Upon successfully completing the major, students should have the ability to:

- demonstrate a conceptual understanding of the physical laws of nature.
- demonstrate a thorough knowledge of the various subject areas of physics (e.g. classical mechanics, quantum physics, electromagnetism, and thermodynamics) and/or astronomy (e.g. stellar structure and evolution, physics of the solar system, physical cosmology, and observational astronomy).
- apply problem-solving skills beyond graduation in advanced physics and/or astronomy courses in graduate school and independent research projects.
- apply problem-solving and computation skills in future situations in applied or technical jobs, or careers in finance and industry.
- make an effective oral presentation to an audience of peers and faculty on a particular research topic.

From Aristotle's Physics to Newton's Principia, the term "physics," taken literally from the Greek φυσική (= Nature), implied natural science in its very broadest sense. Physicists were, in essence, natural philosophers, seeking knowledge of the observable phenomenal world. Astronomy originally concentrated on the study of natural phenomena in the heavens with the intent to understand the constitution, relative positions, and motions of the celestial bodies in our universe. Though practitioners of these disciplines have become somewhat more specialized in the past century, the spirit that guides them in their research remains the same as it was more than two millennia ago.

In cooperation with the faculty of the University, Barnard offers a thorough pre-professional curriculum in both physics and astronomy. The faculty represents a wide range of expertise, with special strength and distinction in theoretical physics, condensed matter physics, and observational astrophysics.

Separate majors in physics and astronomy are offered. A major in astrophysics is also possible. Furthermore, there are many special interdisciplinary majors possible, such as biophysics, chemical physics, engineering physics, and mathematical physics. There is a physics minor as well. Students should consult members of the department early on in their undergraduate careers in order to plan the most effective course of study. Qualified seniors are invited to participate in the seniors honors program, in which they carry out a year-long research project leading to the thesis.

There are several quite distinct introductory sequences in physics, only one of which may be taken for credit:

1. PHYS UN1001 Physics for Poets - PHYS UN1001 Physics for Poets is a lecture course in physics intended for liberal arts students. A semester of this CU lecture course satisfies the BC Quantitative Reasoning requirement. Note, however, that 1001-2 does not satisfy the premed nor physics requirement for any major. It should also not be taken to satisfy the BC lab science requirement.

2. PHYS UN1201 General Physics I - PHYS UN1202 General Physics II is satisfactory preparation for medical school and is appropriate for most non-science major premedical students. This course is taught at Columbia in a large lecture hall setting. It is not recommended as a foundation for more advanced work in the field. Taken in conjunction with PHYS UN1291 General Physics Laboratory - PHYS UN1292 General Physics Laboratory II, this sequence does satisfy the college LAB requirement, but the student population is essentially premed. Note that PHYS UN1201 General Physics I / PHYS UN1202 General Physics II are required in order to take the lab course.

3. PHYS BC2001 Physics I: Mechanics - PHYS BC2002 Physics II: Electricity and Magnetism, PHYS BC3001 Physics II: Classical Waves & Optics is Barnard's own three-semester, calculus based introductory sequence in physics. Characterized by modest class sizes, it is designed specifically for Barnard women with a serious interest in any of the natural sciences or mathematics. Moreover, it is especially appropriate for majors in physics, chemistry, or biochemistry, whether premedical or not. Biology majors with some calculus background are also encouraged to take this sequence. Finally, Barnard women contemplating a major in physics or astronomy should take PHYS BC2001 Physics I: Mechanics - PHYS BC2002 Physics II: Electricity and Magnetism in their first year, if possible, or in their second at the latest, to be followed by the third-semester course, Classical Waves and Optics.
4. First-year students with exceptional aptitude for physics (as evidenced, for example, by scores of 4 or 5 on the advanced placement C exam) and a good mathematical background may be admitted into the Columbia-taught two-semester sequence PHYS UN2801 Accelerated Physics I - PHYS UN2802 Accelerated Physics II, which replaces all three terms of the sequence for majors. Students considering this sequence are strongly encouraged to consult a Barnard faculty member at the start of the term.

Students unsure about the most appropriate sequence should consult members of the department.

The following courses may be substituted for each other:


PHYS BC3001 Physics III: Classical Waves & Optics (sect.1; 5pts) = PHYS UN2601 Physics, III: Classical and Quantum Waves (3.0pts) + PHYS BC3001 Physics III: Classical Waves & Optics (sect.3; 2pts)

ASTR BC1753 Life in the Universe = ASTR UN1403 Earth, Moon and Planets (Lecture) - ASTR C1404 Stars, Galaxies, and Cosmology

Chair: Laura Kay
Professors: Timothy Halpin-Healy (Ann Whitney Olin Professor), Reshmi Mukherjee (Helen Goodhart Altschul Professor)
Associate Professor: Janna Levin
Lab Director: Stiliana Savin

Other officers of the University offering courses listed below:

Professors: James Applegate, Norman Christ, Brian Cole, Arlin Crotts, Charles Hailey, Jules Halpern, Tony Heinz, David Helfand, Robert Mawhinney, John Parsons, Frederik Paerels, Joseph Patterson, Michael Shaevitz, Michael Tuts, Jacqueline van Gorkom, William Zajc
Associate Professors: Greg Bryan, Zoltan Haiman, Kathryn Johnson, Kristen Menou, David Schiminovich
Adjunct Professors: Burton Budick, Morgan May

Requirements for the Astronomy Major

The courses required for the major in astronomy are as follows:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTR UN3602</td>
<td>Physical Cosmology and Extragalactic Astronomy</td>
<td>3</td>
</tr>
<tr>
<td>ASTR UN3273</td>
<td>High Energy Astrophysics</td>
<td>3</td>
</tr>
<tr>
<td>ASTR UN3646</td>
<td>Observational Astronomy</td>
<td>3</td>
</tr>
</tbody>
</table>

* Students may substitute a Columbia College three-semester calculus-based introductory physics sequence with lab taken at Barnard, as in the physics major.
** Students who have taken ASTR BC1753 Life in the Universe-ASTR BC1754 Stars, Galaxies, and Cosmology or ASTR UN1403 Earth, Moon and Planets (Lecture)-ASTR UN1404 Stars, Galaxies and Cosmology (Lecture) may substitute an additional 3000-level ASTR course for ASTR UN2001 Introduction To Astrophysics, I-ASTR UN2002 Introduction To Astrophysics, II.

Students planning to study astronomy or astrophysics in graduate school are strongly urged to take PHYS BC3006 Quantum Physics, PHYS UN3003 Mechanics, PHYS UN3007 Electricity and Magnetism-PHYS UN3008 Electromagnetic Waves and Optics, PHYS GU4023 Thermal and Statistical Physics, some additional courses in mathematics, and Computer Science COMS W1001 Introduction to Information Science or COMS W1004 Introduction to Computer Science and Programming in Java. Note: When any of the required courses is not being given, the department will recommend appropriate substitutions.

Requirements for the Physics Major

The courses required for the major in physics are:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYS BC2001</td>
<td>Physics I: Mechanics</td>
<td>4.5</td>
</tr>
<tr>
<td>PHYS BC2002</td>
<td>Physics II: Electricity and Magnetism</td>
<td>4.5</td>
</tr>
<tr>
<td>PHYS BC3001</td>
<td>Physics III: Classical Waves &amp; Optics</td>
<td>5</td>
</tr>
</tbody>
</table>

Calculus through IV is required, with additional work in mathematics recommended; e.g., MATH E1201x,y, APMA E3102y. The calculus sequence should be completed by the end of the sophomore year.

PHYS UN3003 Mechanics 3
PHYS BC3006 Quantum Physics 3
PHYS UN3007 Electricity and Magnetism 3
PHYS UN3008 Electromagnetic Waves and Optics 3
PHYS BC3086 Quantum Physics Laboratory and Advanced Electromagnetism Laboratory (taken concurrently with their cognate lecture courses) 6

Select one of the following:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Name</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMS W1001</td>
<td>Introduction to Information Science</td>
<td>3</td>
</tr>
<tr>
<td>COMS W1004</td>
<td>Introduction to Computer Science and Programming in Java</td>
<td>3</td>
</tr>
<tr>
<td>PHYS UN3083</td>
<td>Electronics Laboratory</td>
<td>3</td>
</tr>
</tbody>
</table>

* In lieu of the above, any three-semester Columbia introductory sequence acceptable for the physics major in Columbia College will do (e.g., PHYS UN1601 Physics, I: Mechanics and Relativity-PHYS UN1602 Physics, II: Thermodynamics, Electricity, and Magnetism, PHYS UN2601 Physics, III: Classical and Quantum Waves, taken with labs at Barnard). The accelerated two-semester Columbia College sequence PHYS UN2801 Accelerated Physics I-PHYS UN2802 Accelerated Physics II is also acceptable.

Students planning to study physics in graduate school should include several 4000-level electives in their senior year program.
Interdisciplinary Major
Special majors in, for example, astrophysics, biophysics, chemical physics, engineering physics, or mathematical physics are all possible and are arranged in conjunction with the relevant second department at Barnard. A student interested in such possibilities should speak to a faculty member early on (i.e., by late fall of her sophomore year) in order to permit the most effective construction of her program of study and the appropriate petition to be made to the Committee on Programs and Academic Standing. The latter is a straightforward procedure associated with the declaration of all special majors at Barnard.

Requirements for the Physics Minor
Five courses are required for the minor in physics. They are: any three-semester introductory sequence acceptable for the major (see above) plus two additional 3-point courses at the 3000-level.

Astronomy Courses

ASTR BC1753 Life in the Universe. 3 points.
CC/GS: Partial Fulfillment of Science Requirement
Prerequisites: recommended preparation: a working knowledge of high school algebra.
Introduction to astronomy intended primarily for nonscience majors. Includes the history of astronomy, the apparent motions of the moon, sun, stars, and planets; gravitation and planetary orbits; the physics of the earth and its atmosphere; and the exploration of the solar system. This course is similar to ASTR W1403. You cannot enroll in both courses and receive credit for both.

ASTR BC1754 Stars, Galaxies, and Cosmology. 3 points.
Prerequisites: Recommended preparation: A working knowledge of high school algebra.
Corequisites: Suggested parallel laboratory course: ASTR C1904y.
Examines the properties of stars, star formation, stellar evolution and nucleosynthesis, the Milky Way and other galaxies, and the cosmological origin and evolution of the universe. Students may not receive credit for both ASTR BC 1754 and ASTR C1404.

ASTR UN1234 The Universal Timekeeper: Reconstructing History Atom by Atom. 3 points.
CC/GS: Partial Fulfillment of Science Requirement
Prerequisites: high school algebra and latent curiosity are assumed. The goal of the course is to illustrate — and perhaps even inculcate — quantitative and scientific reasoning skills. The subject material employed in this task is the study of atoms and their nuclei which, through a wide variety of physical and chemical techniques, can be used to reconstruct quantitatively the past. Following an introduction to atoms, light, and energy, we will explore topics including the detection of art forgeries, the precise dating of archeological sites, a reconstruction of the development of agriculture and the history of the human diet, the history of past climate (and its implications for the future), the history and age of the Earth, and the history of the Universe. The course has no required text. Readings of relevant articles and use of on-line simulations will be required.

ASTR UN1403 Earth, Moon and Planets (Lecture). 3 points.
CC/GS: Partial Fulfillment of Science Requirement
Prerequisites: recommended preparation: a working knowledge of high school algebra.
The overall architecture of the solar system. Motions of the celestial sphere. Time and the calendar. Major planets, the earth-moon system, minor planets, comets. Life in the solar system and beyond. This course is similar to ASTR BC 1753. You cannot enroll in both courses and receive credit for both.

ASTR UN1404 Stars, Galaxies and Cosmology (Lecture). 3 points.
CC/GS: Partial Fulfillment of Science Requirement
Distances to, and fundamental properties of, nearby stars; nucleosynthesis and stellar evolution; novae and supernovae; galaxies; the structure of the universe and theories concerning its origin, evolution, and ultimate fate. You can only receive credit for ASTR UN1404 if you have not taken ASTR BC 1754, ASTR UN1420 or ASTR UN1836.
ASTR UN1420 Galaxies and Cosmology. 3 points.  
CC/GS: Partial Fulfillment of Science Requirement

Galaxies contain stars, gas dust, and (usually) super-massive black holes. They are found throughout the Universe, traveling through space and occasionally crashing into each other. This course will look at how these magnificent systems form and evolve, and what they can tell us about the formation and evolution of the Universe itself. You cannot enroll in ASTR UN1420 in addition to ASTR BC1754 or ASTR UN1404 and receive credit for both.

<table>
<thead>
<tr>
<th>Fall 2019: ASTR UN1420</th>
<th>Times/Location</th>
<th>Instructor</th>
<th>Points</th>
<th>Enrollment</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTR 1420 001/60274</td>
<td>T Th 10:10am - 11:25am</td>
<td>Mary Putman</td>
<td>3</td>
<td>50/65</td>
</tr>
<tr>
<td></td>
<td>313 Fayerweather</td>
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</tbody>
</table>

ASTR UN1453 Another Earth. 3 points.  
CC/GS: Partial Fulfillment of Science Requirement

This course cannot be taken for credit if BC1753 has been taken.

This course will explore the unique properties of Earth, compared to other planets in the Solar System, and the possibility of Earth-like planets around other stars. The basics of the Solar System, gravity, and light will be covered, as well as the geology and atmospheres of the terrestrial planets. The properties of Earth that allowed life to develop and whether life can develop on other planets will be discussed. Finally, the discovery of planets beyond our Solar System and the likelihood of another Earth will be a key component of the course.

ASTR UN1610 Theories of the Universe: From Babylon to the Big Bang. 3 points.  
CC/GS: Partial Fulfillment of Science Requirement

Milestones in the science of cosmology over the past 6000 years. Skyløre and observation in ancient cultures. The twin revolutions of the Greeks: Pythagoras and Ptolemy; and Aristotle, Aquinas, and the Great Chain of Being. The "scientific revolution": the impersonal and deterministic world-order of Newton, Laplace, and Kelvin. The erosion of that world-order by Being. The "scientific revolution": the impersonal and deterministic world-

<table>
<thead>
<tr>
<th>Spring 2020: ASTR UN1610</th>
<th>Times/Location</th>
<th>Instructor</th>
<th>Points</th>
<th>Enrollment</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTR 1610 001/15111</td>
<td>Th 2:40pm - 3:55pm</td>
<td>Joseph Patterson</td>
<td>3</td>
<td>81/90</td>
</tr>
<tr>
<td>329 Pupin Laboratories</td>
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</tbody>
</table>

ASTR UN1836 Stars and Atoms. 3 points.  
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: recommended preparation: a working knowledge of high school algebra.

What is the origin of the chemical elements? This course addresses this question, starting from understanding atoms, and then going on to look at how how atoms make stars and how stars make atoms. The grand finale is a history of the evolution of the chemical elements throughout time, starting from the Big Bang and ending with YOU. You cannot enroll in ASTR UN1836 in addition to ASTR BC1754 or ASTR UN1404 and receive credit for both.

<table>
<thead>
<tr>
<th>Fall 2019: ASTR UN1836</th>
<th>Times/Location</th>
<th>Instructor</th>
<th>Points</th>
<th>Enrollment</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTR 1836 001/60271</td>
<td>M W 1:10pm - 2:25pm</td>
<td>Frederik Paerels</td>
<td>3</td>
<td>37/40</td>
</tr>
<tr>
<td>415 Schapiro Cesper</td>
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</table>

<table>
<thead>
<tr>
<th>Spring 2020: ASTR UN1836</th>
<th>Times/Location</th>
<th>Instructor</th>
<th>Points</th>
<th>Enrollment</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTR 1836 001/15112</td>
<td>M W 2:40pm - 3:55pm</td>
<td>Marcel Agueros</td>
<td>3</td>
<td>45/45</td>
</tr>
<tr>
<td>303 Hamilton Hall</td>
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</tbody>
</table>

ASTR UN1903 Astronomy Lab 1. 1 point.  
Laboratory for ASTR UN103. Projects include observations with the department's telescopes, computer simulation, laboratory experiments in spectroscopy, and the analysis of astronomical data. Lab 1 ASTR UN1903 - goes with ASTR BC1753, ASTR UN1403 or ASTR UN1453.

<table>
<thead>
<tr>
<th>Fall 2019: ASTR UN1903</th>
<th>Times/Location</th>
<th>Instructor</th>
<th>Points</th>
<th>Enrollment</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTR 1903 001/09066</td>
<td>M 6:00pm - 9:00pm</td>
<td>Laura Kay, Jorge Cortes</td>
<td>1</td>
<td>7/13</td>
</tr>
<tr>
<td>1402 Pupin Laboratories</td>
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<td></td>
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</tbody>
</table>

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<thead>
<tr>
<th>Spring 2020: ASTR UN1903</th>
<th>Times/Location</th>
<th>Instructor</th>
<th>Points</th>
<th>Enrollment</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTR 1903 003/09068</td>
<td>W 6:00pm - 9:00pm</td>
<td>Laura Kay, Tianhuan Lu</td>
<td>1</td>
<td>7/13</td>
</tr>
<tr>
<td>1332 Pupin Laboratories</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| ASTR 1903 001/00678      | W 7:00pm - 10:00pm | Laura Kay, Navin Sridhar | 1      | 8/13      |
| 1332 Pupin Laboratories  |               |            |        |            |
ASTR UN1904 Astronomy Lab. 1 point.
Laboratory for ASTR UN1404. Projects include use of telescopes, laboratory experiments in the nature of light, spectroscopy, and the analysis of astronomical data. Lab 2 ASTR UN1904 - goes with ASTR BC1754 or ASTR UN1404 (or ASTR UN1836 or ASTR UN1420).

ASTR 2900 Frontiers of Astrophysics. 1 point.
Several members of the faculty each offer a brief series of talks providing context for a current research topic in the field and then present results of their ongoing research. Opportunities for future student research collaboration are offered. Grading is Pass/Fail.

ASTR 2001 Introduction To Astrophysics, I. 3 points.
CC/GS: Partial Fulfillment of Science Requirement
Prerequisites: a working knowledge of calculus.
Corequisites: a course in calculus-based general physics.
First term of a two-term calculus-based introduction to astronomy and astrophysics. Topics include the physics of stellar interiors, stellar atmospheres and spectral classifications, stellar energy generation and nucleosynthesis, supernovae, neutron stars, white dwarfs, and interacting binary stars.

ASTR 2002 Introduction To Astrophysics, II. 3 points.
Prerequisites: a working knowledge of calculus.
Corequisites: the second term of a course in calculus-based general physics.
Continuation of ASTR UN2001; these two courses constitute a full year of calculus-based introduction to astrophysics. Topics include the structure of our galaxy, the interstellar medium, star clusters, properties of external galaxies, clusters of galaxies, active galactic nuclei, and cosmology.

ASTR 3101 Modern Stellar Astrophysics II. 3 points.
CC/GS: Partial Fulfillment of Science Requirement
Prerequisites: one year of calculus-based general physics.
Introductory astronomy is not required, but some exposure to astronomy is preferable. In the first half of the course, we will examine the physics of stellar interiors in detail, leading us to develop models of stellar structure and consider how stars evolve. In the second half of the course, we will discuss special topics, such as pre-main sequence evolution, the late stages of stellar evolution, and supernovae and compact objects.

ASTR 3102 Planetary Dynamics and Physics of the Solar System. 3 points.
CC/GS: Partial Fulfillment of Science Requirement
Prerequisites: one year of calculus-based Physics.

ASTR 3103 Galaxies. 3 points.
Prerequisites: one year of calculus-based general physics.
Galaxies fill the universe with structure. They are bound objects that harbor stars, gas, dust and dark matter. This course will discuss the content and structure of galaxies. It will start with the Milky Way, a rotating spiral galaxy, with a particular emphasis on the properties of the interstellar medium. Dwarf galaxies, the building blocks of larger galaxies, will subsequently be discussed, followed by spiral, elliptical and irregular galaxies. The formation and evolution of these different galaxy types will be an important focus of the course, as well as the environment in which the galaxies reside. We will intersperse reviews of current papers on galaxies throughout the semester.

ASTR 3105 Extrasolar Planets and Astrobiology. 3 points.
Prerequisites: One year of calculus-based physics.
The emerging field of extrasolar planets and astrobiology will be covered at a quantitative level, with a major emphasis on astrophysical phenomena and techniques. The subject will be introduced through an investigation of current planetary formation theories and approaches to planet detection, including what we currently know about extrasolar planets and detailed reference to state-of-the-art studies. An astronomer’s view of the origin of life and extreme biology will be developed and applied to questions of cosmo-chemistry, observable life-signatures, habitable zones and other astrophysical constraints on the development of organisms.
ASTR UN3106 The Science of Space Exploration. 3 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: one semester course in introductory astronomy or astrophysics (e.g., ASTR UN1403, ASTR UN1404, ASTR UN1420, ASTR UN1836, ASTR UN2001, ASTR UN2002, ASTR BC1753, ASTR BC1754). Ability in mathematics up to and including calculus is strongly urged. How and why do humans explore space? Why does it require such extraordinary effort? What have we found by exploring our Solar System? We investigate the physics and biological basis of space exploration, and the technologies and science issues that determine what we can accomplish. What has been accomplished in the past, what is being explored now, and what can we expect in the future? How do space scientists explore the Solar System and answer science questions in practice? What do we know about solar systems beyond our own?

ASTR UN3273 High Energy Astrophysics. 3 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: one year of calculus-based general physics. No previous, n’astronomy background required.

A survey of the most energetic and explosive objects in the Universe and their radiation. Topics include: techniques of X-ray and gamma-ray astronomy; observations of neutron stars (pulsars) and black holes; accretion disks and relativistic jets; supernovae, supernova remnants, gamma-ray bursts, quasars and active galactic nuclei; clusters of galaxies; cosmic rays and neutrinos.

ASTR UN3602 Physical Cosmology and Extragalactic Astronomy. 3 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: one year of calculus-based general physics.

The standard hot big bang cosmological model and modern observational results that test it. Topics include the Friedmann equations and the expansion of the universe, dark matter, dark energy, inflation, primordial nucleosynthesis, the cosmic microwave background, the formation of large-scale cosmic structures, and modern cosmological observations.

ASTR UN3646 Observational Astronomy. 3 points.

Prerequisites: one year of general astronomy

Introduction to the basic techniques used in obtaining and analyzing astronomical data. Focus on ‘ground-based’ methods at optical, infrared, and radio wavelengths. Regular use of the telescope facilities atop the roof of the Pupin Labs. In research projects, students also work on the analysis of data obtained at National Observatories.

ASTR UN3985 Statistics and the Universe (Seminar). 3 points.

Prerequisites: First year calculus required, introductory physics or astronomy

Essential statistical methods will be applied in a series of case studies and research projects taken from the latest advances in cosmology, astronomy and physics. Statistics of measurement and detection, fundamentals of hypothesis testing, classifications, data modeling, time-series analysis, correlation and clustering will be explored through hands-on investigation using data from recent experiments and surveys.

ASTR UN3996 Current Research in Astrophysics. 1 point.

Prerequisites: two semesters of astronomy classes and two semesters of physics classes.

The goal of this course is to introduce astronomy and astrophysics majors to the methods and topics of current astronomical research. The course will also help with the development of critical thinking skills. Each week, the topic of the course will be centered on the subject of the Astronomy department colloquium; this may include research on planets, stars, galaxies or cosmology. There will be two required meetings per week: the first will be to discuss papers related to the colloquium (time TBD), and the second will be the colloquium itself (at 4:15 pm each Wednesday). Grading is Pass/Fail.

ASTR GU4302 General Relativity, Black Holes, and Cosmology. 3 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: one year of calculus-based general physics.

Einstein’s General Theory of Relativity replaced Newtonian gravity with an elegant theory of curved spacetime. Einstein’s theory led to unforeseen and unnerving predictions of singularities and cosmological instabilities. Nearly a century later, these mathematical oddities have been confirmed astrophysically in the existence of black holes, an expanding universe, and a big bang. The course will cover Einstein’s General Theory, beginning with special relativity, with an emphasis on black holes and the big bang.

Physics Courses

PHYS BC2001 Physics I: Mechanics. 4.5 points.
BC: Fulfillment of General Education Requirement: Quantitative and Deductive Reasoning (QUA). Lab Required

Corequisites: Calculus I or the equivalent.
Fundamental laws of mechanics. Kinematics, Newton’s laws, work and energy, conservation laws, collisions, rotational motion, oscillations, gravitation.
PHYS BC2002 Physics II: Electricity and Magnetism. 4.5 points.
BC: Fulfillment of General Education Requirement: Quantitative and Deductive Reasoning (QUA), Lab Required
Prerequisites: Physics BC2001 or the equivalent.
Corequisites: Calculus II.

<table>
<thead>
<tr>
<th>Spring 2020: PHYS BC2002</th>
<th>Course Number</th>
<th>Section/Call</th>
<th>Times/Location</th>
<th>Instructor</th>
<th>Points</th>
<th>Enrollment</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYS 2002</td>
<td>001/00398</td>
<td>T Th 10:10am - 11:25am</td>
<td>903 Altschul Hall</td>
<td>Janna Levin</td>
<td>4.5</td>
<td>42</td>
</tr>
</tbody>
</table>

PHYS BC3001 Physics III: Classical Waves & Optics. 5 points.
BC: Fulfillment of General Education Requirement: Quantitative and Deductive Reasoning (QUA), Lab Required
Prerequisites: Physics BC2002 or the equivalent.
Corequisites: Calculus III.
Nonlinear pendula, transverse vibrations-elastic strings, longitudinal sound waves, seism waves, electromagnetic oscillations & light, rainbows, haloes, the Green Flash; polarization phenomena - Haidinger’s Brush, Brewster’s angle, double refraction, optical activity; gravity & capillary waves; interference, diffraction, lenses & mirrors.

<table>
<thead>
<tr>
<th>Fall 2019: PHYS BC3001</th>
<th>Course Number</th>
<th>Section/Call</th>
<th>Times/Location</th>
<th>Instructor</th>
<th>Points</th>
<th>Enrollment</th>
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<tr>
<td>PHYS 3001</td>
<td>001/00132</td>
<td>T Th 10:00am - 11:30am</td>
<td>514 Altschul Hall</td>
<td>Timothy Halpin-Healy, Margaret Kaye</td>
<td>5</td>
<td>12/15</td>
</tr>
<tr>
<td>PHYS 3001</td>
<td>001/00132</td>
<td>W 4:10pm - 8:00pm</td>
<td>514 Altschul Hall</td>
<td>Timothy Halpin-Healy, Margaret Kaye</td>
<td>5</td>
<td>12/15</td>
</tr>
</tbody>
</table>

PHYS BC3006 Quantum Physics. 3 points.
Prerequisites: BC3001 or C2601 or the equivalent.
Wave-particle duality and the Uncertainty Principle. The Schrodinger equation. Basic principles of the quantum theory. Energy levels in one-dimensional potential wells. The harmonic oscillator, photons, and phonons. Reflection and transmission by one-dimensional potential barriers. Applications to atomic, molecular, and nuclear physics.

<table>
<thead>
<tr>
<th>Spring 2020: PHYS BC3006</th>
<th>Course Number</th>
<th>Section/Call</th>
<th>Times/Location</th>
<th>Instructor</th>
<th>Points</th>
<th>Enrollment</th>
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<tbody>
<tr>
<td>PHYS 3006</td>
<td>001/00400</td>
<td>T Th 10:10am - 11:25am</td>
<td>514 Altschul Hall</td>
<td>Reshmi Mukherjee</td>
<td>3</td>
<td>16</td>
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</table>

PHYS BC3082 Advanced Physics Laboratory. 1.5 point.
Barnard College physics laboratory has available a variety of experiments meant to complement 3000-level lecture courses. Each experiment requires substantial preparation, as well as written and oral presentations. Elementary particle experiments: detectors, cosmic ray triggers, muon lifetime.

<table>
<thead>
<tr>
<th>Spring 2020: PHYS BC3082</th>
<th>Course Number</th>
<th>Section/Call</th>
<th>Times/Location</th>
<th>Instructor</th>
<th>Points</th>
<th>Enrollment</th>
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<tr>
<td>PHYS 3900</td>
<td>001/00402</td>
<td></td>
<td></td>
<td>Reshmi Mukherjee</td>
<td>1.5</td>
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</tbody>
</table>

PHYS BC3086 Quantum Physics Laboratory. 3 points.
Experiments illustrating phenomenological aspects of the early quantum theory: (i) Hydrogenic Spectra: Balmer Series & Bohr-Sommerfeld Model; (ii) Photoelectric Effect: Millikan’s Determination of h/e; (iii) Franck-Hertz Experiment; and (iv) Electron Diffraction Phenomena. Substantial preparation required, including written and oral presentations, as well as an interest in developing the knack and intuition of an experimental physicist. This course is best taken concurrently with PHYS BC3006 Quantum Physics.

<table>
<thead>
<tr>
<th>Spring 2020: PHYS BC3086</th>
<th>Course Number</th>
<th>Section/Call</th>
<th>Times/Location</th>
<th>Instructor</th>
<th>Points</th>
<th>Enrollment</th>
</tr>
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<td>001/00401</td>
<td>F 9:00am - 10:00am</td>
<td>510b Altschul Hall</td>
<td>Reshmi</td>
<td>3</td>
<td>14</td>
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</table>

PHYS BC3088 Advanced Electromagnetism Laboratory. 3 points.
Classical electromagnetic wave phenomena via Maxwell’s equations, including: (i) Michaelson and Fabry-Perot Interferometry, as well as a thin-film interference and elementary dispersion theory; (ii) Fraunhofer Diffraction (and a bit of Fresnel); (iii) Wireless Telegraphy I: AM Radio Receivers; and (iv) Wireless Telegraphy II: AM Transmitters. Last two labs pay homage to relevant scientific developments in the period 1875-1925, from the discovery of Hertzian waves to the Golden Age of Radio. Complements PHYS W3008 Electromagnetic Waves and Optics.

<table>
<thead>
<tr>
<th>Fall 2019: PHYS BC3088</th>
<th>Course Number</th>
<th>Section/Call</th>
<th>Times/Location</th>
<th>Instructor</th>
<th>Points</th>
<th>Enrollment</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYS 3088</td>
<td>001/0060</td>
<td>F 10:30am - 12:00pm</td>
<td>510b Altschul Hall</td>
<td>Stiliana Savin</td>
<td>3</td>
<td>5/15</td>
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</tbody>
</table>

PHYS BC3900 Supervised Individual Research. 1-5 points.
1-5 points per term.
Prerequisites: Permission of the departmental representative required. For specially selected students, the opportunity to do a research problem 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.

<table>
<thead>
<tr>
<th>Fall 2019: PHYS BC3900</th>
<th>Course Number</th>
<th>Section/Call</th>
<th>Times/Location</th>
<th>Instructor</th>
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<td>PHYS 3900</td>
<td>001/0065</td>
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<td></td>
<td>0. FACULTY, Reshmi Mukherjee</td>
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<th>Course Number</th>
<th>Section/Call</th>
<th>Times/Location</th>
<th>Instructor</th>
<th>Points</th>
<th>Enrollment</th>
</tr>
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<tr>
<td>PHYS 3900</td>
<td>001/00402</td>
<td></td>
<td></td>
<td>Reshmi Mukherjee</td>
<td>1.5</td>
<td>0</td>
</tr>
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</table>
PHYS UN1001 Physics for Poets. 3 points.
CC/GS: Partial Fulfillment of Science Requirement

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.

PHYS UN1201 General Physics I. 3 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.
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.

Fall 2019: PHYS UN1201
Course Number  Section/Call Number  Times/Location  Instructor  Points  Enrollment
PHYS 1201  1001/47032  M W 10:10am - 11:25am  301 Pupin Laboratories  Michael 3 161/160
PHYS 1201  1002/47033  M W 10:10am - 11:25am  428 Pupin Laboratories  Shavelitz 3 78/130
PHYS 1201  1003/47034  T Th 6:10pm - 7:25pm  428 Pupin Laboratories  Thomas 3 45/130

Spring 2020: PHYS UN1201
Course Number  Section/Call Number  Times/Location  Instructor  Points  Enrollment
PHYS 1201  1001/15888  M W 5:40pm - 6:55pm  428 Pupin Laboratories  Michael Tuts 3 71/130

PHYS UN1202 General Physics II. 3 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. Electricity, magnetism, optics, and modern physics.

Spring 2020: PHYS UN1202
Course Number  Section/Call Number  Times/Location  Instructor  Points  Enrollment
PHYS 1202  1001/15889  M W 10:10am - 11:25am  301 Pupin Laboratories  Cory Dean 3 181/180
PHYS 1202  1003/15890  T Th 6:10pm - 7:25pm  428 Pupin Laboratories  Burton Budick 3 70/130

PHYS UN1291 General Physics Laboratory. 1 point.
Same course as PHYS W1291x, but given off-sequence.

Fall 2019: PHYS UN1291
Course Number  Section/Call Number  Times/Location  Instructor  Points  Enrollment
PHYS 1291  1001/47054  M 1:00pm - 4:00pm  5th Flr Pupin Laboratories  Giuseppina 1 13/15
PHYS 1291  1002/47055  M 1:00pm - 4:00pm  5th Flr Pupin Laboratories  Giuseppina 1 14/15
PHYS 1291  1003/47056  M 4:10pm - 7:10pm  5th Flr Pupin Laboratories  Giuseppina 1 11/15
PHYS 1291  1004/47057  M 4:10pm - 7:10pm  5th Flr Pupin Laboratories  Giuseppina 1 14/15
PHYS 1291  1005/47058  M 7:30pm - 10:30pm  5th Flr Pupin Laboratories  Giuseppina 1 9/15
PHYS 1291  1007/47060  T 1:00pm - 4:00pm  5th Flr Pupin Laboratories  Giuseppina 1 9/15
PHYS 1291  1008/47061  T 1:00pm - 4:00pm  5th Flr Pupin Laboratories  Giuseppina 1 13/15
PHYS 1291  1009/47062  T 4:10pm - 7:10pm  5th Flr Pupin Laboratories  Giuseppina 1 15/15
PHYS 1291  1010/47063  T 4:10pm - 7:10pm  5th Flr Pupin Laboratories  Giuseppina 1 9/15
PHYS 1291  1011/47064  T 7:30pm - 10:30pm  5th Flr Pupin Laboratories  Giuseppina 1 11/15
PHYS 1291  1013/47066  W 1:00pm - 4:00pm  5th Flr Pupin Laboratories  Giuseppina 1 13/15
PHYS 1291  1014/47067  W 1:00pm - 4:00pm  5th Flr Pupin Laboratories  Giuseppina 1 15/15
PHYS 1291  1015/47068  W 4:10pm - 7:10pm  5th Flr Pupin Laboratories  Giuseppina 1 12/15
PHYS 1291  1016/47069  W 4:10pm - 7:10pm  5th Flr Pupin Laboratories  Giuseppina 1 15/15
PHYS 1291  1017/47070  W 7:30pm - 10:30pm  5th Flr Pupin Laboratories  Giuseppina 1 8/15
PHYS 1291  1019/47072  T 1:00pm - 4:00pm  5th Flr Pupin Laboratories  Giuseppina 1 15/15
PHYS 1291  1020/47073  T 1:00pm - 4:00pm  5th Flr Pupin Laboratories  Giuseppina 1 13/15
PHYS 1291  1021/47074  T 4:10pm - 7:10pm  5th Flr Pupin Laboratories  Giuseppina 1 8/15
PHYS 1291  1022/47075  T 4:10pm - 7:10pm  5th Flr Pupin Laboratories  Giuseppina 1 10/15
PHYS 1291  1025/47078  F 1:00pm - 4:00pm  5th Flr Pupin Laboratories  Giuseppina 1 13/15
PHYS 1291  1026/47079  F 1:00pm - 4:00pm  5th Flr Pupin Laboratories  Giuseppina 1 13/15

Spring 2020: PHYS UN1291
Course Number  Section/Call Number  Times/Location  Instructor  Points  Enrollment
PHYS 1291  1001/15923  M 1:00pm - 4:00pm  5th Flr Pupin Laboratories  Giuseppina 1 9/15
PHYS 1291  1002/15924  M 7:30pm - 10:30pm  5th Flr Pupin Laboratories  Giuseppina 1 9/15
PHYS 1291  1003/15927  T 1:00pm - 4:00pm  5th Flr Pupin Laboratories  Giuseppina 1 11/15
PHYS 1291  1004/15928  T 4:10pm - 7:10pm  5th Flr Pupin Laboratories  Giuseppina 1 8/15
PHYS 1291  1005/15929  W 1:00pm - 4:00pm  5th Flr Pupin Laboratories  Giuseppina 1 11/15
PHYS 1291  1007/15932  Th 1:00pm - 4:00pm  5th Flr Pupin Laboratories  Giuseppina 1 15/15

Points  Enrollment
11/15
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PHYS UN1292 General Physics Laboratory II. 1 point.
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 UN1401 Introduction To Mechanics and Thermodynamics. 3 points.
CC/GS: Partial Fulfillment of Science Requirement
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 UN1402 Introduction To Electricity, Magnetism, and Optics. 3 points.
CC/GS: Partial Fulfillment of Science Requirement
Prerequisites: PHYS UN1401
Corequisites: MATH UN1102
Electric fields, direct currents, magnetic fields, alternating currents, electromagnetic waves, polarization, geometrical optics, interference, and diffraction. Corequisite: MATH UN1102 Calculus II or equivalent.
PHYS UN3007 Electricity and Magnetism. 3 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 2019: PHYS UN3007
<table>
<thead>
<tr>
<th>Course Number</th>
<th>Section/Call Number</th>
<th>Times/Location</th>
<th>Instructor</th>
<th>Points</th>
<th>Enrollment</th>
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<tbody>
<tr>
<td>PHYS 3007</td>
<td>001/47001</td>
<td>M W 11:40am - 12:55pm</td>
<td>Alfred Mueller, Giuseppe Cambarei</td>
<td>3</td>
<td>44/100</td>
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</table>

PHYS UN3008 Electromagnetic Waves and Optics. 3 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 2020: PHYS UN3008
<table>
<thead>
<tr>
<th>Course Number</th>
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<th>Instructor</th>
<th>Points</th>
<th>Enrollment</th>
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<tr>
<td>PHYS 3008</td>
<td>001/15898</td>
<td>M W 11:40am - 12:55pm</td>
<td>Alfred Mueller</td>
<td>3</td>
<td>35/70</td>
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</tbody>
</table>

PHYS UN3083 Electronics Laboratory. 3 points.
Enrollment limited to the capacity of the laboratory.

Prerequisites: PHYS UN3003 or PHYS UN3007 May be taken before or concurrently with this course.
A sequence of experiments in solid-state electronics, with introductory lectures.

Spring 2020: PHYS UN3083
<table>
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<tr>
<th>Course Number</th>
<th>Section/Call Number</th>
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<th>Instructor</th>
<th>Points</th>
<th>Enrollment</th>
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<tr>
<td>PHYS 3083</td>
<td>001/15903</td>
<td>M W 1:10pm - 2:25pm</td>
<td>John Parsons</td>
<td>3</td>
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</table>

PHYS GU4003 Advanced Mechanics. 3 points.
Prerequisites: differential and integral calculus, differential equations, and PHYS UN3003 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 2020: PHYS GU4003
<table>
<thead>
<tr>
<th>Course Number</th>
<th>Section/Call Number</th>
<th>Times/Location</th>
<th>Instructor</th>
<th>Points</th>
<th>Enrollment</th>
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<tr>
<td>PHYS 4003</td>
<td>001/15909</td>
<td>M W 1:10pm - 2:25pm</td>
<td>James Hill</td>
<td>3</td>
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</table>

PHYS GU4021 Quantum Mechanics I. 3 points.
Prerequisites: PHYS UN3003 and PHYS UN3007

Fall 2019: PHYS GU4021
<table>
<thead>
<tr>
<th>Course Number</th>
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<th>Instructor</th>
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<tr>
<td>PHYS 4021</td>
<td>001/47002</td>
<td>T Th 11:40am - 12:55pm</td>
<td>William Zajc</td>
<td>3</td>
<td>29/100</td>
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</tbody>
</table>

PHYS GU4022 Quantum Mechanics II. 3 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 2020: PHYS GU4022
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<td>001/15912</td>
<td>T Th 1:10pm - 2:25pm</td>
<td>William Zajc</td>
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</table>

PHYS GU4023 Thermal and Statistical Physics. 3 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 2019: PHYS GU4023
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<th>Enrollment</th>
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<tr>
<td>PHYS 4023</td>
<td>001/47045</td>
<td>T Th 1:10pm - 2:25pm</td>
<td>Andrew Millis</td>
<td>3</td>
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Cross-Listed Courses

PHYS UN3002 From Quarks To the Cosmos: Applications of Modern Physics. 3.5 points.
Not offered during 2019-20 academic year.

Prerequisites: PHYS UN2601 or PHYS UN2802
This course reinforces basic ideas of modern physics through applications to nuclear physics, high energy physics, astrophysics and cosmology. The ongoing Columbia research programs in these fields are used as practical examples. The course is preparatory for advanced work in physics and related fields.

Cross-Listed Courses

Physics