The Department of Physics and Astronomy offers undergraduate and graduate programs for a wide range of interests. The bachelor of arts degree with majors in physics or astronomy is suitable for students who wish to obtain a broad liberal arts education with a concentration in a physical science. The bachelor of science degree with majors in physics, astrophysics, or chemical physics provides preparation for employment or further study in physics, astrophysics, and related technical fields. The minor in physics provides a solid foundation in physics with additional advanced physics topics of the student’s choosing.

Research facilities and thesis supervision are available for MS and PhD students in atomic, molecular, and optical physics; biophysics; condensed matter physics; galactic astronomy; high energy astrophysics, nuclear and particle physics; and space physics.

**Bachelor’s Programs**

- Bachelor of Arts (BA) Degree with a Major in Astronomy ([ga.rice.edu/programs-study/departments-programs/natural-sciences/physics-astronomy/astronomy-ba](ga.rice.edu/programs-study/departments-programs/natural-sciences/physics-astronomy/astronomy-ba))
- Bachelor of Arts (BA) Degree with a Major in Physics ([ga.rice.edu/programs-study/departments-programs/natural-sciences/physics-astronomy/physics-ba](ga.rice.edu/programs-study/departments-programs/natural-sciences/physics-astronomy/physics-ba))
- Bachelor of Science (BS) Degree with a Major in Astrophysics ([ga.rice.edu/programs-study/departments-programs/natural-sciences/physics-astronomy/astrophysics-bs](ga.rice.edu/programs-study/departments-programs/natural-sciences/physics-astronomy/astrophysics-bs))
- Bachelor of Science (BS) Degree with a Major in Physics
  - and a Major Concentration in Biological Physics ([ga.rice.edu/programs-study/departments-programs/natural-sciences/physics-astronomy/biological-physics-bs](ga.rice.edu/programs-study/departments-programs/natural-sciences/physics-astronomy/biological-physics-bs))
  - and a Major Concentration in Computational Physics ([ga.rice.edu/programs-study/departments-programs/natural-sciences/physics-astronomy/computational-physics-bs](ga.rice.edu/programs-study/departments-programs/natural-sciences/physics-astronomy/computational-physics-bs))
  - and a Major Concentration in General Physics ([ga.rice.edu/programs-study/departments-programs/natural-sciences/physics-astronomy/general-physics-bs](ga.rice.edu/programs-study/departments-programs/natural-sciences/physics-astronomy/general-physics-bs))

**Minor**


**Coordinated Program**

- Bachelor of Science (BS) Degree with a Major in Chemical Physics ([ga.rice.edu/programs-study/departments-programs/natural-sciences/chemical-physics/chemical-physics-bs](ga.rice.edu/programs-study/departments-programs/natural-sciences/chemical-physics/chemical-physics-bs))

* This degree is jointly managed by the Department of Chemistry and the Department of Physics and Astronomy. For more information, see Chemical Physics. ([ga.rice.edu/programs-study/departments-programs/natural-sciences/chemical-physics/chemical-physics-bs](ga.rice.edu/programs-study/departments-programs/natural-sciences/chemical-physics/chemical-physics-bs))

**Master’s Program**

- Master of Science (MS) Degree in the field of Physics*

**Doctoral Program**

- Doctor of Philosophy (PhD) Degree in the field of Physics ([ga.rice.edu/programs-study/departments-programs/natural-sciences/physics-astronomy/physics-phd](ga.rice.edu/programs-study/departments-programs/natural-sciences/physics-astronomy/physics-phd))

* Although students are not normally admitted to a Master of Science (MS) degree program, graduate students may earn the MS as they work towards the PhD.

**Coordinated Program**

- Master of Science Teaching (MST) Degree ([ga.rice.edu/programs-study/departments-programs/natural-sciences/science-teaching/teaching-mst](ga.rice.edu/programs-study/departments-programs/natural-sciences/science-teaching/teaching-mst))

**Chair**

Douglas Natelson

**Professors**

David Alexander
Matthew G. Baring
Anthony A. Chan
Pengcheng Dai
Michael W. Deem
Rui-Rui Du
F. Barry Dunning
Jason H. Hafner
Naomi J. Halas
Patrick M. Hartigan
Huey W. Huang
Randall G. Hulet
Christopher M. Johns-Krull
Thomas C. Killian
Junichiro Kono
Herbert Levine
Eugene H. Levy
Edison P. Liang
Frederick C. MacKintosh
Emilia Morosan
Peter Nordlander
Jose Nelson Onuchic
B. Paul Padley
Physics and Astronomy

Han Pu
Patricia H. Reiff
Jabus B. Roberts Jr.
Gustavo E. Scuseria
Qimiao Si
Frank R. Toffoletto
Peter C. Wolynes

Associate Professors
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Karl M. Ecklund
Franciscus Johannes Maria Geurts
Ching-Hwa Kiang
Wei Li
Andriy Nevidomskyy

Assistant Professors
Mustafa Amin
Matthew S. Foster
Kaden Hazzard
Andrea Isella

Professors Emeriti
Paul A. Cloutier
Thomas W. Hill
Neal F. Lane
Carl Rau
Richard A. Wolf

Associate Research Professors
Stanislav Sazykin
Ian Smith
Pablo P. Yepes

Assistant Research Professor
Petr Chaguine

Lecturers
James L. Burch
Sergio Kapusta

Instructors
Robert Beaird
Michael Cone
Jared Stenson
Lam Yu

Adjunct Faculty
Franklin R. Chang Diaz
Stefan Kirchner
Hui Li
Carolyn Sumners
Jon C. Weisheit
Jian-Xin Zhu

For Rice University degree-granting programs:

To view the list of official course offerings, please see Rice's Course Catalog (https://courses.rice.edu/admweb/ISWKSCAT.cat?p_action=cata)
To view the most recent semester's course schedule, please see Rice's Course Schedule (https://courses.rice.edu/admweb/ISWKSCAT.cat)

Astronomy (ASTR)

ASTR 100 - EXPLORING THE COSMOS
Short Title: EXPLORING THE COSMOS
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Seminar
Credit Hour: 1
Restrictions: Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.
Course Level: Undergraduate Lower-Level
Description: Introduction to concepts, methods and discoveries of astronomy and astrophysics, with a theme to be chosen from the frontier topics of modern astrophysics. Will emphasize student presentations. Designed for first year students interested in science or engineering, but other majors are welcome.

ASTR 201 - STARS, GALAXIES, AND THE UNIVERSE
Short Title: STARS, GALAXIES & THE UNIVERSE
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Distribution Group: Distribution Group III
Credit Hours: 3
Restrictions: Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.
Course Level: Undergraduate Lower-Level
Description: An introductory course for students in academic programs. The formation, evolution, and death of stars; the composition and evolution of galaxies; the structure and evolution of the universe.

ASTR 202 - EXPLORATION OF THE SOLAR SYSTEM
Short Title: EXPLORATN OF THE SOLAR SYSTEM
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Distribution Group: Distribution Group III
Credit Hours: 3
Restrictions: Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.
Course Level: Undergraduate Lower-Level
Description: The physical processes governing the nature and behavior of the various Solar System bodies are discussed with a focus on the origins, evolution and fate of the Solar System and its parts. This broader context leads to a deeper understanding of the Earth as a life-supporting planet.
astronomy. Possible effects of solar variability will be explored. Together, ASTR 350 and ASTR 360 provide a comprehensive survey of modern astrophysics needed for senior research and graduate study in astronomy. Either ASTR 350 or 360 may be taken first. Recommended Prerequisite(s): MATH 212

ASTR 360 - INTRODUCTION TO ASTROPHYSICS-GALAXY AND COSMO

Short Title: INTRO ASTROPHYSIC-GALAXY&COSMO
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.
Course Level: Undergraduate Upper-Level
Prerequisite(s): MATH 211 and PHYS 202
Description: Morphology, kinematics, and dynamics of the Milky Way and external galaxies, including interstellar matter and evidence for dark matter. Peculiar and active galaxies, including interacting systems and evidence for super massive black holes in active galactic nuclei such as quasars. Large-scale structure and expansion of the universe, including various cosmologies ranging from the inflationary big bang theory to steady state and anthropic concepts. Either ASTR 350 or 360 may be taken first. PHYS 202 may be taken as a prereq or concurrently with ASTR 360.

ASTR 400 - UNDERGRADUATE RESEARCH SEMINAR

Short Title: UNDERGRADUATE RESEARCH SEMINAR
Department: Physics and Astronomy
Grade Mode: Satisfactory/Unsatisfactory
Course Type: Seminar
Credit Hour: 1
Restrictions: Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.
Course Level: Undergraduate Upper-Level
Description: Seminar on current research topics in astronomy, astrophysics, and space physics for juniors and seniors. Students will be expected to give one oral presentation each semester. Graduate/Undergraduate Equivalency: ASTR 500. Repeatable for Credit.
ASTR 451 - ASTROPHYSICS I: SUN AND STARS
Short Title: ASTROPHYSICS I: SUN AND STARS
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Undergraduate, Professional or Visiting Undergraduate level students.
Course Level: Undergraduate Upper-Level
Prerequisite(s): ASTR 350 or ASTR 360 and (PHYS 301 and PHYS 302)
Description: Study of the Sun, solar-terrestrial relationships, solar wind; planetary atmospheres, ionospheres and magnetospheres. Graduate/Undergraduate Equivalency: ASTR 450. Mutually Exclusive: Credit cannot be earned for ASTR 470 and ASTR 402.

ASTR 470 - SOLAR SYSTEM PHYSICS
Short Title: SOLAR SYSTEM PHYSICS
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Undergraduate, Professional or Visiting Undergraduate level students.
Course Level: Undergraduate Upper-Level
Prerequisite(s): PHYS 301 and PHYS 302
Description: Overview of the Earth and the solar system: structure, evolution, and dynamics. Includes non-calculus mathematics: algebra, logarithms and simple trigonometry, including Kepler’s laws. Observing sessions at campus observatory and George Observatory TBD. Designed for inservice and preservice science teachers (grades 4-12), but open to undergraduates considering a teaching career. Mutually Exclusive: Credit cannot be earned for ASTR 502 and ASTR 402.

ASTR 500 - GRADUATE RESEARCH SEMINAR
Short Title: GRADUATE RESEARCH SEMINAR
Department: Physics and Astronomy
Grade Mode: Satisfactory/Unsatisfactory
Course Type: Seminar
Credit Hour: 1
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Description: A presentation of current research programs in the department. Graduate/Undergraduate Equivalency: ASTR 400. Repeatable for Credit.

ASTR 502 - TEACHING EARTH AND SPACE SCIENCE
Short Title: TEACHING EARTH & SPACE SCIENCE
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Description: Overview of the Earth and the solar system: structure, evolution, and dynamics. Includes non-calculus mathematics: algebra, logarithms and simple trigonometry, including Kepler’s laws. Observing sessions at campus observatory and George Observatory TBD. Designed for inservice and preservice science teachers (grades 4-12), but open to undergraduates considering a teaching career. Mutually Exclusive: Credit cannot be earned for ASTR 502 and ASTR 402.

ASTR 503 - ASTRONOMY FOR TEACHERS
Short Title: ASTRONOMY FOR TEACHERS
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Description: Overview of the Sun, stars, galaxies, and the Universe at a non-calculus level. Methods to help students master content, including lab activities suitable for K-12. Observing sessions at Rice campus observatory and George Observatory TBD. Designed for inservice and preservice teachers (grades 5-12), but open to undergraduates considering a teaching career.

ASTR 505 - PROCESSES IN COSMIC PLASMAS
Short Title: PROCESSES IN COSMIC PLASMAS
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Description: Study of plasma phenomena that occur widely in nature. May include quasi-static equilibrium, magnetic equilibrium, magnetic reconnection, particle acceleration, plasma winds and jets, and interchange instabilities.
ASTR 530 - TEACHING ASTRONOMY LABORATORY
Short Title: TEACHING ASTRONOMY LABORATORY
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Laboratory
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Prerequisite(s): ASTR 230 or ASTR 350 or ASTR 360 or ASTR 402 or ASTR 403 or ASTR 502 or ASTR 503
Description: Methods of observational astronomy for public education: telescopes, astronomical binoculars, portable planetariums, digital cameras, and photography (still, 3D, and time lapse). Students will train beginners in the use of telescopes and carry out a modest observational program. The course requires one public presentation. Topics vary with each offering. Mutually Exclusive: Credit cannot be earned for ASTR 530 and ASTR 430.

ASTR 542 - NEBULAR ASTROPHYSICS
Short Title: NEBULAR ASTROPHYSICS
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Prerequisite(s): ASTR 451
Description: The physics of emission nebulae, including radiative transfer, photo ionization and thermal equilibria, and internal gaseous dynamics. Physical processes in the interstellar medium. Recommended Prerequisite(s): PHYS 541.

ASTR 554 - ASTROPHYSICS OF THE SUN
Short Title: ASTROPHYSICS OF THE SUN
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Description: Analysis of physical processes at work in the sun, such as helioseismology, solar variability, solar activity, magnetic reconnection, heliosphere interactions and modern observational techniques.

ASTR 555 - PROTOSTARS AND PLANETS
Short Title: PROTOSTARS AND PLANETS
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Prerequisite(s): ASTR 451
Description: Physics of star and planet information, including molecular cloud dynamics and chemistry, circumstellar accretion disks, jets, dust, debris disks, atmospheres rotation, and magnetic fields of young stars, binaries, brown dwarfs, comets, Kuiper belt objects, giant planet formation and discoveries of extra solar planets.

ASTR 565 - COMPACT OBJECTS
Short Title: COMPACT OBJECTS
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Description: Selected topics involving white dwarfs, neutron stars, black holes and their environments, e.g., pulsars, supernova remnants, and accretion disks.

ASTR 570 - SOLAR SYSTEM PHYSICS
Short Title: SOLAR SYSTEM PHYSICS
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Description: The Sun, solar-terrestrial relationships, solar wind; planetary atmospheres, ionospheres and magnetospheres. Includes a research paper and presentation on a physical process in the solar system. Graduate/Undergraduate Equivalency: ASTR 470. Mutually Exclusive: Credit cannot be earned for ASTR 570 and ASTR 470.

ASTR 600 - ADVANCED TOPICS IN ASTROPHYSICS
Short Title: ADV TOPICS IN ASTROPHYSICS
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Seminar
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Description: Lecture/seminars which treat topics of departmental interest. Not offered every year. Repeatable for Credit.

ASTR 677 - SPECIAL TOPICS
Short Title: SPECIAL TOPICS
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Internship/Practicum, Lecture, Seminar, Laboratory
Credit Hours: 1-4
Restrictions: Enrollment is limited to Graduate or Visiting Graduate level students.
Course Level: Graduate
Description: Topics and credit hours vary each semester. Contact department for current semester’s topic(s). Repeatable for Credit.

Physics (PHYS)

PHYS 100 - EXPLORING PHYSICS
Short Title: EXPLORING PHYSICS
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Seminar
Credit Hour: 1
Restrictions: Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.
Course Level: Undergraduate Lower-Level
Description: Introduction to concepts, methods, debates, and discoveries of physics, with a theme to be chosen from one of many fields of modern physics research. Designed for students interested in understanding science. This includes both science and non-science majors.
<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Short Title</th>
<th>Department</th>
<th>Grade Mode</th>
<th>Course Type</th>
<th>Distribution Group</th>
<th>Credit Hours</th>
<th>Restrictions</th>
<th>Course Level</th>
<th>Corequisite</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYS 101</td>
<td>MECHANICS (WITH LAB)</td>
<td>MECHANICS (WITH LAB)</td>
<td>Physics and Astronomy</td>
<td>Standard Letter</td>
<td>Lecture/Laboratory</td>
<td>Distribution Group III</td>
<td>4</td>
<td>Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.</td>
<td>Undergraduate Lower-Level</td>
<td>PHYS 103</td>
<td>A calculus-based introduction to mechanics. Includes classes and lab exercises on kinematics, Newton's Laws, work and energy, conservation laws and rotational motion. Primarily for physical science and engineering students. May receive credit for only one of PHYS 101, 111, 125, AP-Physics-B (PHYS 141 and 142) and AP Physics-C E&amp;M. Students must register for PHYS 103.</td>
</tr>
<tr>
<td>PHYS 102</td>
<td>ELECTRICITY &amp; MAGNETISM (WITH LAB)</td>
<td>ELECTRICITY&amp;MAGNETISM W/LAB</td>
<td>Physics and Astronomy</td>
<td>Standard Letter</td>
<td>Lecture/Laboratory</td>
<td>Distribution Group III</td>
<td>4</td>
<td>Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.</td>
<td>Undergraduate Lower-Level</td>
<td>PHYS 104</td>
<td>A calculus-based survey of mechanics primarily intended for physical science and engineering students with strong high school backgrounds in physics and particularly calculus. May receive credit for only one of PHYS 101, 111, 125, AP-Physics-B (PHYS 141 and 142), and AP Physics-C, E&amp;M.</td>
</tr>
<tr>
<td>PHYS 103</td>
<td>MECHANICS DISCUSSION</td>
<td>MECHANICS DISCUSSION</td>
<td>Physics and Astronomy</td>
<td>Satisfactory/Unsatisfactory</td>
<td>Seminar</td>
<td>Distribution Group III</td>
<td>0</td>
<td>Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.</td>
<td>Undergraduate Lower-Level</td>
<td>PHYS 101</td>
<td>Small group discussion section to extend and reinforce concepts presented in PHYS 101. Students must also register for PHYS 101.</td>
</tr>
<tr>
<td>PHYS 104</td>
<td>ELECTRICITY AND MAGNETISM DISCUSSION</td>
<td>E &amp; M DISCUSSION</td>
<td>Physics and Astronomy</td>
<td>Satisfactory/Unsatisfactory</td>
<td>Seminar</td>
<td>Distribution Group III</td>
<td>0</td>
<td>Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.</td>
<td>Undergraduate Lower-Level</td>
<td>PHYS 102</td>
<td>Small group discussion section to extend and reinforce concepts presented in PHYS 102. Students must also register for PHYS 102.</td>
</tr>
</tbody>
</table>
PHYS 143 - PHYSICS FOR CITIZENSHIP
Short Title: PHYSICS FOR CITIZENSHIP
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Distribution Group: Distribution Group III
Credit Hours: 3
Restrictions: Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.
Course Level: Undergraduate Lower-Level
Description: Physics is critical to our understanding of nuclear weapons, radiation, electronics, energy and global warming. The most interesting and important topics in physics, with applications to current events will be presented. Topics covered may include energy and conservation, radioactivity, nuclear physics, the Theory of Relativity, lasers, explosions and quantum physics.

PHYS 144 - THE PHYSICS OF MUSIC AND SOUND
Short Title: THE PHYSICS OF MUSIC AND SOUND
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Distribution Group: Distribution Group III
Credit Hours: 3
Restrictions: Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.
Course Level: Undergraduate Lower-Level
Description: This course explores our scientific understanding of sound and music by studying the properties of sound and its production by a variety of musical instruments. Additional topics include an analysis of musical scales, the physiology of hearing, and the technology of sound reproduction. For non-science and non-engineering majors.

PHYS 201 - WAVES, LIGHT, AND HEAT
Short Title: WAVES, LIGHT, AND HEAT
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.
Course Level: Undergraduate Lower-Level
Description: An introductory course in modern physics. Topics include special relativity, early quantum theory, quantum mechanics, atomic physics, statistical physics, nuclear and particle physics. The course is descriptive in nature with emphasis on phenomena rather than on calculations.
<table>
<thead>
<tr>
<th>Course Code</th>
<th>Title</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYS 238</td>
<td>SPECIAL TOPICS</td>
<td>Survey of history and current state of nuclear and particle physics. The emphasis is on experimental results and how they led to our current understanding of the strong and electroweak interactions. Some recent advances are discussed in detail. Graduate/Undergraduate Equivalency: PHYS 542. Mutually Exclusive: Credit cannot be earned for PHYS 411 and PHYS 542.</td>
</tr>
<tr>
<td>PHYS 311</td>
<td>INTRODUCTION TO QUANTUM PHYSICS I</td>
<td>Fundamentals of quantum mechanics and applications to atomic and molecular structure.</td>
</tr>
<tr>
<td>PHYS 312</td>
<td>INTRODUCTION TO QUANTUM PHYSICS II</td>
<td>Continuation of PHYS 311.</td>
</tr>
<tr>
<td>PHYS 301</td>
<td>INTERMEDIATE MECHANICS</td>
<td>Classical mechanics and appropriate mathematical methods. Emphasis on problem solving.</td>
</tr>
<tr>
<td>PHYS 302</td>
<td>INTERMEDIATE ELECTRODYNAMICS</td>
<td>Classical electrodynamics and appropriate mathematical methods. Emphasis on problem solving.</td>
</tr>
<tr>
<td>PHYS 311</td>
<td>INTRODUCTION TO QUANTUM PHYSICS II</td>
<td>Fundamentals of quantum mechanics and applications to atomic and molecular structure.</td>
</tr>
<tr>
<td>PHYS 331</td>
<td>JUNIOR PHYSICS LAB I</td>
<td>Lab exercises in electronics, noise reduction, statistics and particle counting.</td>
</tr>
<tr>
<td>PHYS 332</td>
<td>JUNIOR PHYSICS LAB II</td>
<td>Lab exercises illustrating topics in the upper-division physics curriculum.</td>
</tr>
<tr>
<td>PHYS 411</td>
<td>INTRODUCTION TO NUCLEAR &amp; PARTICLE PHYSICS</td>
<td>Survey of history and current state of nuclear and particle physics. The emphasis is on experimental results and how they led to our current understanding of the strong and electroweak interactions. Some recent advances are discussed in detail. Graduate/Undergraduate Equivalency: PHYS 542. Mutually Exclusive: Credit cannot be earned for PHYS 411 and PHYS 542.</td>
</tr>
</tbody>
</table>
PHYS 412 - SOLID STATE PHYSICS  
Short Title: SOLID STATE PHYSICS  
Department: Physics and Astronomy  
Grade Mode: Standard Letter  
Course Type: Lecture  
Credit Hours: 3  
Restrictions: Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.  
Course Level: Undergraduate Upper-Level  
Prerequisite(s): (PHYS 311 and PHYS 425) or ELEC 361  
Description: Introduction to topics in solid state physics, including crystal structure, lattice vibrations, electronic band structure and transport. 

PHYS 416 - COMPUTATIONAL PHYSICS  
Short Title: COMPUTATIONAL PHYSICS  
Department: Physics and Astronomy  
Grade Mode: Standard Letter  
Course Type: Lecture  
Credit Hours: 3  
Restrictions: Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.  
Course Level: Undergraduate Upper-Level  
Description: Use of computational techniques to solve selected physics problems. Examine benefits and pitfalls of doing physics by computation. Graduate/Undergraduate Equivalency: PHYS 517. Mutually Exclusive: Credit cannot be earned for PHYS 416 and PHYS 517. 

PHYS 425 - STATISTICAL & THERMAL PHYSICS  
Short Title: STATISTICAL & THERMAL PHYSICS  
Department: Physics and Astronomy  
Grade Mode: Standard Letter  
Course Type: Lecture  
Credit Hours: 3  
Restrictions: Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.  
Course Level: Undergraduate Upper-Level  
Prerequisite(s): PHYS 301 and PHYS 311  
Description: Includes classical thermodynamics; classical & quantum statistical mechanics; Fermi, Bose, and classical gases; magnetic systems; and phase equilibria. 

PHYS 461 - INDEPENDENT RESEARCH  
Short Title: INDEPENDENT RESEARCH  
Department: Physics and Astronomy  
Grade Mode: Standard Letter  
Course Type: Research  
Credit Hours: 1-6  
Restrictions: Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.  
Course Level: Undergraduate Upper-Level  
Prerequisite(s): PHYS 302  
Description: Mentored research under the supervision of a Physics and Astronomy faculty member. To register, students must provide a research plan approved by the faculty mentor. Instructor Permission Required. Repeatable for Credit. 

PHYS 462 - INDEPENDENT RESEARCH  
Short Title: INDEPENDENT RESEARCH  
Department: Physics and Astronomy  
Grade Mode: Standard Letter  
Course Type: Research  
Credit Hours: 1-6  
Restrictions: Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.  
Course Level: Undergraduate Upper-Level  
Description: Mentored research under the supervision of a Physics and Astronomy faculty member. To register, students must provide a research plan approved by the faculty mentor. Instructor Permission Required. Repeatable for Credit. 

PHYS 465 - REU RESEARCH IN PHYSICS AND ASTRONOMY  
Short Title: REU RESEARCH IN PHYS & ASTR  
Department: Physics and Astronomy  
Grade Mode: Standard Letter  
Course Type: Research  
Credit Hours: 1-3  
Restrictions: Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.  
Course Level: Undergraduate Upper-Level  
Description: Repeatable for Credit. 

PHYS 477 - SPECIAL TOPICS  
Short Title: SPECIAL TOPICS  
Department: Physics and Astronomy  
Grade Mode: Standard Letter  
Course Type: Internship/Practicum, Seminar, Lecture, Laboratory  
Credit Hours: 1-4  
Restrictions: Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.  
Course Level: Undergraduate Upper-Level  
Description: Topics and credit hours may vary each semester. Contact department for current semester's topic(s). Repeatable for Credit. 

PHYS 480 - INTRODUCTION TO PLASMA PHYSICS  
Short Title: INTRODUCTION TO PLASMA PHYSICS  
Department: Physics and Astronomy  
Grade Mode: Standard Letter  
Course Type: Lecture  
Credit Hours: 3  
Restrictions: Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.  
Course Level: Undergraduate Upper-Level  
Prerequisite(s): PHYS 302  
Description: Fundamental processes in cosmic and laboratory plasmas. Basic plasma characteristics, charged particle motion, waves in plasmas, magnetohydrodynamics, kinetic theory. Graduate/Undergraduate Equivalency: PHYS 580. Mutually Exclusive: Credit cannot be earned for PHYS 480 and PHYS 580. 

PHYS 487 - SPECIAL TOPICS  
Short Title: SPECIAL TOPICS  
Department: Physics and Astronomy  
Grade Mode: Standard Letter  
Course Type: Internship/Practicum, Seminar, Lecture, Laboratory  
Credit Hours: 1-4  
Restrictions: Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.  
Course Level: Undergraduate Upper-Level  
Description: Topics and credit hours may vary each semester. Contact department for current semester's topic(s). Repeatable for Credit.
PHYS 491 - UNDERGRADUATE RESEARCH
Short Title: UNDERGRADUATE RESEARCH
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Research
Credit Hours: 2
Restrictions: Enrollment limited to students with a class of Junior or Senior. Enrollment is limited to students with a major in Astronomy, Astrophysics, Chemical Physics or Physics. Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.
Course Level: Undergraduate Upper-Level
Prerequisite(s): PHYS 301 and PHYS 302 and PHYS 311
Description: Research projects conducted under supervision of departmentally approved faculty. Open to juniors and seniors majoring in physics and astronomy. May be repeated for credit. PHYS 493/494 must be taken concurrently with PHYS 491/492 when used in partial fulfillment of B.S. degree requirements. Repeatable for Credit.

PHYS 492 - UNDERGRADUATE RESEARCH
Short Title: UNDERGRADUATE RESEARCH
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Research
Credit Hours: 2
Restrictions: Enrollment limited to students with a class of Junior or Senior. Enrollment is limited to students with a major in Astronomy, Astrophysics, Chemical Physics or Physics. Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.
Course Level: Undergraduate Upper-Level
Prerequisite(s): PHYS 491
Description: Research projects conducted under supervision of departmentally approved faculty culminating in a thesis. Open to juniors and seniors majoring in physics and astronomy. May be repeated for credit. PHYS 493/494 must be taken concurrently with PHYS 491/492 when used in partial fulfillment of B.S. degree requirements. Repeatable for Credit.

PHYS 493 - UNDERGRADUATE RESEARCH SEMINAR
Short Title: UNDERGRADUATE RESEARCH SEMINAR
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Seminar
Credit Hour: 1
Restrictions: Enrollment limited to students with a class of Junior or Senior. Enrollment is limited to students with a major in Astronomy, Astrophysics, Chemical Physics or Physics. Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.
Course Level: Undergraduate Upper-Level
Prerequisite(s): PHYS 301 and PHYS 302 and PHYS 311
Description: Weekly seminar for juniors and seniors in which presentations on research topics and/or topics in the scientific literature will be given. Open to juniors and seniors majoring in physics and astronomy. Repeatable for Credit.

PHYS 494 - UNDERGRADUATE RESEARCH SEMINAR
Short Title: UNDERGRADUATE RESEARCH SEMINAR
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Seminar
Credit Hour: 1
Restrictions: Enrollment limited to students with a class of Junior or Senior. Enrollment is limited to students with a major in Astronomy, Astrophysics, Chemical Physics or Physics. Enrollment is limited to Undergraduate, Undergraduate Professional or Visiting Undergraduate level students.
Course Level: Undergraduate Upper-Level
Prerequisite(s): PHYS 493
Description: Weekly seminar for juniors and seniors in which presentations on research topics and/or topics in the scientific literature will be given. Open to juniors and seniors majoring in physics and astronomy. Repeatable for Credit.

PHYS 501 - PHYSICS OF THE RADIO FOR TEACHERS
Short Title: PHYSICS OF HAM RADIO TEACHERS
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Description: Fundamentals of electromagnetic waves and propagation, the ionosphere and space weather. Basic electronics, antenna design and safety, magnetism. Provides information necessary to pass the "Technician" level of ham radio license. Non-calculus mathematics. Other topics include: use of GPS, geocaching. Mutually Exclusive: Credit cannot be earned for PHYS 501 and PHYS 401.

PHYS 510 - MAGNETOSPHERIC PHYSICS
Short Title: MAGNETOSPHERIC PHYSICS
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Description: Plasma physics of the earth's magnetosphere, including interactions of the magnetosphere with the solar wind and the ionosphere. The emphasis is on large-scale phenomena, but small scale (kinetic) physics is discussed in cases where it affects the large-scale phenomena.

PHYS 515 - CLASSICAL DYNAMICS
Short Title: CLASSICAL DYNAMICS
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Description: Lagrangian and Hamiltonian mechanics.
PHYS 516 - MATHEMATICAL METHODS
Short Title: MATHEMATICAL METHODS
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Description: Survey of analytical methods used by research physicists and astronomers. Includes complex variables, ordinary differential equations, infinite series, evaluation of integrals, integral transforms, normal-mode analysis, special functions, partial differential equations, eigenfunctions, Green's functions, and variational calculus.

PHYS 517 - COMPUTATIONAL PHYSICS
Short Title: COMPUTATIONAL PHYSICS
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Description: Use of computational techniques to solve selected physics problems. Examine benefits and pitfalls of doing physics by computation. Requires completion of project using a low-level programming language. Graduate/Undergraduate Equivalency: PHYS 416. Mutually Exclusive: Credit cannot be earned for PHYS 517 and PHYS 416.

PHYS 519 - PLASMA KINETIC THEORY
Short Title: PLASMA KINETIC THEORY
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Description: Plasma kinetic equations (Klimontovich, Liouville, BBGY, Balescu-Lenard, Fokker-Planck, Vlasov), Vlasov theory of waves and instabilities, connections to fluid plasma models.

PHYS 521 - QUANTUM MECHANICS I
Short Title: QUANTUM MECHANICS I
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Description: Graduate level course on non-relativistic quantum mechanics. Topics include early quantum theory, one-dimensional systems, matrix formulation, quantum dynamics, symmetries and conservation laws, bound states, scattering, spin, and identical particles, perturbation theory.

PHYS 522 - QUANTUM MECHANICS II
Short Title: QUANTUM MECHANICS II
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Description: Continuation of PHYS 521.

PHYS 526 - STATISTICAL PHYSICS
Short Title: STATISTICAL PHYSICS
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Description: Selected topics in statistical mechanics, including phase transitions and transport phenomena.

PHYS 532 - CLASSICAL ELECTRODYNAMICS
Short Title: CLASSICAL ELECTRODYNAMICS
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Description: Maxwell's equations, wave propagation, special relativity and covariant formulation, charged-particle dynamics, and radiation.

PHYS 533 - NANOSTRUCTURE AND NANOTECHNOLOGY I
Short Title: NANOSTRUCTURE/NANOTECHNOLOGY I
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Description: Physics of structures and devices at the nanometer scale. After a review of solid state physics, topics include nanostructured materials, nanoelectronics, and nanomagnetism. Emphasis on relevance of nanophysics to current and future technologies.

PHYS 534 - NANOSTRUCTURE AND NANOTECHNOLOGY II
Short Title: NANOSTRUCTURE/NANOTECHNOLOGY II
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Description: Physics of structures and devices at the nanometer scale. Topics include nanomechanics, bionanotechnology, advanced sensors and photonics. Continuation of PHYS 533.

PHYS 535 - CRYSTALLOGRAPHY AND DIFFRACTION
Short Title: CRYSTALLOGRAPHY & DIFFRACTION
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Description: Study of crystals by diffraction techniques, focusing on x-ray, with an overview of electron and neutron diffraction as well as complementary techniques. Provides mathematical foundations and nomenclature for diffraction and related phenomena. Includes basics of crystallographic analysis and surface/point/space group symmetry, experiment design (courses, geometry, detectors), and data analysis and interpretation. Required for undergraduate MSNE major. Meets with MSNE 435 (additional work for the graduate version). Cross-list: MSNE 535.
<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Short Title</th>
<th>Department</th>
<th>Grade Mode</th>
<th>Course Type</th>
<th>Credit Hours</th>
<th>Restrictions</th>
<th>Course Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYS 537</td>
<td>METHODS OF EXPERIMENTAL PHYSICS I</td>
<td>METH EXPERIMENTAL PHYSICS I</td>
<td>Physics and Astronomy</td>
<td>Graduate</td>
<td>Lecture/Laboratory</td>
<td>3</td>
<td>Enrollment is limited to Graduate level students.</td>
<td>Graduate</td>
<td>A course to familiarize students with basic experimental techniques that are common in academic and industrial laboratories. Topics will include lab safety, mechanical design, LabVIEW(TM) programming, statistics, laboratory electronics, particle detection and vacuum technology. PHYS 537 and PHYS 538 may be taken independently of each other.</td>
</tr>
<tr>
<td>PHYS 538</td>
<td>METHODS OF EXPERIMENTAL PHYSICS II</td>
<td>METH EXPERIMENTAL PHYSICS II</td>
<td>Physics and Astronomy</td>
<td>Graduate</td>
<td>Lecture/Laboratory</td>
<td>3</td>
<td>Enrollment is limited to Graduate level students.</td>
<td>Graduate</td>
<td>A course to familiarize students with basic experimental techniques that are common in academic and industrial laboratories. Topic will include computer interfacing and data acquisition, charged particle optics, light optics, thermal measurement and control, and cryogenics. PHYS 537 and PHYS 538 may be taken independently of each other.</td>
</tr>
<tr>
<td>PHYS 539</td>
<td>CHARACTERIZATION AND FABRICATION AT THE NANOSCALE</td>
<td>CHARACTER&amp;FABRICATN NANOSCALE</td>
<td>Physics and Astronomy</td>
<td>Graduate</td>
<td>Lecture</td>
<td>3</td>
<td>Enrollment is limited to Graduate level students.</td>
<td>Graduate</td>
<td>Introduction to study and creation of nanoscale structures, emphasizing relevant physical principles. Techniques covered include optical, X-ray, electron-based and scanned-probe characterization, as well as patterning, deposition and removal of material.</td>
</tr>
<tr>
<td>PHYS 541</td>
<td>RADIATIVE PROCESSES</td>
<td>RADIATIVE PROCESSES</td>
<td>Physics and Astronomy</td>
<td>Graduate</td>
<td>Lecture</td>
<td>3</td>
<td>Enrollment is limited to Graduate level students.</td>
<td>Graduate</td>
<td>Radiation processes and their applications to astrophysical phenomena and space science. The course treats radiative transfer, radiation from moving charges, relativistic covariance and kinematics, bremsstrahlung, synchrotron radiation, Compton scattering, some plasma effects, and radiative transitions in atoms and molecules.</td>
</tr>
<tr>
<td>PHYS 542</td>
<td>INTRODUCTION TO NUCLEAR AND PARTICLE PHYSICS</td>
<td>INTRO NUCLEAR&amp;PARTIC PHYSICS</td>
<td>Physics and Astronomy</td>
<td>Graduate</td>
<td>Lecture</td>
<td>3</td>
<td>Enrollment is limited to Graduate level students.</td>
<td>Graduate</td>
<td>Survey of history and current state of nuclear and particle physics with the emphasis on experimental results and how they led to our current understanding of the strong and electroweak interactions. Some recent advances are discussed in detail. Requires completion of a Monte Carlo simulation project. Graduate/Undergraduate Equivalency: PHYS 411. Mutually Exclusive: Credit cannot be earned for PHYS 542 and PHYS 411.</td>
</tr>
<tr>
<td>PHYS 543</td>
<td>PHYSICS OF QUARKS AND LEPTONS</td>
<td>PHYSICS OF QUARKS AND LEPTONS</td>
<td>Physics and Astronomy</td>
<td>Graduate</td>
<td>Lecture</td>
<td>3</td>
<td>Enrollment is limited to Graduate level students.</td>
<td>Graduate</td>
<td>A continuation of PHYS 542.</td>
</tr>
<tr>
<td>PHYS 551</td>
<td>BIOLOGICAL PHYSICS</td>
<td>BIOLOGICAL PHYSICS</td>
<td>Physics and Astronomy</td>
<td>Graduate</td>
<td>Lecture</td>
<td>3</td>
<td>Enrollment is limited to Graduate level students.</td>
<td>Graduate</td>
<td>Introduction to biological physics. Review of basic physical concepts. Cells and their components. Diffusion and random walks. Entropy and energy concepts and their roles in biological systems. Modern experimental methods. Applications to biological macromolecules.</td>
</tr>
<tr>
<td>PHYS 552</td>
<td>TOPICS IN BIOLOGICAL PHYSICS</td>
<td>TOPICS IN BIOLOGICAL PHYSICS</td>
<td>Physics and Astronomy</td>
<td>Graduate</td>
<td>Lecture</td>
<td>3</td>
<td>Enrollment is limited to Graduate level students.</td>
<td>Graduate</td>
<td>Topics will be selected based on special or current research interests.</td>
</tr>
<tr>
<td>PHYS 561</td>
<td>GENERAL RELATIVITY</td>
<td>GENERAL RELATIVITY</td>
<td>Physics and Astronomy</td>
<td>Graduate</td>
<td>Lecture</td>
<td>3</td>
<td>Enrollment is limited to Graduate level students.</td>
<td>Graduate</td>
<td>Study of Einstein’s theory of gravitation, including cosmological models.</td>
</tr>
</tbody>
</table>
PHYS 563 - INTRODUCTION TO SOLID STATE PHYSICS I
Short Title: INTRO TO SOLID STATE PHYSICS I
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Description: Fundamental concepts of crystalline solids, including crystal structure, band theory of electrons, and lattice vibration theory. Cross-list: ELEC 563.

PHYS 564 - INTRODUCTION TO SOLID STATE PHYSICS II
Short Title: INTRO SOLID STATE PHYSICS II
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Description: Continuation of PHYS 563, including scattering of waves by crystals, transport theory, and magnetic phenomena. Cross-list: ELEC 564.

PHYS 566 - SURFACE PHYSICS
Short Title: SURFACE PHYSICS
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Description: An introduction to surface- and low-dimensional physics covering experimental surface physics and ultra-high vacuum technology, crystal structure, chemical analysis, epitaxy, nanoscale electronic and magnetic structures and devices, elementary excitations, optical properties and nanoscale sensitive magnetic and non-magnetic spectroscopies.

PHYS 567 - QUANTUM MATERIALS
Short Title: QUANTUM MATERIALS
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Prerequisite(s): (PHYS 425 or PHYS 526) and (PHYS 311 or PHYS 521)
Description: This course uses real data on archetypal materials to illustrate the thermodynamic and transport properties of solids, and principles of materials synthesis. The goal is building a phenomenological understanding of topics including the origin of magnetism; interactions and long range order; phase transitions (magnetism; superconductivity); quantum oscillations and Landau levels.

PHYS 568 - QUANTUM PHASE TRANSITIONS
Short Title: QUANTUM PHASE TRANSITIONS
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Description: Introductory course for graduate students. Topics include the concepts of classical and quantum phase transitions, mean field theory, renormalization group and quantum phase transitions in magnetic, fermionic, and bosonic systems.

PHYS 569 - ULTRAFAST OPTICAL PHENOMENA
Short Title: ULTRAFAST OPTICAL PHENOMENA
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Description: This course covers the generation, propagation, and measurement of short laser pulses, of duration less than one picosecond. Concepts include mode locking, the effects of dispersion, optical pulse amplification, and time-domain non-linear optical phenomena. Intended as an introduction to ultrafast phenomena for graduate students or advanced undergraduates; a basic understanding of electromagnetic waves and of quantum mechanics is assumed. Cross-list: ELEC 569.
Course URL: www.ece.rice.edu/~daniel/569/569files.html

PHYS 571 - MODERN ATOMIC PHYSICS
Short Title: MODERN ATOMIC PHYSICS
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Description: This is an introductory course at the graduate level. Topics to be discussed include: atomic structure, principles of lasers, fundamental interactions of atoms with electro-magnetic radiation, including coherent effects, laser spectroscopy, quantum optics, and laser cooling and trapping of atoms, and Bose-Einstein condensation.

PHYS 572 - FUNDAMENTALS OF QUANTUM OPTICS
Short Title: FUNDAMENTALS OF QUANTUM OPTICS
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Description: Discussion of quantization and statistical properties of light fields; interaction between atoms and light; non-classical states; basic laser theory; quantum effects of nonlinear optics; introduction to atom optics.
PHYS 580 - INTRODUCTION TO PLASMA PHYSICS
Short Title: INTRODUCTION TO PLASMA PHYSICS
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Description: Fundamental processes in cosmic and laboratory plasmas. Basic plasma characteristics, charged particle motion, waves in plasmas, magnetohydrodynamics, kinetic theory. Includes a substantial computational project related to plasma physics. Graduate/Undergraduate Equivalency: PHYS 480. Mutually Exclusive: Credit cannot be earned for PHYS 580 and PHYS 480.

PHYS 600 - ADVANCED TOPICS IN PHYSICS
Short Title: ADVANCED TOPICS IN PHYSICS
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Description: Lecture/seminars which treat topics of departmental interest. Repeatable for Credit.

PHYS 601 - FRONTIERS IN CONDENSED MATTER PHYSICS
Short Title: FRONTIERS IN CONDENSED MATTER
Department: Physics and Astronomy
Grade Mode: Satisfactory/Unsatisfactory
Course Type: Seminar
Credit Hour: 1
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Description: This seminar will serve as an introduction to current research topics in modern condensed matter physics. Lectures will be given by experts in condensed matter physics at Rice, Columbia University, and other international locations. Repeatable for Credit.

PHYS 605 - COMPUTATIONAL ELECTRODYNAMICS AND NANOPHOTONICS
Short Title: ELECTRODYNAMICS & NANOPHOTONIC
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Description: This course covers computational and numerical methods for calculating electromagnetic fields and propagation in complex geometries on the nano and microscale. Methods include the finite difference time domain method, boundary element methods, Greens functions methods, finite element methods, the discrete dipole approximation and relaxation methods. Cross-list: ELEC 605. Repeatable for Credit.

PHYS 610 - BIOLOGICAL AND MOLECULAR SIMULATION
Short Title: METHODS OF MOLECULAR SIMUL
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Prerequisite(s): CHBE 611 or BIOC 589 or BIOE 589 or BIOS 589 or CHEM 520 or PHYS 526
Description: Modern simulation techniques for classical atomistic systems. Review of statistical mechanical systems. Monte Carlo and molecular dynamics simulation techniques. Extensions of the basic methods to various ensembles. Applications to simulations of large molecules such as proteins. Advanced techniques for simulation of complex systems, including constraint satisfaction, cluster moves, biased sampling, and random energy models. Cross-list: BIOE 610.

PHYS 622 - QUANTUM FIELD THEORY
Short Title: QUANTUM FIELD THEORY
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Description: An introduction to relativistic quantum field theory. Topics include: quantization of scalar, spinor, and vector fields; Feynman diagrams; gauge theories, including QED and QCD; renormalization; and functional-integral methods.

PHYS 643 - CELL MECHANICS, MECHANOTRANSDUCTION AND THE CELL MICROENVIRONMENT
Short Title: MECHANOTRANSDUCTION
Department: Physics and Astronomy
Grade Mode: Standard Letter
Course Type: Lecture
Credit Hours: 3
Restrictions: Enrollment is limited to Graduate level students.
Course Level: Graduate
Description: Mechanotransduction is a fundamental process essential for living systems and plays a fundamental role in cell signaling, cancer metastasis and stem cell differentiation. Additionally, fundamental biological processes such as endocytosis cell fusion and cell migration are driven by a coordinated interplay of molecular interactions that drive membrane deformation. This course will survey the current understanding of mechanotransduction and the mechanical properties of cells and their microenvironment, including membrane and cytoskeletal mechanics. Experimental approaches for measuring and manipulating the material properties of cells and their environment; including optical, electrical and magnetic techniques will be covered. A variety of application will be covered, including manipulation in engineering of mechanotransduction pathways to drive cell migration and stem cell differentiation. Instructor Permission Required. Cross-list: BIOC 643, BIOE 643.
PHYS 663 - CONDENSED MATTER THEORY: APPLICATIONS  
**Short Title:** CONDENSED MATTER THRY:APLICATN  
**Department:** Physics and Astronomy  
**Grade Mode:** Standard Letter  
**Course Type:** Lecture  
**Credit Hours:** 3  
**Restrictions:** Enrollment is limited to Graduate level students.  
**Course Level:** Graduate  
**Description:** Applications of techniques developed in PHYS 664.

PHYS 664 - CONDENSED MATTER THEORY: MANY-BODY FORMALISM  
**Short Title:** COND MATTR THRY:MANY BODY FORM  
**Department:** Physics and Astronomy  
**Grade Mode:** Standard Letter  
**Course Type:** Lecture  
**Credit Hours:** 3  
**Restrictions:** Enrollment is limited to Graduate level students.  
**Course Level:** Graduate  
**Description:** Formal structure of many-body theory as used in condensed matter physics.

PHYS 665 - THEORETICAL TOPICS IN CONTEMPORARY QUANTUM PHYSICS  
**Short Title:** CONTEMPORARY QUANTUM THEORY  
**Department:** Physics and Astronomy  
**Grade Mode:** Standard Letter  
**Course Type:** Lecture  
**Credit Hours:** 3  
**Restrictions:** Enrollment is limited to Graduate level students.  
**Course Level:** Graduate  
**Prerequisite(s):** PHYS 521 and PHYS 664  
**Description:** The course covers advanced mathematical methods and techniques used in contemporary research in theoretical quantum physics. This course builds upon the foundations of many-body theory and focuses on its applications to more advanced problems. It may be useful for students pursuing theoretical research in CM or AMO physics, or anyone interested in modern theoretical developments.

PHYS 677 - SPECIAL TOPICS  
**Short Title:** SPECIAL TOPICS  
**Department:** Physics and Astronomy  
**Grade Mode:** Standard Letter  
**Course Type:** Internship/Practicum, Seminar, Lecture, Laboratory  
**Credit Hours:** 1-4  
**Restrictions:** Enrollment is limited to Graduate or Visiting Graduate level students.  
**Course Level:** Graduate  
**Description:** Topics and credit hours vary each semester. Contact department for current semester's topic(s). Repeatable for Credit.

PHYS 700 - TEACHING PRACTICUM  
**Short Title:** TEACHING PRACTICUM  
**Department:** Physics and Astronomy  
**Grade Mode:** Standard Letter  
**Course Type:** Internship/Practicum  
**Credit Hours:** 3  
**Restrictions:** Enrollment is limited to Graduate level students.  
**Course Level:** Graduate  
**Description:** Supervised teaching for graduate students. Repeatable for Credit.

PHYS 710 - GRADUATE SEMINAR IN PHYSICS AND ASTRONOMY  
**Short Title:** GRAD SEMINAR IN PHYS & ASTR  
**Department:** Physics and Astronomy  
**Grade Mode:** Satisfactory/Unsatisfactory  
**Course Type:** Seminar  
**Credit Hour:** 1  
**Restrictions:** Enrollment is limited to Graduate level students.  
**Course Level:** Graduate  
**Description:** Participation in department colloquia and additional sessions on topics of interest to entering graduate students. Required of all Physics and Astronomy graduate students during their first Fall semester at Rice.

PHYS 800 - GRADUATE RESEARCH  
**Short Title:** GRADUATE RESEARCH  
**Department:** Physics and Astronomy  
**Grade Mode:** Standard Letter  
**Course Type:** Research  
**Credit Hours:** 1-15  
**Restrictions:** Enrollment is limited to Graduate level students.  
**Course Level:** Graduate  
**Description:** Thesis research under the supervision of department faculty. Repeatable for Credit.

**Description and Code Legend**  
*Note: Internally, the university uses the following descriptions, codes, and abbreviations for this academic program. The following is a quick reference:*

**Course Catalog/Schedule:**
- Course offerings/subject code for Astronomy: ASTR
- Course offerings/subject code for Physics: PHYS

**Department Description and Code**  
- Physics and Astronomy: PHYS

**Undergraduate Degree Descriptions and Codes**  
- Bachelor of Arts degree: BA
- Bachelor of Science degree: BS

**Undergraduate Major Descriptions and Codes**  
- Major in Physics (attached to the BA and BS degrees): PHYS
- Major in Astronomy (attached to the BA degree): ASBA
- Major in Astrophysics (attached to the BS degree): ASTR
- Major in Chemical Physics (attached to the BS degree): CPHY

**Undergraduate Major Concentration Descriptions and Codes**  
- Major Concentration in Applied Physics (BS degree-PHYS majors): APPS
- Major Concentration in Biological Physics (BS degree-PHYS majors): BIPS
- Major Concentration in Computational Physics (BS degree-PHYS majors): COPS
- Major Concentration in General Physics (BS degree-PHYS majors): GEPS

**Undergraduate Minor Description and Code**  
- Minor in Physics: PHYM
Graduate Degree Descriptions and Codes

- Master of Science Teaching degree: MST
- Master of Science degree: MS
- Doctor of Philosophy degree: PhD

Graduate Degree Program Description and Code

- Degree Program in Physics: PHYS
- Degree Program in Science Teaching: STEA

CIP Code and Description

1 Classification of Instructional Programs (CIP) 2010 Codes and Descriptions from the National Center for Education Statistics: https://nces.ed.gov/ipeds/cipcode/