://bulletin.columbia.edu/columbia-college/departments-instruction/biological-sciences/#requirementstext

For chemical physics requirements please see:
http://bulletin.columbia.edu/columbia-college/departments-instruction/chemistry/#requirementstext

PHYS UN1001 PHYSICS FOR POETS. 3.00 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: high school algebra.
Prerequisites: high school algebra. This course does not fulfill the physics requirement for admission to medical school. No previous background in physics is expected. An introduction to physics taught through the exploration of the scientific method, and the application of physical principles to a wide range of topics from quantum mechanics to cosmology.

Spring 2024: PHYS UN1001

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PHYS UN1018 WEAPONS OF MASS DESTRUCTION. 3.00 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: high school science and math.
Prerequisites: high school science and math. A review of the history and environmental consequences of nuclear, chemical, and biological weapons of mass destruction (WMD); of how these weapons work, what they cost, how they have spread, how they might be used, how they are currently controlled by international treaties and domestic legislation, and what issues of policy and technology arise in current debates on WMD. What aspects of the manufacture of WMD are easily addressed, and what aspects are technically challenging? It may be expected that current events/headlines will be discussed in class.

Spring 2024: PHYS UN1018

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PHYS UN1111 ORIGINS AND MEANING. 3.00 points.
This course is a one-semester journey across cosmological history, from the beginning of time to something akin to its end. We will explore the origin of inanimate physical structures (the cosmos as a whole, as well as that of galaxies, stars, planets, particles, atoms and complex molecules), the origin of life (replicating molecules, the first cells, as well as more complex life forms), the origin of mind (self-reflective conscious awareness) and the origin of culture (language, myth, religion, art, and science). We will then consider what science in particular tells us about the very far future, where we will encounter the likely demise of all complex matter, all life and all consciousness. In the face of such disintegration we will examine the nature of value and purpose. We will recognize that the deepest understanding of reality emerges from blending all of the accounts we discuss—from the reductionist to the humanist to the cosmological—and only through such amalgamation can we fully grasp the long-standing human search for meaning.
PHYS 1201 GENERAL PHYSICS I. 3.00 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: some basic background in calculus or be concurrently taking MATH UN1101 Calculus I. The accompanying laboratory is PHYS UN1291-UN1292
Prerequisites: some basic background in calculus or be concurrently taking MATH UN1101 Calculus I. The accompanying laboratory is PHYS UN1291-UN1292 The course will use elementary concepts from calculus. The accompanying laboratory is PHYS UN1291 - UN1292. Basic introduction to the study of mechanics, fluids, thermodynamics, electricity, magnetism, optics, special relativity, quantum mechanics, atomic physics, and nuclear physics

PHYS UN1201 GENERAL PHYSICS I - REC. 0.00 points.

PHYS UN1202 GENERAL PHYSICS II. 3.00 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: This course will use elementary concepts from calculus. Students should therefore have had some high school calculus, or be concurrently enrolled in MATH UN1101. Taken with accompanying lab PHYS UN1291- PHYS UN1292, the sequence PHYS UN1201- PHYS UN1202 satisfies requirements for medical school.

Prerequisites: This course will use elementary concepts from calculus. Students should therefore have had some high school calculus, or be concurrently enrolled in MATH UN1101. Taken with accompanying lab PHYS UN1291- PHYS UN1292, the sequence PHYS UN1201- PHYS UN1202 satisfies requirements for medical school. Electricity, magnetism, optics, and modern physics

PHYS UN1203 GENERAL PHYSICS II - REC. 0.00 points.

PHYS 1202

PHYS 1203
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Corequisites: PHYS UN1201

Corequisites: PHYS UN1201 This course is the laboratory for the corequisite lecture course and can be taken only during the same term as the corresponding lecture

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PHYS UN1292 GENERAL PHYSICS II LABORATORY. 1.00 point.
Corequisites: PHYS UN1201, PHYS UN1202
Corequisites: PHYS UN1201, PHYS UN1202 This course is the laboratory for the corequisite lecture course (PHYS UN1201 - PHYS UN1202) and can be taken only during the same term as the corresponding lecture.

PHYS UN1292 INTRO ELEC/MAGNETSM # OPTCS. 3.00 points.
CC/GS: Partial Fulfillment of Science Requirement
Prerequisites: PHYS UN1401
Corequisites: MATH UN1102
Prerequisites: PHYS W1401, Corequisites: MATH V1102 or the equivalent. Electric fields, direct currents, magnetic fields, alternating currents, electromagnetic waves, polarization, geometrical optics, interference, and diffraction.

PHYS UN1401 INTRO TO MECHANICS # THERMO. 3.00 points.
CC/GS: Partial Fulfillment of Science Requirement
Corequisites: MATH UN1101
Corequisites: MATH UN1101 Fundamental laws of mechanics, kinematics and dynamics, work and energy, rotational dynamics, oscillations, gravitation, fluids, temperature and heat, gas laws, the first and second laws of thermodynamics. Corequisite: MATH UN1101 or the equivalent.

PHYS UN1403 INTRO-CLASSCL # QUANTUM WAVES. 3.00 points.
CC/GS: Partial Fulfillment of Science Requirement
Prerequisites: PHYS UN1402 PHYS W1402.
Corequisites: MATH V1201 or the equivalent. Classical waves and the wave equation, Fourier series and integrals, normal modes, wave-particle duality, the uncertainty principle, basic principles of quantum mechanics, energy levels, reflection and transmission coefficients, applications to atomic physics.
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PHYS 1603

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<th>Course Number</th>
<th>Section/Call Number</th>
<th>Times/Location</th>
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PHYS 1604

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<td>Th 4:10pm - 5:25pm 376 Pupin Laboratories</td>
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</table>
PHYS UN2001 SPECIAL RELATIVITY. 3.00 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: a working knowledge of high school algebra, trigonometry, and physics. Some familiarity with calculus is useful but not essential. This course is a comprehensive, one-semester introduction to the essential ideas and mathematical structures underlying Einstein’s Special Theory of Relativity. Among the topics covered will be: the relativity of simultaneity, time dilation, Lorentz contraction, velocity combination laws, time dilation over large distances, the Lorentz transformation, spacetime diagrams, the basic (seeming) paradoxes of special relativity, relativistic equations of motion and $E = mc^2$.

PHYS UN2601 PHYSICS III: CLASS/QUANTUM WAVE. 3.50 points.
Prerequisites: PHYS UN1402 or PHYS UN1602 Corequisite: MATH UN1202 or equivalent.
Prerequisites: PHYS UN1402 or PHYS UN1602 Corequisite: MATH UN1202 or equivalent. Classical waves and the wave equation, geometrical optics, interference and diffraction, Fourier series and integrals, normal modes, wave-particle duality, the uncertainty principle, basic principles of quantum mechanics, energy levels, reflection and transmission coefficients, the harmonic oscillator. The course is preparatory for advanced work in physics and related fields.

PHYS UN3002 From Quarks To the Cosmos: Applications of Modern Physics. 3 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: (PHYS UN1601 or PHYS UN1401) and (PHYS UN1602 or PHYS UN1402) and PHYS UN2601 PHYS W1601 (or W1401), W1602 (or W1402), and W2601.
Laboratory work associated with the three prerequisite lecture courses. Experiments in mechanics, thermodynamics, electricity, magnetism, optics, wave motion, atomic physics, and nuclear physics.

PHYS UN2801 ACCELERATED PHYSICS I. 4.50 points.
Prerequisites: Advanced Placement in physics and mathematics, or the equivalent, and the instructor’s permission. (A special placement meeting is held during Orientation.)
Prerequisites: Advanced Placement in physics and mathematics, or the equivalent, and the instructor’s permission. (A special placement meeting is held during Orientation.) This accelerated two-semester sequence covers the subject matter of PHYS UN1601, PHYS UN1602 and PHYS UN2601, and is intended for those students who have an exceptionally strong background in both physics and mathematics. The course is preparatory for advanced work in physics and related fields. There is no accompanying laboratory; however, students are encouraged to take the intermediate laboratory, PHYS UN3081, in the following year.

PHYS UN3003. 3.00 points.
Prerequisites: general physics, and differential and integral calculus.
Prerequisites: general physics, and differential and integral calculus. Newtonian mechanics, oscillations and resonance, conservative forces and potential energy, central forces, non-inertial frames of reference, rigid body motion, an introduction to Lagrange-formulation of mechanics, coupled oscillators, and normal modes.

PHYS UN2801 ACCELERATED PHYSICS II. 4.50 points.
Prerequisites: PHYS UN2801
Prerequisites: PHYS UN2801 This accelerated two-semester sequence covers the subject matter of PHYS UN1601, PHYS UN1602 and PHYS UN2601, and is intended for those students who have an exceptionally strong background in both physics and mathematics. The course is preparatory for advanced work in physics and related fields. There is no accompanying laboratory; however, students are encouraged to take the intermediate laboratory, PHYS UN3081, in the following year.
PHYS UN3007 ELECTRICITY-MAGNETISM. 3.00 points.
Prerequisites: general physics, and differential and integral calculus.
Electrostatics and magnetostatics, Laplace’s equation and boundary-value problems, multipole expansions, dielectric and magnetic materials, Faraday’s law, AC circuits, Maxwell’s equations, Lorentz covariance, and special relativity

Fall 2023: PHYS UN3007

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<td>William Zajc</td>
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PHYS UN3008 ELECTROMAGNETIC WAVES # OPTICS. 3.00 points.
Prerequisites: PHYS UN3008
Maxwell’s equations and electromagnetic potentials, the wave equation, propagation of plane waves, reflection and refraction, geometrical optics, transmission lines, wave guides, resonant cavities, radiation, interference of waves, and diffraction

Spring 2024: PHYS UN3008

<table>
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<th>Course Number</th>
<th>Section/Call Number</th>
<th>Times/Location</th>
<th>Instructor</th>
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<td>001/11298</td>
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<td>William Zajc</td>
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PHYS UN3072 SEM IN CURRENT RES. PROBLEMS. 2.00 points.
A detailed study of a selected field of active research in physics. The motivation, techniques, and results obtained to the present, as well as the difficulties and unsolved problems. For Physics majors only. Priority given to seniors; juniors by permission of the instructor

Fall 2023: PHYS UN3072

<table>
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<th>Course Number</th>
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<th>Times/Location</th>
<th>Instructor</th>
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<td>001/13301</td>
<td>M 5:00pm - 6:30pm 705 Pupin Laboratories</td>
<td>Kerstin Perez</td>
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</table>

PHYS UN3081 INTERMEDIATE LABORATORY WORK. 2.00 points.
May be repeated for credit by performing different experiments. The laboratory has available fifteen individual experiments, of which two are required per 2 points.

Prerequisites: phys UN2601 or phys un2802 Primarily for junior and senior physics majors; other majors must obtain the instructor’s permission.

Spring 2024: PHYS UN3081

<table>
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<tr>
<th>Course Number</th>
<th>Section/Call Number</th>
<th>Times/Location</th>
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<tr>
<td>PHYS 3081</td>
<td>002/13303</td>
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<tr>
<td>PHYS 3081</td>
<td>003/13304</td>
<td>F 1:10pm - 5:00pm 6th Fl Pupin Laboratories</td>
<td>Morgan May</td>
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PHYS UN3083 ELECTRONICS LABORATORY. 3.00 points.
Enrollment limited to the capacity of the laboratory.

Prerequisites: PHYS UN3003 or PHYS UN3007 May be taken before or concurrently with this course.

Spring 2024: PHYS UN3083

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<th>Course Number</th>
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<td>001/11300</td>
<td>M W 1:10pm - 4:00pm 513 Pupin Laboratories</td>
<td>John Parsons</td>
<td>3.00</td>
<td>14/14</td>
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</table>
PHYS UN3084 Quantum Simulation and Computing Lab. 3.00 points.
The "Quantum Simulation and Computing Lab" will give students hands-on experience in quantum optics, quantum simulation and quantum computing. The course combines lectures, tutorials, and two lab sections. In one lab section, students will do experiments with entangled photons. In the second lab section, students will program quantum computers and run algorithms on them using the IBM Qiskit platform. The course starts with a recap of linear algebra and quantum mechanics, followed by an introduction to quantum optics and quantum information. Two-level systems, Bloch sphere, quantum gates, and elementary quantum algorithms will be discussed. Quantum teleportation and quantum key distribution will be introduced as applications of entanglement. The lecture content will be directly applied in experiments with entangled photons. In the following, state-of-the-art quantum algorithms will be discussed, related to cutting-edge research results in quantum computing. This includes quantum Fourier transform, quantum simulation of the Schrödinger equation, and the variational quantum eigensolver (VQE) algorithm. During the course students will do one experimental project with entangled photons and one quantum programming project. Students will be guided to implement a quantum algorithm of their choice and run it on a quantum computer (IBM, IonQ, QuEra).

PHYS UN3500 SUPERVISED READINGS IN PHYSICS. 3.00 points.
Prerequisites: the written permission of the faculty member who agrees to act as supervisor, and the director of undergraduate studies permission. Readings in a selected field of physics under the supervision of a faculty member. Written reports and periodic conferences with the instructor.

Spring 2024: PHYS UN3900
Course Number Section/Call Number Times/Location Instructor Points Enrollment
PHYS 3900 001/11303 M W 4:10pm - 5:25pm Jeremy Dodd 3.00 14/20

PHYS UN3900 SUPERVISED INDIVIDUAL RESEARCH. 3.00-5.00 points.
Prerequisites: Permission of the departmental representative required. For specially selected students, the opportunity to do a research project in contemporary physics under the supervision of a faculty member. Each year several juniors are chosen in the spring to carry out such a project beginning in the autumn term. A detailed report on the research is presented by the student when the project is complete.

Spring 2024: PHYS UN4018
Course Number Section/Call Number Times/Location Instructor Points Enrollment
PHYS 4018 001/11305 T Th 2:40pm - 3:55pm Frederik Denef 3.00 19/30

PHYS GU4003 ADVANCED MECHANICS. 3.00 points.
Prerequisites: differential and integral calculus, differential equations, and PHYS UN3900 or the equivalent.
Prerequisites: differential and integral calculus, differential equations, and PHYS UN3900 or the equivalent. Lagrange's formulation of mechanics, calculus of variations and the Action Principle, Hamilton's formulation of mechanics, rigid body motion, Euler angles, continuum mechanics, introduction to chaotic dynamics.

Spring 2024: PHYS GU4003
Course Number Section/Call Number Times/Location Instructor Points Enrollment
PHYS 4003 001/11304 M W 4:10pm - 5:25pm Frederik Denef 3.00 35/50

PHYS GU4011 PARTICLE ASTROPHYS # COSMOLOGY. 3.00 points.
Prerequisites: (PHYS UN1403 or PHYS UN2601 or PHYS UN2802) and (MATH UN1202 or MATH UN1208) students are recommended but not required to have taken PHYS UN3003 and PHYS UN3007.
Prerequisites: (PHYS UN1403 or PHYS UN2601 or PHYS UN2802) and (MATH UN1202 or MATH UN1208) students are recommended but not required to have taken PHYS UN3003 and PHYS UN3007. An introduction to the basics of particle astrophysics and cosmology. Particle physics - introduction to the Standard Model and supersymmetry/higher dimension theories; Cosmology – Friedmann-Robertson-Walker line element and equation for expansion of universe; time evolution of energy/matter density from the Big Bang; inflationary cosmology; microwave background theory and observation; structure formation; dark energy; observational tests of geometry of universe and expansion; observational evidence for dark matter; motivation for existence of dark matter from particle physics; experimental searches of dark matter; evaporating and primordial black holes; ultra-high energy phenomena (gamma-rays and cosmic-rays).

PHYS GU4012 STRING THEORY. 3.00 points.
Prerequisites: PHYS UN3003 and PHYS UN3008 and PHYS GU4021. PHYS GU4023 would be helpful but is not required. Students should have some familiarity with tools for graphical presentation and numeric problem solving such as Mathematica and/or MathLab.
This course is intended as an introduction to string theory for undergraduates. No advanced graduate-level preparation is assumed, and the material will be covered at (no higher than) the advanced undergraduate level. Advanced topics such as supersymmetry, T-duality, and covariant quantization will not be covered. The focus will be on the dynamics of classical and quantum mechanical strings, with an emphasis on integrating undergraduate material in classical mechanics, relativity, electrodynamics and quantum mechanics.

PHYS GU4018 SOLID STATE PHYSICS. 3.00 points.
Prerequisites: PHYS GU4021 and PHYS GU4023 or the equivalent.
Prerequisites: PHYS GU4021 and PHYS GU4023 or the equivalent. Introduction to solid-state physics: crystal structures, properties of periodic lattices, electrons in metals, band structure, transport properties, semiconductors, magnetism, and superconductivity.
PHYS GU4019 MATHEMATICAL METHODS OF PHYSICS. **3.00 points.**
Prerequisites: PHYS UN3003 and PHYS UN3007 and differential and integral calculus; linear algebra; or the instructor's permission. Prerequisites: PHYS UN3003 and PHYS UN3007 and differential and integral calculus; linear algebra; or the instructor's permission. This course will present a wide variety of mathematical ideas and techniques used in the study of physical systems. Topics will include: ordinary and partial differential equations; generalized functions; integral transforms; Green's functions; nonlinear equations, chaos, and solitons; Hilbert space and linear operators; Feynman path integrals; Riemannian manifolds; tensor analysis; probability and statistics. There will also be a discussion of applications to classical mechanics, fluid dynamics, electromagnetism, plasma physics, quantum mechanics, and general relativity.

Fall 2023: PHYS GU4019

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<td>PHYS 4019</td>
<td>001/13308</td>
<td>T Th 10:10am - 11:25am 414 Pupin Laboratories</td>
<td>Alberto Nicolis 3.00</td>
<td>22/40</td>
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PHYS GU4021 QUANTUM MECHANICS I. **3.00 points.**
Prerequisites: PHYS UN3003 and PHYS UN3007 Formulation of quantum mechanics in terms of state vectors and linear operators. Three dimensional spherically symmetric potentials. The theory of angular momentum and spin. Identical particles and the exclusion principle. Methods of approximation. Multi-electron atoms.

Fall 2023: PHYS GU4021

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<th>Course Number</th>
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<td>M W 11:40am - 12:55pm 329 Pupin Laboratories</td>
<td>Alfred Mueller, Giuseppina Cambarei 3.00</td>
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PHYS GU4022 QUANTUM MECHANICS II. **3.00 points.**
Prerequisites: PHYS GU4021. Formulation of quantum mechanics in terms of state vectors and linear operators, three-dimensional spherically symmetric potentials, the theory of angular momentum and spin, time-independent and time-dependent perturbation theory, scattering theory, and identical particles. Selected phenomena from atomic physics, nuclear physics, and elementary particle physics are described and then interpreted using quantum mechanical models.

Spring 2024: PHYS GU4022

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<th>Course Number</th>
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<th>Instructor</th>
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<td>Alfred Mueller 3.00</td>
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PHYS GU4023 THERMAL & STATISTICAL PHYSICS. **3.00 points.**
Prerequisites: PHYS GU4021 or the equivalent. Thermodynamics, kinetic theory, and methods of statistical mechanics; energy and entropy; Boltzmann, Fermi, and Bose distributions; ideal and real gases; blackbody radiation; chemical equilibrium; phase transitions; ferromagnetism.

Fall 2023: PHYS GU4023

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<td>PHYS 4023</td>
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<td>M W 2:40pm - 3:55pm 214 Pupin Laboratories</td>
<td>Gustaf Brooijmans 3.00</td>
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PHYS GU4024 Applied Quantum Mechanics. **3 points.**
Prerequisites: (PHYS GU4021 and PHYS GU4022) In this course, we will learn how the concepts of quantum mechanics are applied to real physical systems, and how they enable novel applications in quantum optics and quantum information. We will start with microscopic, elementary quantum systems – electrons, atoms, and ions - and understand how light interacts with atoms. Equipped with these foundations, we will discuss fundamental quantum applications, such as atomic clocks, laser cooling and ultracold quantum gases - a synthetic form of matter, cooled down to just a silver above absolute zero temperature. This leads us to manybody quantum systems. We will introduce the quantum physics of insulating and metallic behavior, superfluidity and quantum magnetism – and demonstrate how the corresponding concepts apply both to real condensed matter systems and ultracold quantum gases. The course will conclude with a discussion of the basics of quantum information science - bringing us to the forefront of today's quantum applications.

PHYS GU4040 INTRO TO GENERAL RELATIVITY. **3.00 points.**
Prerequisites: PHYS UN3003 and PHYS UN3007 or the equivalent. Tensor algebra, tensor analysis, introduction to Riemann geometry. Motion of particles, fluid, and fields in curved spacetime. Einstein equation. Schwarzschild solution; test-particle orbits and light bending. Introduction to black holes, gravitational waves, and cosmological models.

Spring 2024: PHYS GU4040

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<th>Course Number</th>
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<td>001/11307</td>
<td>T Th 4:10pm - 5:25pm 214 Pupin Laboratories</td>
<td>James Hill 3.00</td>
<td>25/50</td>
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PHYS GU4050 Introduction to Particle Physics. **3.00 points.**
Prerequisites: PHYS UN2601 or PHYS UN2802 or the equivalent. This course covers the Standard Model of Particle Physics, including it conception, successes, and limitations, with the goal of introducing upper-level physics majors to the foundations and current status of particle physics as a field of research. Specific topics to be covered include: historical introduction and review of the Standard Model; particle interactions and particle dynamics; relativistic kinematics; Feynman calculus, quantum electrodynamics, quantum chromodynamics, and weak interactions; electroweak unification and the Higgs mechanism; neutrino oscillations; and beyond-standard model physics and evidence. Along the way, students will research special topics and familiarize themselves with particle physics research.

PHYS GU4051 ADVANCED LABORATORY WORK. **2.00 points.**
Prerequisites: the instructors permission. The laboratory has 13 available individual experiments, of which two are required per 2 points. Each experiment requires two (four-hour) laboratory sessions. Registration is limited by the laboratory capacity. May be repeated for credit with different experiment selection. Experiments (classical and modern) cover topics in electricity, magnetism, optics, atomic physics, and nuclear physics.

PHYS GU4998 SUPERVISED READINGS. **3.00 points.**