ries course, approved by the Graduate Advisor, but on an individual basis. It will be devoted to completion of a graduate paper based on research or criticism related to the 100-series course. Faculty guides and evaluations will be provided throughout the quarter. Graded Satisfactory (S) or No Credit (NC). May be repeated for credit.

PHIL 297 Directed Research (1-6) Graded Satisfactory (S) or No Credit (NC). Course is repeatable.

PHIL 299 Research for Thesis or Dissertation (1-12) Graded Satisfactory (S) or No Credit (NC). Course is repeatable.

Professional Courses

PHIL 301 Directed Studies in the Teaching of Philosophy (1) Seminar, 1 hour. Prerequisite(s): graduate standing. A program of orientation, lectures, and workshops designed to enhance the Teaching Assistant's understanding of teaching methods in philosophy and to provide opportunities to work closely with experts in college teaching in order to improve the quality of instruction. Required of all new Teaching Assistants. Graded Satisfactory (S) or No Credit (NC). Course is repeatable.

PHIL 302 Teaching Practicum (1-4) Prerequisite(s): employment as Teaching Assistant or Associate. Supervised teaching in lower-division courses and LWSO 100. Required of all teaching assistants in philosophy. Does not count toward the unit requirement for the M.A. degree. Graded Satisfactory (S) or No Credit (NC). May be repeated for credit.

PHIL 400 Research and Professional Development Workshop (1) Workshop, 8 hours per quarter; extra reading, 8 hours per quarter. Prerequisite(s): graduate standing. A series of presentations and workshops focused on a variety of issues in research, professional development, and teaching. Graded Satisfactory (S) or No Credit (NC). Course is repeatable to a maximum of 18 units.

Physical Sciences

College of Natural and Agricultural Sciences

The Physical Sciences major is not accepting new students at this time. For more information, contact the CNAS Undergraduate Academic Advising Center, 1223 Pierce Hall, or call (951) 827-7294.

Physics and Astronomy

Subject abbreviation: PHYS
College of Natural and Agricultural Sciences

Umar Mohideen, Ph.D., Chair
Department Office, 3047 Physics
(951) 827-5331; **physics.ucr.edu**

Professors
Kenneth N. Barish, Ph.D.
Mark Bockrath, Ph.D.
E. Gabriela Canalizo, Ph.D.
Robert B. Clare, Ph.D.
John A. Ellison, Ph.D.
J. William Gary, Ph.D.
Gail G. Hanson, Ph.D.
Chun Ning "Jeanie" Lau, Ph.D.
Owen Long, Ph.D.
Allen P. Mills, Ph.D.
Bahram Mobasher, Ph.D.
Umar Mohideen, Ph.D.
Richard K. Seto, Ph.D.
Jing Shi, Ph.D.
Kirill Shtengel, Ph.D.
Harry W.K. Tom, Ph.D.
Chandra M. Varma, Ph.D.
Gillian Wilson, Ph.D.
Stephen J. Wimpenny, Ph.D.
Jose Wudka, Ph.D.
Jory A. Yarmoff, Ph.D.
Roya Zandi, Ph.D.

Professors Emeriti
Frederick W. Cummings, Ph.D
Bipin R. Desai, Ph.D.
Sun-Yiu Fung, Ph.D.
Peter E. Kaus, Ph.D.
Anne Kernan, Ph.D.
Nai-Li H. Liu, Ph.D.
Ernest S. Ma, Ph.D.
Donald C. McCollum, Ph.D.
John C. Nickel, Ph.D.
Douglas E. MacLaughlin, Ph.D.
Raymond L. Orbach, Ph.D.
Michael Pollak, Ph.D.
Eugen S. Simanek, Ph.D.
R. Stephen White, Ph.D.
Allen D. Zych, Ph.D.

Associate Professors
Ward Beyermann, Ph.D.
Leonid P. Pryadko, Ph.D.
Shan-Wen Tsai, Ph.D.

Assistant Professors
Vivek Aji, Ph.D.
George Becker, Ph.D.
Nathaniel Gabor, Ph.D.
Naveen Reddy, Ph.D.
Brian Siana, Ph.D.
Hai-Bo Yu, Ph.D.

**

Research Physicist
Roland Kawakami, Ph.D.

Major

The Department of Physics and Astronomy offers two degrees: the B.A. and B.S. in Physics.

The **B.S. program** is designed for students with a strong interest in the sciences or engineering who wish to emphasize this aspect of their education and training. The B.S. degree provides a strong background for students who wish to continue on to graduate school.

The **B.A. program** follows the liberal arts tradition with a broader coverage of the humanities and social sciences. It is selected often by students who intend to obtain a teaching credential with a specialty in science or to pursue a career combining business management opportunities with a knowledge in science and technology.

The extensive course offerings and modern facilities within the Department of Physics and Astronomy, coupled with close, personal counseling by faculty advisors, provide students with a physics program that is characterized by its breadth and flexibility.

Career Opportunities

Graduates with a bachelor's degree in Physics generally begin their careers in government or industry. Professions include research and development, system modeling and analysis, and sales in a large variety of fields. A Physics degree provides one of the most flexible qualifications with direct applications to materials science, advanced electronics, lasers and microwave devices, computing and communications.

The federal government and national laboratories employ many physicists as do industries in medical and scientific instruments, computers, audio and telecommunications equipment, financial analysis and investments, material science, and engineering.

The bachelor's degree programs in the UCR Department of Physics and Astronomy are well suited for continued education in graduate school and for preparation in technical and professional careers. Colleges or universities, national laboratories, industry, and governmental agencies employ students with graduate training.

Transfer Students

Students transferring to the Physics major must complete courses comparable to the following one-year sequences before they transfer:

1. General physics (calculus-based) equivalent to PHYS 040A, PHYS 040B, PHYS 040C, each course completed with a grade of "C" or better
2. First-year calculus, equivalent to MATH 009A, MATH 009B, MATH 009C, each course completed with a grade of "B-" or better

At least one of the following one-year sequences:

1. General chemistry, equivalent to CHEM 001A, CHEM 001B, CHEM 001C, CHEM 01LA, CHEM 01LB, CHEM 01LC, each course completed with a grade of "C" or better
2. Second-year calculus, equivalent to MATH 010A, MATH 010B, MATH 046, each course completed with a grade of "C" or better
3. Organic chemistry (one-year lower-division), each course completed with a grade of "B" or better

Students must have a minimum grade point average of 2.70 in transferable college courses. UCR has articulation agreements with most of the California community colleges. These agreements list specific community college courses that have been designated as comparable to UCR courses (see the statewide articulation Web site at **www.assist.org**). Transfer students will usually find it advantageous to complete most or all sequences before starting at UCR. All prospective transfers should try to complete the sequences they begin rather than divide a sequence between two campuses.

University Requirements

See Undergraduate Studies section.

College Requirements

See College of Natural and Agricultural Sciences, Colleges and Programs section.

Some of the following requirements for the major may also fulfill some of the college's breadth requirements. Consult with a department advisor for course planning.

Major Requirements

The major requirements consist of a core curriculum and additional requirements for various B.S. degrees. The core requirements for the B.A. and B.S. degrees in Physics are as follows:

1. Lower-division requirements (69 units)
   a) one of the following sequences: PHYS 041A, PHYS 041B, PHYS 041C, or PHYS 040A, PHYS 040B, PHYS 040C, PHYS 040D, PHYS 040E. The first sequence is preferred for the B.S. in Physics.
   b) PHYS 39
   c) MATH 008B or MATH 009A, MATH 009B,MATH 009C, MATH 010A, MATH 010B, MATH 046
   d) CHEM 001A, CHEM 001B, CHEM 001C, CHEM 01LA, CHEM 01LB, CHEM 01LC
   e) CS 010 or CS 010V. A higher-level CS course may satisfy the CS 010 requirement with approval.
2. Upper-division requirements (46 units)
   a) PHYS 130A, PHYS 130B, PHYS 132, PHYS 135A, PHYS 135B, PHYS 156A, PHYS 156B
   b) PHYS 139L (5 units), PHYS 142L (5 units).
   c) 8 units of upper division Physics electives. Upper division math, science of engineering may be substituted with approval. A student may take up to a maximum of 4 units of undergraduate research (PHYS 195A, PHYS 195B, PHYS 195C, and/or PHYS 195D). This may include a Physics internship at an approved government or industrial laboratory.

Physics : Standard Track (B.S. degree)

1. Additional upper-division requirements (21 units)
   a) PHYS 133, PHYS 136
   b) PHYS 142L (additional 5 units- 1 quarter). Approved undergraduate research (PHYS 195A, PHYS 195B, PHYS 195C, PHYS 195D) in physics or an internship (PHYS 198-I) in physics at a government or industrial laboratory can be used in place of up to 5 units of PHYS 142L.
   c) 8 additional units of upper division Physics electives. PHYS 156C is highly recommended for those planning to go to graduate school in physics.

Physics: Biophysics Track (B.S. degree)

1. Additional lower-division requirements (12 units)
   a) BIOL 005A, BIOL 005B, BIOL 005C, BIOL 05LA
2. Additional upper-division requirements (24 units)
   a) CHEM 112A, CHEM 112B which may be used to satisfy the core requirement 2c.
   b) 16 additional upper division units taken from CHEM 112C, BCH 110A, BCH 110B, BCH 110C or BIOL 107A (other upper division CHEM/BIOL/BCH may be substituted upon approval)

Physics Education Track (B.S. degree only)

1. Additional lower-division requirements (10 units)
   a) EDUC 003, EDUC 004
   b) LING 020 or LING 021
2. Additional upper-division requirements (16 units)
   a) EDUC 110, EDUC 177A, and either EDUC 172 or EDUC 174.
3. Upper division recommendations (4 units)
   a) EDUC 104/MATH 104

Physics: Applied Physics and Engineering Track (B.S degree)

1. Additional upper-division requirements (21 units)
   a) PHYS 142L (additional 5 units- 1 quarter). Approved undergraduate research (PHYS 195A, PHYS 195B, PHYS 195C, PHYS 195D) in physics or an internship (PHYS 198-I) in physics at a government or industrial laboratory can be used in place of up to 5 units of PHYS 142L.
   b) 8 additional units of upper division Physics electives.
   c) 8 units of upper division Engineering electives.

Students seeking an emphasis in environmental physics or chemical physics should consult with an advisor. The physics electives may be selected on an individual basis to stress one of these concentrations.

Students continuing on to graduate school are encouraged to take additional upper-division courses in Mathematics, such as MATH 146A, MATH 146B, MATH 146C, MATH 165A, MATH 165B, and MATH 113.

Students may wish to earn a Minor in Mathematics which requires an additional 24 units of upper division math.

To graduate, a minimum grade point average of 2.00 (C) is necessary overall and in the upper-division courses taken for the major (courses listed under 2.).

Bachelor of Arts

For the B.A. degree, additional units are required in Humanities, Social Sciences, and foreign language to meet the breadth requirements.

Minor

The minor in Physics consists of 26 upper-division units in Physics. A minimum of 16 units must be unique to the minor and may not be used to satisfy major requirements.

1. First Tier (16 units)
   a) PHYS 130A
   b) PHYS 132
   c) PHYS 135A
   d) One Upper Division Physics elective from PHYS 111, PHYS 150A, PHYS 151, PHYS 164, PHYS 165, PHYS 166, PHYS 177
2. Second Tier: at least 10 units from any upper-division Physics courses not chosen in the First Tier. The combined units from the First and Second Tiers should add to at least 26.
3. No more than 4 units of 190-199 courses may be used to fulfill the upper-division units for the minor.

See Minors under the College of Natural and Agricultural Sciences in the Colleges and Programs section of this catalog for additional information on minors.

Community College Transfers

The department provides special advisory services to aid community college transfer students in formulating their program and in remedying any deficiencies in required course work. Transfer students who have followed the prescribed program at the community college should be able to continue with the sample program at the junior level.

Graduate Program

The Department of Physics and Astronomy offers the M.S. and Ph.D. degrees in Physics.

Ongoing research in the Department of Physics and Astronomy includes astrophysics and space physics, condensed matter physics, particle physics, heavy ion physics, surface science, laser physics, and environmental physics. Large-scale experiments are carried out at the major U.S. and European accelerator laboratories or observatories.

Admission All applicants must submit scores from the GRE General and Physics subject tests. Questions about requirements for admission should be directed to the graduate advisor at (951) 827-5332.

Master's Degree

A student is recommended for the degree of M.A. or M.S. in Physics upon completion of the following requirements:

1. Satisfactory completion of a minimum of 36 quarter units of approved physics courses taken for a letter grade after admission to graduate study. Of these, at least 24 quarter units must be in the 200 series. Each course must be passed with a grade of "B-" or better. Each student must maintain an average for all courses of "B" or better.
2. Either of the following two plans:

Plan I (Thesis) Satisfactory completion of a thesis in a field of physics to be chosen in consultation with a faculty supervisor. This thesis is approved by a committee designated by the department.

Plan II (Comprehensive Examination) Satisfactory performance on the comprehensive examination.

Under either plan all requirements for the master's degree must be completed not later than the end of the sixth quarter.

Normative Time to Degree Six quarters

Doctoral Degree

The Department of Physics and Astronomy offers the Ph.D. degree in Physics.

It is recommended that students in the Ph.D. program become associated with a research advisor by the end of Spring Quarter of their first year.

A student is recommended for advancement to candidacy for the Ph.D. degree in Physics upon completion of requirements (1), (2), and (3) below. The student is recommended for the Ph.D. degree upon completion of requirements (4) and (5) below.

1. **Course Work** Each course must be passed with a grade of "B-" or better. Each student must maintain an average of "B" or better for all courses.

   1A. Core courses for students pursuing a program in Physics (other than Astronomy):

   PHYS 205 (Classical Mechanics)

   PHYS 210A, PHYS 210B, PHYS 210C (Electromagnetic Theory)

   PHYS 212A, PHYS 212B (Thermo dynamics and Statistical Mechanics)

   PHYS 221A, PHYS 221B, PHYS 221C (Quantum Mechanics)

   PHYS 296 (Summer Research in Physics and Astronomy)

   1B. Core courses for students pursuing a specialization in Astronomy:

   PHYS 205 (Classical Mechanics)

   PHYS 210A, PHYS 210B, PHYS 210C (Electromagnetic Theory)

   PHYS 212A (Thermo dynamics and Statistical Mechanics, Part A)

   PHYS 214 (Techniques of Observational Astrophysics)

   PHYS 215 (Dynamics and Evolution of Galaxies)

   PHYS 218 (Fundamentals of Astrophysics)

   PHYS 219 (Cosmology and Galaxy Formation)

   PHYS 296 (Summer Research in Physics and Astronomy)

In addition, students in both programs must complete at least three additional graduate lecture courses in the area of their specialization. Students pursuing program 1A should choose courses from section "a-f" below. Students pursuing program 1B should choose courses from section "g" below. The program for each student must be approved by the graduate committee and the student's research advisor. Such a program may entail more than the minimum number of courses, and may also involve a mixture of courses from different areas in addition to those in the lists below.

The elective courses include the following:

a) Nuclear and Particle Physics

PHYS 225A, PHYS 225B (Elementary Particles)

PHYS 230A, PHYS 230B (Advanced Quantum Mechanics and Quantum Theory of Fields)

b)Condensed Matter, Surface, Biophysics and Optical Physics

PHYS 209A, PHYS 209B (Introduction to Quantum Electronics)

PHYS 234 (Physics of Nanoscale Systems)

PHYS 235 (Spintronics and Nanoscale Systems)

PHYS 236 (Advanced Imaging Techniques)

PHYS 240A*, PHYS 240B*, PHYS 240C (Condensed Matter Physics)

PHYS 241A, PHYS 241B, PHYS 241C (Advanced Statistical Physics and Field Theory)

PHYS 242 (Physics at Surfaces and Interfaces)

PHYS 246 (Biophysics)

*For specialization in this track, students are required to take PHYS 240A and PHYS 240B successively as two of their three additional courses.

c)Astrophysics

PHYS 203 (Statistical Astronomy)

PHYS 204 (Advanced Galaxy Formation and Cosmology)

PHYS 208 (General Relativity)

PHYS 211A (Radiative Processes in Astrophysics)

PHYS 211B (Astrophysical Fluid Dynamics)

PHYS 213 (Astrophysics of the Interstellar Medium)

PHYS 216 (Star Formation)

PHYS 217 (Stellar Structure and Evolution)

Additional astrophysics courses may be taken at other UC campuses through the Intercampus Exchange Program.

d)Cosmology and Astroparticle Physics

PHYS 203 (Statistical Astronomy)

PHYS 204 (Advanced Galaxy Formation and Cosmology)

PHYS 208 (General Relativity)

PHYS 225A, PHYS 225B (Elementary Particles)

PHYS 230A (Advanced Quantum Mechanics)

PHYS 226 (Cosmology)

PHYS 227 (Particle Astrophysics)

e)Environmental Physics

Two courses chosen from track (b) and two courses chosen from below:

SWSC 203 (Surface Chemistry of Soils)

SWSC 213 (Soil Mineralogy)

or other approved graduate-level courses in related fields.

f) Materials and Nanoscale Physics

Two courses chosen from track (b) and two additional approved courses from the departments of Chemistry, Chemical and Environmental Engineering, Mechanical Engineering, or Electrical and Computer Engineering.

g) Astronomy

PHYS 203 (Statistical Astronomy)

PHYS 204 (Advanced Galaxy Formation and Cosmology)

PHYS 208 (General Relativity)

PHYS 211A (Radiation)

PHYS 213 (Astrophysics of the Interstellar Medium)

PHYS 216 (Star Formation)

PHYS 217 (Stellar Structure and Evolution)

PHYS 226 (Cosmology)

2. **Written Comprehensive Examinations** Students must have satisfactory performance on a comprehensive examination, to be taken at the end of the student's first year. In the event of a failure, a make-up exam is offered in the winter quarter of the second year. The comprehensive examination for students pursuing the physics program consists of an exam that covers Mechanics, Statistical and Thermal Physics, Quantum Mechanics, and Electromagnetism. The comprehensive examination for students pursuing the astronomy specialization consists of an exam that covers Mechanics, Statistical and Thermal Physics, Electromagnetism, and Fundamental Astrophysics.

3. **Oral Qualifying Examination in General Area of Proposed Research** Satisfactory performance on an oral examination in the general area of the student's proposed research. This examination is conducted by a doctoral committee, charged with general supervision of the student's research. It is normally taken during the academic year following that in which the comprehensive examination requirement has been successfully completed. A student who fails this examination on the first attempt may, at the discretion of the committee, be permitted to take it a second time.

4. **Dissertation Examination** Students must complete a dissertation containing a review of existing knowledge relevant to the area of the candidate's research, and the results of the candidate's original research. This research must be of sufficiently high quality to constitute a contribution to knowledge in the subject area.

5 **Final Oral Examination** A final oral defense may be required.

Normative Time to Degree For students pursuing program 1A: 15 quarters for theoretical physics; 18 quarters for experimental physics; 17 quarters for specialization in environmental

physics (theory); 20 quarters for specialization in environmental physics (experimental). For students pursuiing the astronomy program, 1B: 18 quarters.

Lower-Division Courses

Only one of the following sequences, PHYS 002A, PHYS 002B, PHYS 002C, or PHYS 040A, PHYS 040B, PHYS 040C may be taken for credit.

PHYS 002A General Physics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 008B with a grade of "C-" or better or MATH 009A with a grade of "C-" or better or MATH 09HA with a grade of "C-" or better; concurrent enrollment in PHYS 02LA or a grade of "C-" or better in PHYS 02LA. Covers topics in classical mechanics including Newton's laws of motion in one and two dimensions; work, energy, and conservation of energy; momentum and collisions; rotational motion; and orbital motion. For biological sciences students. Credit is not awarded for PHYS 002A if it has been awarded for PHYS 040A or PHYS 041A.

PHYS 002B General Physics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 009B or MATH 09HB (may be taken concurrently); PHYS 002A with a grade of "C-" or better; concurrent enrollment in PHYS 02LB or a grade of "C-" or better in PHYS 02LB. Covers topics in mechanics, thermodynamics, and electromagnetism. Includes fluid mechanics; temperature and heat; the laws of thermodynamics; kinetic theory of gases; electric fields and potentials; current and DC circuits; capacitance and inductance; magnetism; and Faraday's law. For biological sciences students. Credit is not awarded for PHYS 002B if it has already been awarded for both PHYS 040B and PHYS 040C or PHYS 041B.

PHYS 002C General Physics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 002B with a grade of "C-" or better; concurrent enrollment in PHYS 02LC or a grade of "C-" or better in PHYS 02LC. Covers topics in waves and modern physics. Includes harmonic oscillations; mechanical and electromagnetic waves; geometrical optics; reflection, refraction, interference, diffraction, and polarization; and quantum, atomic, and nuclear physics. For biological sciences students. Credit is not awarded for PHYS 002C if it has already been awarded for both PHYS 040D and PHYS 040E or PHYS 041C.

PHYS 005 History of the Universe (4) Lecture, 3 hours; discussion, 1 hour. An introduction to "The Big Bang" model and its observational tests. Topics include dark energy, dark matter, rapid growth of universe at early times, leftover radiation from "The Big Bang", galaxy formation, bending of light by gravity, black holes, extraterrestrial life, and the likely fate of the universe.

PHYS 006 The Violent Universe (4) Lecture, 3 hours; discussion, 1 hour. An introduction to violent phenomena that power the universe, specifically phenomena that illustrate basic astrophysical principles. Topics include impacts in our planetary system: explosions of stars, bursts of star formation, galaxy collisions, black holes, quasars, cosmic jets, and the "Big Bang."

PHYS 007 Space-Time, Relativity, and Cosmology (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): none. A nontechnical presentation of the growth of modern science covering topics from Newton and gravitation, Kepler and the motion of celestial bodies, Einstein and relativity, and Planck and Bohr up to present theories on the origin and evolution of the universe. Explores the philosophical ideas, scientific method, historical settings, and intellectual impacts. Includes demonstrations and visual illustrations.

PHYS 008 Color and Sound: Dimensions in Communication (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): none. Discusses the interplay between visual and aural sensory experiences and the physical principles of light and sound. Topics include visual perception and pattern recognition; the color spectrum; optical instruments; anatomy of the camera and the eye; lasers and holography; vibrations and sound waves; acoustics; reverberation; and sound production in speech, music, and high-fidelity audio devices. Involves demonstrations and illustrations.

PHYS 010 How Things Work (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): none. Survey of the physical basis of modern technology, with an emphasis on electronics and electrical devices. Topics include electro- and magneto-statics and dynamics (xerographic copiers, magnetic levitation, electrical power distribution), communication (radio, TV, computers, tape recorders, CD players), and imaging (cameras, DVD players, x rays, magnetic resonance imaging).

PHYS 016 Principles of Physics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 005 is recommended. Topics include classical laws of motion, force, energy, electricity and magnetism, properties of matter, atomic structure, waves, sound, light, heat, the Earth, and the solar system and universe. Includes demonstrations and visual illustrations. Not open to students with credit or concurrent enrollment in PHYS 002A, PHYS 002B, PHYS 002C, PHYS 040A, PHYS 040B, PHYS 040C, PHYS 040D, or PHYS 040E.

PHYS 018 Energy and the Environment (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): none. Covers the physics of energy (thermal, kinetic, potential, chemical, nuclear), its storage and use, primary sources of energy (fossil fuel, nuclear, wind, solar) and their relative effects on the environment. Particular emphasis on determining individual carbon footprints, physical models of global climate change and identifying pathways toward a sustainable infrastructure.

PHYS 020 Exploring the Universe: An Adventure in Astronomy (4) Lecture, 3 hours; workshop, 3 hours. Prerequisite(s): none. An astronomy course for non-science students. The excitement of an evolving and sometimes violent universe of stars and galaxies is explored in a descriptive manner. Here, the union of modern and ancient observations with astrophysical laws will provide a sophisticated but by no means complete picture of the universe. Special topics such as Astrology and Extraterrestrial Life will be discussed.

PHYS 024 DNA in Your Life: The Physical Basis for Structure, Function, and Control (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): none. An introduction to various medical, biological, and commercial aspects of physical DNA science.

PHYS 02LA General Physics Laboratory (1) Laboratory, 3 hours. Prerequisite(s): concurrent enrollment in PHYS 002A or a grade of "C-" or better in PHYS 002A. Illustrates the experimental foundations of physics presented in PHYS 002A. Covers the basic principles of classical mechanics.

PHYS 02LB General Physics Laboratory (1) Laboratory, 3 hours. Prerequisite(s): PHYS 002A and PHYS 02LA with a grade of "C-" or better; concurrent enrollment in PHYS 002B or a grade of "C-" or better in PHYS 002B. Illustrates the experimental foundations of physics presented in PHYS 002B. Covers the basic principles of fluid and rotational mechanics, temperature, heat, and electromagnetism.

PHYS 02LC General Physics Laboratory (1) Laboratory, 3 hours. Prerequisite(s): PHYS 002B and PHYS 02LB with a grade of "C-" or better; concurrent enrollment in PHYS 002C or a grade of "C-" or better in PHYS 002C. Illustrates the experimental foundations of physics presented in PHYS 002C. Covers the basic principles of oscillations, waves, optics, and radioactivity.

PHYS 037 The Origins (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): none. Explores the most fundamental questions in cosmology, physics, and chemical sciences through their origins. Topics include the origin of the Universe, origin of matter, first generation of stars and galaxies, origin of chemical elements, chemistry of life, and astrobiology.

PHYS 039 Adventures in Physics (3) Lecture, 3 hours. Prerequisite(s): none. General introduction to frontiers of physics research. Introduces the outstanding issues in physics research along with work of UC Riverside faculty. Includes tours of the research labs. Graded Satisfactory (S) or No Credit (NC).

PHYS 040A General Physics (5) Lecture, 3 hours; discussion, 1 hour; laboratory, 3 hours. Prerequisite(s): MATH 008B with a grade of "C-" or better or MATH 009A with a grade of "C-" or better or MATH 09HA with a grade of "C-" or better; MATH 009B or MATH 09HB (MATH 009B or MATH 09HB may be taken concurrently). Designed for engineering and physical sciences students. Covers topics in classical mechanics including Newton's laws of motion; friction; circular motion; work, energy, and conservation of energy; dynamics of particle systems; collisions; rigid-body motion; torque; and angular momentum. Laboratories provide exercises illustrating experimental foundations of physical principles and selected applications. Credit is not awarded for PHYS 040A if it has already been awarded for PHYS 002A or PHYS 041A.

PHYS 040B General Physics (5) Lecture, 3 hours; discussion, 1 hour; laboratory, 3 hours. Prerequisite(s): MATH 009C or MATH 09HC (may be taken concurrently); PHYS 040A with a grade of "C-" or better. Designed for engineering and physical sciences students. Covers topics in mechanics and thermodynamics including elasticity; oscillations; gravitation; fluids; mechanical waves and sound; temperature, heat, and the laws of thermodynamics; and the kinetic theory of gases. Laboratories provide exercises illustrating the experimental foundations of physical principles and selected applications.

PHYS 040C General Physics (5) Lecture, 3 hours; discussion, 1 hour; laboratory, 3 hours. Prerequisite(s): MATH 009C or MATH 09HC; PHYS 040B with a grade of "C-" or better. Designed for engineering and physical sciences students. Covers topics in electricity and magnetism including electric fields and potential; Gauss' law; capacitance; magnetic fields; Ampere's law; Faraday's law and induction; electromagnetic oscillations; dc and ac current; and circuits. Laboratories provide exercises illustrating the experimental foundations of physical principles and selected applications. Credit is not awarded for PHYS 040C if it has been awarded for PHYS 002B or PHYS 041B.

PHYS 040D General Physics (5) Lecture, 3 hours; discussion, 1 hour; laboratory, 3 hours. Prerequisite(s): PHYS 040C with a grade of "C-" or better or consent of instructor. For engineering and physical sciences students. Topics in electromagnetic waves including Maxwell's equations; geometrical optics; optical instruments, cavities, and waveguides; interference, diffraction, and polarization; and special theory of relativity. Laboratories provide exercises illustrating the experimental foundations of physical principles and selected applications. Credit is not awarded for PHYS 040D if it has already been awarded for PHYS 002C or PHYS 041C.

PHYS 040E General Physics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 046 (may be taken concurrently); PHYS 040D with a grade of "C-" or better. For engineering and physical sciences students. Covers topics in modern physics including the quantum theory of light and particles; quantum mechanics in one and three dimensions; tunneling phenomena; the hydrogen atom; statistical physics; lasers; molecular structure; and solid state, nuclear, and particle physics. Credit is not awarded for PHYS 040E if it has already been awarded for PHYS 002C or PHYS 041C.

PHYS 041A Introductory Physics for Physics Majors (8) Lecture, 4 hours; discussion, 2 hours; laboratory,

6 hours. Prerequisite(s): MATH 009A with a grade of "C-" or better or MATH 09HA with a grade of "C-" or better (MATH 009A or MATH 09HA may be taken concurrently). Covers topics in classical mechanics, including Newton's laws of motion in one and two dimensions; work, energy, and conservation of energy; momentum and collisions; rotational motion; and orbital motion. Credit is not awarded for PHYS 041A if it has already been awarded for PHYS 040A.

PHYS 041B Introductory Physics for Physics Majors (8) Lecture, 4 hours; discussion, 2 hours; laboratory, 6 hours. Prerequisite(s): MATH 009B with a grade of "C-" or better or MATH 09HB with a grade of "C-" or better (MATH 009B or MATH 09HB may be taken concurrently); PHYS 002A with a grade of "B-" or better or PHYS 040A with a grade of "C-" or better or PHYS 041A with a grade of "C-" or better or consent of instructor. Covers relativity oscillations, mechanical waves, fluids, electrostatics, magnetism, and circuits. Credit is not awarded for PHYS 041B if it has already been awarded for PHYS 040C.

PHYS 041C Introductory Physics for Physics Majors (8) Lecture, 4 hours; discussion, 2 hours; laboratory, 6 hours. Prerequisite(s): MATH 009C with a grade of "C-" or better or MATH 09HC with a grade of "C-" or better (MATH 009C or MATH 09HC may be taken concurrently); PHYS 002B with a grade of "B-" or better or PHYS 040C with a grade of "C-" or better or PHYS 041B with a grade of "C-" or better or consent of instructor. Covers electromagnetism, geometric and wave optics, and modern physics. Credit is not awarded for PHYS 041C if it has already been awarded for both PHYS 040D and PHYS 040E.

PHYS 097 Lower-Division Research (1-4) Individual study, 3-12 hours. Prerequisite(s): consent of instructor. Special research projects in physics performed under the supervision of a member of the staff. This course may not be used to satisfy the undergraduate unit requirements in the major. Graded Satisfactory (S) or No Credit (NC). Course is repeatable to a maximum of 8 units.

Upper-Division Courses

PHYS 111 Astrophysics and Stellar Astronomy (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 010B, MATH 046, or equivalents; one of the following: PHYS 040D with a grade of C- or better, PHYS 041C with a grade of C- or better, PHYS 002C with a grade of B- or better. Covers stellar interiors, radiations, and evolution; the origin of the elements; particle and electromagnetic radiation; pulsars, quasars, and other unusual objects; and galactic structure and cosmology.

PHYS 130A Classical Mechanics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 009C, MATH 010A (may be taken concurrently); one of the following: PHYS 002A with a grade of B- or better, PHYS 040A with a grade of C- or better, PHYS 041A with a grade of C- or better. Explores vector calculus, single-particle motion, oscillations, Lagrangian and Hamiltonian dynamics, central-forces motion, and celestial mechanics.

PHYS 130B Classical Mechanics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 010A, MATH 010B (may be taken concurrently), PHYS 130A. Topics include dynamics of a system of particles, motion in non-inertial reference systems, dynamics of rigid bodies, coupled oscillations, and special theory of relativity.

PHYS 132 Thermodynamics (5) Lecture, 3 hours; discussion, 1 hour; laboratory, 3 hours. Prerequisite(s): MATH 010B; MATH 046 (may be taken concurrently); PHYS 130B. Covers thermodynamic systems, heat, work, laws of thermodynamics, and formal mathematical relations. Credit is awarded for only one of PHYS 132 or PHYS 134.

PHYS 133 Statistical Physics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 156B. Covers statistical mechanics, ensembles, and classical and quantum statistical mechanics. Explores the connection between statistical mechanics and thermodynamics. Credit is awarded for only one of PHYS 133 or PHYS 134.

PHYS 134 Thermal Physics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 010B; one of the following: PHYS 002C with a B- or better, PHYS 040E with a C- or better, PHYS 041C with a C- or better. Covers macroscopic properties of many-particle systems. Examines laws and applications of thermodynamics (entropy, thermodynamic potentials, and ideal gases). Addresses principles and applications of statistical mechanics including probability distributions; canonical, microcanonical, and grand canonical ensembles; specific heat of solids; paramagnetism; kinetic theory of gases; phase transitions; and quantum statistics. Credit is not awarded for PHYS 134 if it has already been awarded for PHYS 132 or PHYS 133.

PHYS 135A Electromagnetism (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 010B; MATH 046; one of the following: PHYS 002B with B- or better, PHYS 040C with a C- or better, PHYS 041B with a C- or better. Topics include vector calculus; Coulomb's law and the electric field; Gauss' law; scalar potential; conductors in electrostatic fields; electrostatic energy; electric multipoles; boundary conditions; electrostatics in the presence of matter; and special methods in electrostatics.

PHYS 135B Electromagnetism (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 135A. Topics include electric currents and circuits, Ampere's law, the magnetic field, the integral form of Ampere's law, the vector potential, Faraday's law of induction, magnetic energy, magnetic multipoles, magnetism in the presence of matter, Maxwell's equations, and plane waves.

PHYS 136 Electromagnetic Waves (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 135B. Covers Maxwell's equations; propagation of electromagnetic waves in wave guides, coaxial lines, and optical fibers; reflection, refraction, and diffraction of waves; dispersion of waves in gases and plasmas; interference and coherence and their role in holography; electromagnetic radiation from charged particles, antennas, masers, and lasers; and relativistic electrodynamics.

PHYS 139L Electronics for Scientists (5) Lecture, 3 hours; laboratory, 6 hours. Prerequisite(s): One of the following: PHYS 002B with B- or better, PHYS 040C with a C- or better, PHYS 041B with a C- or better, or consent of instructor. Introduces basic analog and digital circuit designs that emphasize practical applications. Includes properties of diodes and transistors; operational amplifiers for use as amplifiers, oscillators, and function generators; properties and use of logic gates, counters, and timers; data storage and synchronization; multiplexer and decoder applications; microprocessor functions; and computer interfacing.

PHYS 142L Advanced Physics Laboratory (5) Laboratory, 15 hours. Prerequisite(s): one of the following: PHYS 002C with a grade of B- or better, PHYS 040E with a grade of C- or better, PHYS 041C with a grade of C- or better; upper-division standing in Physics; consent of advisor. Consists of experiments chosen from areas in contemporary physics. Course is repeatable to a maximum of 10 units.

PHYS 145A Biophysics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): CHEM 001C or CHEM 01HC; MATH 010B; MATH 046; one of the following: PHYS 002C with B- or better, PHYS 041C with a C- or better, PHYS 040E with a C- or better. Covers physical modeling of the structure of proteins; protein folding; structure of nucleic acids; electrostatic potential of DNA; dynamics of biomolecules; structure of a biological cell; osmotic pressures of cells; non-equilibrium thermodynamics; and biochemical reactions.

PHYS 145B Biophysics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 145A; BCH 100 or BCH 110B; or consent of instructor. Covers conformation of biopolymers, intermolecular forces, dynamics of biopolymers, Brownian motion, biopolymers as polyelectrolytes, electrolytic solutions, and the Debye-Huckel theory.

PHYS 145C Biophysics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 145B or consent of instructor. Examines stochastic thermodynamics; the Fluctuation Theorems and the Jarzynski relation; protein and RNA denaturation; tests of the Jarzynski relation; chemical forces and self-assembly; enzymes and molecular machines; survey of molecular devices found in cells; and kinetics of real enzymes and machines.

PHYS 150A Introduction to Condensed Matter Physics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): One of the following: PHYS 002B with B- or better, PHYS 040E with a C- or better, PHYS 041C with a C- or better; or consent of instructor. Covers properties of systems composed of many atoms arranged in a periodic lattice. Topics include crystal structure, symmetry, and diffraction; crystal cohesion; lattice dynamics; thermal properties; metallic properties and the Fermi surface; band theory of metals and semiconductors; and collective excitations.

PHYS 150B Introduction to Condensed Matter Physics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 150A. Covers properties of systems composed of many atoms arranged in a periodic lattice. Topics include superconductivity; magnetism; non-crystalline solids; defects in solids; surface and interface physics; and alloys.

PHYS 151 Topics in Modern Condensed Matter Research (4) Lecture, 3 hours; term paper, 3 hours. Prerequisite(s): One of the following: PHYS 002B with B- or better, PHYS 040E with a C- or better, PHYS 041C with a C- or better. Consent of instructor is required for students repeating the course. Introduces cutting-edge physics research being conducted in laboratories and institutes around the world. Focuses on a single research area (e.g., nanoscale physics, biological physics) that may change each quarter. Includes experimental methods and theoretical concepts. Course is repeatable as content changes to a maximum of 12 units.

PHYS 152A Exploring Many-Body Quantum Physics with Mathematica (2) W Lecture, 2 hours. Prerequisite(s): MATH 046; one of the following: PHYS 002C with a B- or better, PHYS 040E with a C- or better, PHYS 041C with a C- or better; or consent of instructor. MATH 031 is recommended. An introduction to numerics and visualization using Mathematica. Topics include random numbers and stochastic processes; time-dependent and stationary equations in matrix form; single-particle tight-binding model; single-spin dynamics; pure and mixed states; spin echo; the direct product of matrices; many-body quantum mechanics; and quantum spin chains.

PHYS 152B Exploring Many-Body Quantum Physics with Mathematica (2) Lecture, 2 hours. Prerequisite(s): PHYS 152A or consent of instructor. Covers the symmetry of many-body wavefunction, including bosons and fermions; secondary quantization; harmonic oscillators; ladder operators, eigenvalues, and eigenfunctions; interacting many-body systems; mean field approximation; and density matrix of a subsystem and decoherence.

PHYS 156A Quantum Mechanics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 010B, MATH 046, PHYS 130B; one of the following: PHYS 002C with a grade of B- or better, PHYS 040E with a grade of C- or better, PHYS 041C with a grade of C- or better. Topics include wave-particle duality, the

Schrdinger equation, superposition, the uncertainty principle, and one-dimensional harmonic oscillator.

PHYS 156B Quantum Mechanics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 156A. Topics include the hydrogen atom, angular momentum and spin representations, many-electron systems, the Pauli exclusion principle, and perturbation theory.

PHYS 156C Quantum Mechanics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 156B. Applications in quantum mechanics. Includes perturbation theory and other approximations, scattering, and an introduction to advanced topics such as relativistic quantum mechanics.

PHYS 163 Atomic Physics and Spectroscopy (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): CHEM 113 or equivalent; one of the following: PHYS 002A with a grade of B- or better, PHYS 040A with a grade of C- or better, PHYS 041A with a grade of C- or better; or consent of instructor. Covers fine structure and spin-orbit coupling in single-electron atoms; angular momentum coupling and magnetic moments in many-electron atoms; Hartree-Fock solution to many-electron problem; hyperfine structure; atoms in the various electromagnetic fields; the two-level atom; electron spin and nuclear magnetic resonance spectroscopy; laser spectroscopy; and fundamentals of chemical bonding in molecules.

PHYS 164 Introduction to Nuclear Physics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): One of the following: PHYS 002C with a grade of B- or better, PHYS 040E with a grade of C- or better, PHYS 041C with a grade of C- or better. Addresses the basic nuclear properties, as well as the nuclear building blocks and structure. Explores radioactivity, nuclear interactions, the strong force, the confinement and chiral phase transitions, the quantum chromodynamics (QCD) vacuum, and matter at extreme temperatures and densities.

PHYS 165 Introduction to Particle Physics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 156A. Explores the classification of particles in terms of the Standard Model. Includes methods and techniques for particle acceleration and detection; conservation laws and symmetries; the basic interactions of particles (electromagnetic, strong, weak); and electroweak unification.

PHYS 166 Cosmology (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 156A. Discusses current topics in astrophysics and cosmology from the perspective of elementary particle physics. Topics include the development and structure of the early universe, dark matter and dark energy, cosmic radiation, and particle physics in the stars.

PHYS 168 Environmental Physics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 046; PHYS 040C; one of the following: CHEM 110B, PHYS 002C with a B- or better, both PHYS 040D and PHYS 040E both with a grade of C- or better, PHYS 041C with a grade of C- or better. Covers the application of physics to environmental problems. Includes global climate, energy for human use, transport of pollutants, noise, environmental spectroscopy, and the evaluation of environmental issues in the context of society.

PHYS 177 Computational Methods for Physical Sciences (4) Lecture, 3 hours; laboratory, 3 hours. Prerequisite(s): one of the following: PHYS 002C with a grade of B- or better, PHYS 040E with a grade of C- or better, PHYS 041C with a grade of C- or better. Covers computer applications for solving problems in physical sciences. Addresses symbolic manipulation languages such as Mathematica, mathematical operations, plotting, and symbolic and numerical techniques in calculus. Includes numerical methods such as histogramming, the Monte-Carlo method for modeling experiments, statistical analysis, curve fitting, and numerical algorithms. Prior computer knowledge not required.

PHYS 190 Special Studies (1-5) Individual study, 3-15 hours. Prerequisite(s): consent of department chair. Individual study to meet special curricular needs. May not be used to satisfy major requirements unless taken as a replacement for a course not being offered during the student's remaining tenure. Students who take the course as a substitute for PHYS 142L receive a letter grade; other students may petition for a Satisfactory (S) or No Credit (NC) grade. Course is repeatable to a maximum of 9 units; a maximum of 5 units may be used to substitute for PHYS 142L.

PHYS 190L Special Studies at Los Alamos National Laboratory (1-8) Individual study, 3-24 hours. Prerequisite(s): admission to the UCR/LANL Educational Internship Program; consent of advisor and department chair. Individual study to meet special curricular needs. Course is repeatable to a maximum of 16 units.

PHYS 195A Senior Thesis (1-4) Thesis, 3-12 hours. Prerequisite(s): senior standing; consent of instructor. A thesis written on research conducted under the supervision of a faculty member. May be undertaken as a one-, two-, three-, or four-quarter course (PHYS 195A, PHYS 195B, PHYS 195C, PHYS 195D). Total credit awarded for PHYS 195A plus PHYS 195B plus PHYS 195C plus PHYS 195D may not exceed 8 units; a maximum of 4 units may be used to satisfy the unit requirement for the major, and a maximum of 5 units of any combination of PHYS 195A, PHYS 195B, PHYS 195C, and PHYS 195D may be used to substitute for PHYS 142L. Graded In Progress (IP) until the last quarter is completed, at which time a final grade is assigned; a Satisfactory (S) or No Credit (NC) grade is awarded unless the course is taken to substitute for PHYS 142L.

PHYS 195B Senior Thesis (1-4) Thesis, 3-12 hours. Prerequisite(s): senior standing; consent of instructor; PHYS 195A. A thesis written on research conducted under the supervision of a faculty member. May be undertaken as a one-, two-, three-, or four-quarter course (PHYS 195A, PHYS 195B, PHYS 195C, PHYS 195D). Total credit awarded for PHYS 195A plus PHYS 195B plus PHYS 195C plus PHYS 195D may not exceed 8 units; a maximum of 4 units may be used to satisfy the unit requirement for the major, and a maximum of 5 units of any combination of PHYS 195A, PHYS 195B, PHYS 195C, and PHYS 195D may be used to substitute for PHYS 142L. Graded In Progress (IP) until the last quarter is completed, at which time a final grade is assigned; a Satisfactory (S) or No Credit (NC) grade is awarded unless the course is taken to substitute for PHYS 142L.

PHYS 195C Senior Thesis (1-4) Thesis, 3-12 hours. Prerequisite(s): senior standing; consent of instructor; PHYS 195B. A thesis written on research conducted under the supervision of a faculty member. May be undertaken as a one-, two-, three-, or four-quarter course (PHYS 195A, PHYS 195B, PHYS 195C, PHYS 195D). Total credit awarded for PHYS 195A plus PHYS 195B plus PHYS 195C plus PHYS 195D may not exceed 8 units; a maximum of 4 units may be used to satisfy the unit requirement for the major, and a maximum of 5 units of any combination of PHYS 195A, PHYS 195B, PHYS 195C, and PHYS 195D may be used to substitute for PHYS 142L. Graded In Progress (IP) until the last quarter is completed, at which time a final grade is assigned; a Satisfactory (S) or No Credit (NC) grade is awarded unless the course is taken to substitute for PHYS 142L.

PHYS 195D Senior Thesis (1-4) Thesis, 3-12 hours. Prerequisite(s): senior standing; consent of instructor; PHYS 195C. A thesis written on research conducted under the supervision of a faculty member. May be undertaken as a one-, two-, three-, or four-quarter course (PHYS 195A, PHYS 195B, PHYS 195C, PHYS 195D). Total credit awarded for PHYS 195A plus PHYS 195B plus PHYS 195C plus PHYS 195D may not exceed 8 units; a maximum of 4 units may be used to satisfy the unit requirement for the major, and a maximum of 5 units of any combination of PHYS 195A, PHYS 195B, PHYS 195C, and PHYS 195D may be used to substitute for PHYS 142L. Graded In Progress (IP) until the last quarter is completed, at which time a final grade is assigned; a Satisfactory (S) or No Credit (NC) grade is awarded unless the course is taken to substitute for PHYS 142L.

PHYS 197 Research for Undergraduates (1-4) Individual study, 3-12 hours. Prerequisite(s): upper-division standing and consent of instructor. Special research projects in physics performed under the supervision of a member of the staff. This course may not be used to satisfy the undergraduate unit requirement in the major. Graded Satisfactory (S) or No Credit (NC). Course is repeatable to a maximum of 8 units.

PHYS 198-I Individual Internship in Physics (1-12) Written work, 1-12 hours; internship, 2-24 hours. Prerequisite(s): upper-division standing; consent of department chair. Provides experience as a practicing scientist in a government or industrial laboratory. Includes joint supervision by an off-campus sponsor and a Physics faculty member. Graded Satisfactory (S) or No Credit (NC) unless taken to substitute for PHYS 142L. Course is repeatable to a maximum of 12 units; a maximum of 4 units may be used to satisfy major requirements, and a maximum of 5 units may be used to substitute for PHYS 142L.

Graduate Courses

PHYS 202 Interdisciplinary Overview of Current Issues in Semiconductor Processing (3) Lecture, 3 hours. Prerequisite(s): graduate standing in Chemistry, Physics, Engineering, or a related subject or consent of instructor. An interdisciplinary overview of present-day semiconductor processing. Introduces topics such as properties of semiconductors, cleanroom environment, epitaxy, ion implantation, etching, lithography, device architecture, testing, and fault detection. May offer field trips. Cross-listed with CHEM 208 and MSE 245D.

PHYS 203 Statistical Astronomy (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 218. Introduces statistical methods needed to analyze astronomical data. Provides case examples of problems in observational astronomy and applies statistical techniques to solve them. Covers probability, correlation and association, hypothesis testing, data modelling, maximum likelihood technique, detection and surveys, sequential data, and surface distribution.

PHYS 204 Advanced Galaxy Formation and Cosmology (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 218 and PHYS 219. Covers topics on galaxy formation, star formation in galaxies, intergalactic medium, first generation of stars and galaxies, high redshift Universe, dark matter and dark energy, and big bang chronology and nucleosynthesis. Also introduces new techniques and the latest data sets and data archives used for research.

PHYS 205 Classical Mechanics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing in Physics. Covers the Lagrangian formulation, calculus of variations, Hamilton's principle, conservation principles and symmetry properties, the two-body central force problem, the Kepler problem, and scattering. Also examines orthogonal transformations, rigid body motion, the inertia tensor, Euler's equations, Hamiltonian formulation, canonical transformations, and complex integration. **Tsai**

PHYS 208 General Relativity (4) Lecture, 3 hours; consultation, 1 hour. Prerequisite(s): PHYS 205. Tensors, covariant derivative, the Riemann curvature tensor and Einstein's equation. The Schwartzchild metric and applications to the solar system and black holes. Gravity waves and expanding universe.

PHYS 209A Quantum Electronics (4) Lecture, 4.5 hours. Prerequisite(s): PHYS 134, PHYS 135A, PHYS 135B, PHYS 156A; or consent of instructor. Quantum theory of light and interaction of light with atoms.

Density matrix formulation of atomic susceptibility. Propagation of light in matter and optical waveguides. Optical resonators. Theory and operation of common lasers. Letter grades are assigned to students whose research is related to atomic, molecular, or optical physics. Other students receive either a letter or Satisfactory (S) or No Credit (NC) grade.

PHYS 209B Nonlinear Optics (4) Lecture, 4.5 hours. Prerequisite(s): PHYS 209A or consent of instructor. Wave propagation in nonlinear media. Electro-optic effect, three- and four-wave mixing, high-resolution nonlinear spectroscopies, rare atom and molecule detection, laser manipulation of particles, high-intensity laser physics, laser-plasma interactions. Letter grades are assigned to students whose research is related to atomic, molecular, or optical physics. Other students receive either a letter or Satisfactory (S) or No Credit (NC) grade.

PHYS 210A Electromagnetic Theory (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing; consent of instructor. Covers topics in electrostatics, including Coulomb potential, boundary value problems, multipoles, and dielectric media. Also addresses Laplace's equation and Green's function in Cartesian, spherical, and cylindrical coordinates.

PHYS 210B Electromagnetic Theory (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 210A; graduate standing; consent of instructor. Covers topics in electromagnetism. Includes magnetostatics, quasistationary electromagnetism, Maxwell's equations, gauge transformations, Maxwell's stress tensor, analyticity of dielectric susceptibility, and electromagnetic waves in uniform media and waveguides.

PHYS 210C Electromagnetic Theory (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 210B or consent of instructor. Covers electromagnetic radiation and scattering; propagation of electromagnetic fields in non-uniform media (geometrical optics, interference, and diffraction); special theory of relativity; Lagrangian formalism; and dynamics of relativistic particles in external fields. Also examines Cherenkov radiation and magnetic monopoles.

PHYS 211A Radiative Processes in Astrophysics (4) Lecture, 3 hours; consultation, 1 hour. Prerequisite(s): PHYS 135A, PHYS 135B, PHYS 136, PHYS 156A, PHYS 156B. Radiative transfer of continuum and line radiation, Einstein coefficients, photoionization equilibria, radiation by free electrons, bremsstrahlung and synchrotron emission, Compton and inverse Compton scattering, wave propagation through magnetized plasmas, atomic and molecular structure and spectra, atomic fine structure, and molecular hyperfine lines. Letter grades are assigned to students whose research is related to astrophysics. Other students receive either a letter or Satisfactory (S) or No Credit (NC) grade.

PHYS 211B Astrophysical Fluid Dynamics (4) Lecture, 3 hours; consultation, 1 hour. Prerequisite(s): PHYS 211A. Covers hydrodynamics, sound waves, turbulence, supersonic turbulence, magnetohydrodynamics, Alfven waves, extragalactic relativistic jets, supersonic jets, galactic spiral structure and density-wave theory, accretion disk theory, Balbus-Hawley instability, and stellar winds. Students whose research is related to astrophysics receive a letter grade; other students receive a letter grade or Satisfactory (S) or No Credit (NC) grade.

PHYS 212A Thermodynamics and Statistical Mechanics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing; consent of instructor. Covers thermodynamics, statistical mechanics, ideal Bose systems, ideal Fermi systems, and bulk motion. Cross-listed with MSE 204. **Wudka**

PHYS 212B Thermodynamics and Statistical Mechanics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MSE 204/PHYS 212A; graduate standing; consent of instructor. Addresses functional integrals and approximation techniques. Provides an introduction to phase transitions and the renormalization group.

PHYS 213 Astrophysics of the Interstellar Medium (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing. An overview of the interstellar medium and relevant physical processes. Covers the structure and evolution of ionized hydrogen regions associated with massive stars and supernovae. Also addresses the neutral and ionized phases of the interstellar medium, as well as cooling processes. Includes the interpretation of spectral lines. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 214 Techniques of Observational Astrophysics (4) Lecture, 2 hours; laboratory, 3 hours; written work, 3 hours. Prerequisite(s): graduate standing. An introduction to the basic tools of observational astronomy. Topics include astronomical telescopes and detectors, observing techniques, calibration, and error analysis. Students whose research is related to astronomy receive a letter grade; other students receive a letter grade or Satisfactory (S) or No Credit (NC) grade.

PHYS 215 Dynamics and Evolution of Galaxies (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing. Discusses the structure, stability, and dynamic and cosmologic evolution of galaxies. Interprets observational data on galaxies within a coherent theoretical framework. Topics include potential theory, orbits, collisionless systems, and the structure and evolutionary history of galaxies. Students whose research is related to astronomy receive a letter grade; other students receive a letter grade or Satisfactory (S) or No Credit (NC) grade.

PHYS 216 Star Formation (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing. Discusses the processes involved in the formation of stars: the initial conditions in the interstellar medium that leads to star formation and the formation of planets and planetary systems around young stars. Topics include molecular cloud formation, the properties of young stars, jets and outflows, massive stars, and cosmological star formation. Students whose research is related to astronomy receive a letter grade; other students receive a letter grade or Satisfactory (S) or No Credit (NC) grade.

PHYS 217 Stellar Structure and Evolution (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing. Topics include physics of stellar structure and main sequence evolution, and energy production and transport; postmain sequence evolution through the giant stage and the formation of compact objects; supernovae, nucleosynthesis, pulsars, and the roll of accretion within the framework of stellar evolution; and the physics of white dwarfs, neutron stars, and black holes. Students whose research is related to astronomy receive a letter grade; other students receive a letter grade or Satisfactory (S) or No Credit (NC) grade.

PHYS 218 Fundamentals of Astrophysics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing or consent of instructor. Develops basic astrophysical concepts from fundamental physics. Topics include nucleosynthesis, stellar structure, evolution of stars of different masses, end-states of stars, and bremsstrahlung and synchroton radiation. Also covers cross-sections, opacities, hydrogen atom transitions, forbidden lines, and molecular lines. Addresses the ongoing search of life in the Universe. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 219 Cosmology and Galaxy Formation (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing or consent of instructor. Topics include cosmology, models for the universe, galaxy formation scenarios, evolution of galaxies and stellar population, and number counts. Also covers luminosity functions, correlation function and clustering, star formation activity in the universe, cosmic background radiation, dark matter, and dark energy. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 221A Quantum Mechanics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing; consent of instructor. Examines the fundamental concepts of quantum mechanics including wave functions and the uncertainty relations. Also covers time dependence of quantum systems, such as the simple harmonic oscillator and simple two-level systems. **Desai**

PHYS 221B Quantum Mechanics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 221A; graduate standing; consent of instructor. Covers angular momentum and approximation methods, including perturbation theory.

PHYS 221C Quantum Mechanics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 221B; graduate standing; consent of instructor. Covers symmetries in quantum mechanics, identical particles, and scattering theory. **Desai**

PHYS 225A Elementary Particles (4) Lecture, 3 hours; consultation, 1 hour. Prerequisite(s): PHYS 221A, PHYS 221B, PHYS 221C; or consent of instructor. Provides an overview of particle physics. Topics include Quantum Electrodynamics (QED), the Quark-Parton Model, and Quantum Chromodynamics (QCD). Also discusses experimental techniques for particle detection and energy measurement. Students whose research is related to high-energy physics receive a letter grade; other students receive a letter grade or Satisfactory (S) or No Credit (NC) grade.

PHYS 225B Elementary Particles (4) Lecture, 3 hours; consultation, 1 hour. Prerequisite(s): PHYS 225A or consent of instructor. Covers advanced topics in particle physics such as the Standard model, Charge-Parity (CP) violation and conservation laws, and mixing in the neutral strange and bottom meson systems. Students whose research is related to high-energy physics receive a letter grade; other students receive a letter grade or Satisfactory (S) or No Credit (NC) grade.

PHYS 226 Cosmology (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing; PHYS 208. Discusses advanced topics in cosmology: Friedmann models and the large-scale structure of the universe, Hubble constant and deceleration parameter, and galaxy counting and the physics of the early universe. Also covers vacuum phase transitions, inflation, baryon number generation, fluctuations, topological defects and textures, primordial nucleosynthesis, density fluctuations, dark matter candidates, and the age of the universe. Students whose research is related to cosmology or astroparticle physics receive a letter grade; other students receive a letter grade or Satisfactory (S) or No Credit (NC) grade.

PHYS 227 Particle Astrophysics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing; PHYS 226. An introduction to current research in particle astrophysics: the very early universe, the origin of matter, primordial perturbations, the origin of structure, the nature of dark matter, vacuum energy, matter-antimatter asymmetry, neutrino astrophysics, gravitational radiation, black holes, the origin of ultrahigh energy cosmic rays, and Hawking radiation. Students whose research is related to cosmology or astroparticle physics receive a letter grade; other students receive a letter grade or Satisfactory (S) or No Credit (NC) grade.

PHYS 230A Advanced Quantum Mechanics and Quantum Theory of Fields (4) Lecture, 3 hours; consultation, 1 hour. Prerequisite(s): PHYS 221A, PHYS 221B, PHYS 221C; or consent of instructor. Topics include quantization of fields for particles with spins 0, 1/2,

and 1; path integrals; Feynman diagrams; and scattering amplitude and cross sections. Students whose research is related to quantum mechanics receive a letter grade; other students receive a letter grade or Satisfactory (S) or No Credit (NC) grade.

PHYS 230B Advanced Quantum Mechanics and Quantum Theory of Fields (4) Lecture, 3 hours; consultation, 1 hour. Prerequisite(s): PHYS 230A or consent of instructor. Explores renormalization of quantum field theory, gauge invariance, spontaneous breaking of gauge symmetry, Quantum Chromodynamics, and electroweak interactions. Students whose research is related to quantum mechanics receive a letter grade; other students receive a letter grade or Satisfactory (S) or No Credit (NC) grade.

PHYS 230C Advanced Quantum Mechanics and Quantum Theory of Fields (4) Lecture, 3 hours; consultation, 1 hour. Prerequisite(s): PHYS 230B or consent of instructor. A study of current topics in quantum field theory, including solitons and instantons, supersymmetry, and the unification of all forces. Students whose research is related to quantum mechanics receive a letter grade; other students receive a letter grade or Satisfactory (S) or No Credit (NC) grade.

PHYS 231 Methods of Theoretical Physics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing or consent of instructor. A study of analytic functions, Cauchy's theorem, Taylor series, Laurent series expansions, the residue theorem, and analytic continuation.

PHYS 234 Physics of Nanoscale Systems (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing or consent of instructor. Explores the fundamental concepts and techniques of nanoscale physics, including nanoscale fabrication and characterization techniques, electronic properties in reduced dimensions, properties of carbon nanotubes, nanoelectromechanical systems, superconductivity in reduced dimensions, and nanophotonics. Students whose research is related to materials and nanoscale systems physics receive a letter grade; other students receive a letter grade or Satisfactory (S) or No Credit (NC) grade. Cross-listed with MSE 234A.

PHYS 235 Spintronics and Nanoscale Magnetism (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing or consent of instructor. Provides an overview of contemporary issues in nanoscale magnetism and spin-dependent phenomena in solids, including the fundamentals of magnetism, magnetism in reduced dimensions, novel magnetic materials, spin-polarized transport, spin coherence in semiconductors, magnetization dynamics, and device applications. Students whose research is related to materials and nanoscale systems physics receive a letter grade; other students receive a letter grade or Satisfactory (S) or No Credit (NC) grade. Cross-listed with MSE 234B.

PHYS 236 Advanced Imaging Techniques (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing or consent of instructor. Covers advanced fabrication and characterization techniques of nanoscale materials, structures, and devices, including lithographic methods (top-down approach), self-assembling growth of nanowires and nanocrystals, scanned probe microscopy, and electron microscopy. Students whose research is related to materials and nanoscale systems physics receive a letter grade; other students receive a letter grade or Satisfactory (S) or No Credit (NC) grade.

PHYS 240A Condensed Matter Physics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 221C; graduate standing or consent of instructor. Topics include classical and quantum theories of the electron gas; crystal and reciprocal lattices; X-ray diffraction; crystal symmetries; electrons in a periodic potential; nearly free electrons; tight binding; semiclassical dynamics; and semiclassical transport. Students whose research is related to condensed matter physics receive a letter grade; other students receive a letter grade or Satisfactory (S) or No Credit (NC) grade. Cross-listed with MSE 214.

PHYS 240B Condensed Matter Physics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 240A or consent of instructor. Topics include measuring the Fermi surface, band structure, electron scattering, electron-electron interactions, surface effects, classification of solids, cohesive energy, classical and quantum harmonic crystals, and phonon dispersion relations. Students whose research is related to condensed matter physics receive a letter grade; other students receive a letter grade or Satisfactory (S) or No Credit (NC) grade.

PHYS 240C Condensed Matter Physics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 240B or consent of instructor. Topics include anharmonic phonon effects, phonons in metals, dielectric properties, homogeneous and inhomogeneous semiconductors, defects, diamagnetism, paramagnetism, magnetic interactions, magnetic ordering, and superconductivity. Students whose research is related to condensed matter physics receive a letter grade; other students receive a letter grade or Satisfactory (S) or No Credit (NC) grade.

PHYS 240D Advanced Solid State Physics (4) W Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 240C. Discusses the techniques of group theory and symmetry considerations applied to solid state physics. Uses these techniques to analyze and develop the theory and experiments of ferro and anti-ferromagnetism, ferroelectricity, spintronics, and correlated fermions. Students whose research is related to solid state physics receive a letter grade; other students receive a letter grade or Satisfactory (S) or No Credit (NC) grade.

PHYS 241A Advanced Statistical Physics and Field Theory (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing; PHYS 212B or consent of instructor; PHYS 221C or consent of instructor. PHYS 240A, PHYS 240B, and PHYS 240C are recommended. Topics include elementary excitations in many-body systems, critical phenomena and the renormalization group technique, Green's functions and Feynman diagrams, and other field-theory techniques, and advanced topics in condensed matter physics. Students whose research is related to condensed matter physics receive a letter grade; other students receive a letter grade or Satisfactory (S) or No Credit (NC) grade.

PHYS 241B Advanced Statistical Physics and Field Theory (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing; PHYS 241A. Topics include advanced field-theory techniques applied to many-body systems, exactly soluble classical and quantum models in one and two dimensions, quantum Hall effect, and other advanced topics in condensed matter physics. Students whose research is related to condensed matter physics receive a letter grade; other students receive a letter grade or Satisfactory (S) or No Credit (NC) grade.

PHYS 241C Advanced Statistical Physics and Field Theory (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): graduate standing; PHYS 241B. Topics include quantum magnetism, unconventional superconductivity, localization, transport phenomena, mesoscopic systems, nonequilibrium phenomena, and advanced field-theory methods, such as methods for treating disorder. Students whose research is related to condensed matter physics receive a letter grade; other students receive a letter grade or Satisfactory (S) or No Credit (NC) grade.

PHYS 242 Physics at Surfaces and Interfaces (4) Lecture, 3 hours; consultation, 1 hour. Prerequisite(s): graduate standing or consent of instructor. Overview of surface science, electronic and geometric structure of clean surfaces, techniques for investigating structure, electron spectroscopy of surfaces, adsorption on surfaces, vibrations on surfaces, and epitaxial growth and applications of surface science. Letter grades will be assigned to students whose research is related to surface physics. Other students will receive either a letter or Satisfactory (S) or No Credit (NC) grade.

PHYS 246 Biological Physics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 134 or consent of instructor. Introduces topics at the interface of physics and biology: cell physiology, probability and information, diffusion, random walks, electrostatics, elasticity of biopolymers and membranes, DNA topology, friction in fluids, and low Reynolds numbers. May be taken Satisfactory (S) or No Credit (NC) with consent of instructor and graduate advisor.

PHYS 250 Special Topics Seminar in Physics and Astronomy (2) Seminar, 2 hours. Prerequisite(s): graduate standing in Physics and Astronomy or consent of instructor. Includes oral presentations and intensive small-group discussion of selected topics in the area of specialization of each faculty member. Emphasizes recent advances in the special topic area; course content varies accordingly. Students who present a seminar receive a letter grade; other students receive a Satisfactory (S) or No Credit (NC) grade. Course is repeatable to a maximum of 99 units.

PHYS 253 (E-Z) Special Topics (3) Seminar, 3 hours. Prerequisite(s): graduate standing or consent of instructor. Additional prerequisites may be required for segments of this course; see department. Discusses subjects such as magnetohydrodynamics, astrophysics, and high-energy physics. Graded Satisfactory (S) or No Credit (NC). Some segments of this course may be repeatable; see Department. **Zych**

PHYS 256 Advances in Nanoscale Physics (1 or 2) Seminar, 1 hour; individual study, 0-3 hours. Prerequisite(s): graduate standing. Seminars on current topics in nanoscale physics and materials science, including nanoelectronic devices, nanoelectromechanical systems, nanoscale biophysics, spintronics, nanoscale magnetism, nanophotonic systems, and advanced characterization techniques. Students who give class presentations receive credit for 2 units; other students receive credit for 1 unit. Graded Satisfactory (S) or No Credit (NC). Course is repeatable.

PHYS 258 Seminar in Surface Science (1) Seminar, 1 hour. Prerequisite(s): graduate standing in Physics or Chemistry or consent of instructor. Oral presentations by participating visiting scholars, postdoctoral researchers, students, and UCR faculty on current research topics in surface science. Students who present a seminar or submit a term paper receive a letter grade; other students receive a Satisfactory (S) or No Credit (NC) grade. Course is repeatable. Cross-listed with CHEM 258. **Yarmoff**

PHYS 288 Current Research Themes in Physics (2) F Seminar, 1 hour; discussion, 1 hour. Prerequisite(s): graduate standing or consent of instructor. Introduces first-year graduate students to current issues in physics research at UCR. Involves seminars by faculty on their research and interaction with advanced students and postdoctoral researchers. Graded Satisfactory (S) or No Credit (NC). Course is repeatable.

PHYS 289 Colloquium in Physics (1) Colloquium, 1 hour. Prerequisite(s): graduate standing; consent of instructor. Specialized discussions by visiting scientists, faculty, and students on current research topics in physics. Graded Satisfactory (S) or No Credit (NC). Course is repeatable. **Chair in charge**

PHYS 290 Directed Studies (1-6) Outside research, 3-18 hours. Prerequisite(s): graduate standing; consent of instructor; consent of advisor or Department Chair. Individual study, directed by a faculty member, of specially selected topics. Graded Satisfactory (S) or No Credit (NC). Course is repeatable.

PHYS 291 Individual Study in Coordinated Areas (1-6) Individual study, 3-18 hours. Prerequisite(s): graduate standing; consent of instructor. Faculty-assisted programs of individual study for candidates who are preparing for examinations. Graded Satisfactory (S) or No Credit (NC). Course is repeatable within the following limits: Up to 6 units may be taken prior to award of the Master's degree, such units to be in addition to minimum unit requirements for the degree. Up to 12 additional units may be taken (continued) prior to advancement to candidacy for the Ph.D.

PHYS 296 Summer Research in Physics (2) Summer Outside research, 12-20 hours. Prerequisite(s): graduate standing. Introduces first-year graduate students to current issues in physics research at UCR. Involves mentoring by faculty on research and interaction with advanced students and postdoctoral researchers. Offered in summer only. Graded Satisfactory (S) or No Credit (NC).

PHYS 297 Directed Research (1-6) Outside research, 3-18 hours. Prerequisite(s): graduate standing; consent of instructor. Original research, in an area selected for the advanced degree, performed under the direction of a faculty member. Graded Satisfactory (S) or No Credit (NC). Course is repeatable.

PHYS 299 Research for Thesis or Dissertation (1-12) Thesis, 3-36 hours. Prerequisite(s): graduate standing; consent of instructor. Original research, in an area selected for the advanced degree, performed under the direction of a faculty member. This research is to be included as a part of the dissertation. Graded Satisfactory (S) or No Credit (NC). Course is repeatable.

Professional Courses

PHYS 301 Teaching of Physics at the College Level (2) Lecture, 2 hours. Prerequisite(s): graduate standing in Physics or consent of instructor. Required of all Teaching Assistants in the Department. Designed to introduce effective methods for teaching physics and to evaluate and improve teaching skills. Topics covered include lecture techniques, effective visual aids, improving laboratory and recitation section learning situations. Credit not applicable toward degree course requirements. Graded Satisfactory (S) or No Credit (NC). Course is repeatable. **Chair in charge**

PHYS 302 Teaching Practicum (1-4) Consultation, 1 hour; laboratory, 3-12 hours; practicum, 3-12 hours. Prerequisite(s): Appointment as a departmental Teaching Assistant; graduate standing. Supervised teaching in Physics courses and regular consultation with faculty supervisor(s) regarding teaching responsibilities. Credit not applicable toward degree course requirements. Graded Satisfactory (S) or No Credit (NC). Course is repeatable to a maximum of 12 units. **Chair in charge**

PHYS 401 Scientific Writing and Illustration (1) Lecture, 1 hour. Prerequisite(s): consent of instructor. The research notebook. The thesis. References. The form of a technical article. Figures and slides. Patent requirements. Periodical requirements. Graded Satisfactory (S) or No Credit (NC).

Plant Biology

See Botany and Plant Sciences

Plant Pathology and Microbiology

Subject abbreviation: PLPA
College of Natural and Agricultural Sciences

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Joseph W. Eckert, Ph.D.
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Peter H. Tsao, Ph.D.
Seymour D. Van Gundy, Ph.D. (Plant Pathology and Microbiology/Nematology)
Lewis G. Weathers, Ph.D.

Associate Professors
Wenbo Ma, Ph.D.
James Ng, Ph.D.
Jason E. Stajich, Ph.D.

Assistant Professors
Emma Aronson, Ph.D.
Caroline Roper, Ph.D.

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Lecturers
Akif Eskalen, Ph.D.
Georgios Vidalakis, Ph.D.

Affiliated Faculty
Ellis F. Darley, Ph.D. (Plant Pathologist Emeritus)
Thomas Eulgem, Ph.D. (Botany and Plant Sciences)
Steven Garnsey, Ph.D. (Citrus Virology)
Isgouhi Kaloshian, Ph.D. (Nematology)
Philip Roberts, Ph.D. (Nematology)
Linda Walling, Ph.D. (Botany and Plant Sciences)

Undergraduate Curriculum

The Department of Plant Pathology and Microbiology participates in the Microbiology and Botany and Plant Sciences major leading to the baccalaureate degree. See the Microbiology or Botany and Plant Sciences section of this catalog.

Graduate Program

The Department of Plant Pathology and Microbiology offers the M.S. and Ph.D. degrees in Plant Pathology.

Admission In addition to meeting the requirements for admission to the Graduate Division, students typically have a baccalaureate major in a biological science or training equivalent to that given in the Plant Science curriculum of the College of Natural and Agricultural Sciences. Majors in the physical sciences are welcomed, but students must be prepared to augment their undergraduate preparation with courses in the biological sciences. All applicants must provide GRE General Test scores (verbal, quantitative, analytical).

All candidates for the M.S. or the Ph.D. degree should have good basic preparation in chemistry and biology. It is common for students to have completed courses in biochemistry, organic chemistry, cell and molecular biology, elementary college mathematics, general physics, general botany, microbiology, statistics, genetics, plant physiology, mycology, and plant pathology. If these courses have been completed as an undergraduate, graduate study is facilitated. If students have not completed these courses prior to admission, they may be required to take them early in their graduate career.

Master's Degree

The Department of Plant Pathology and Microbiology offers the M.S. degree in Plant Pathology.

General university requirements are given in the Graduate Studies section of this catalog. The master's degree in Plant Pathology is offered under Plans I or II.

Plan I (Thesis) requires 36 units of upper-division and graduate courses, of which at least 24 must be in the 200 series courses in Plant Pathology or Nematology. A maximum of 12 units may be in graduate research for the thesis.

Plan II (Comprehensive Examination) requires 36 units of upper-division and graduate courses, of which at least 18 must be in the 200-series courses in Plant Pathology or Nematology, excluding graduate research for a thesis or dissertation, and a comprehensive final examination in the major subject.

The departmental graduate advisory committee, in consultation with the student's major professor or curriculum advisor, is responsible for prescribing the course of study, which requires as a minimum PLPA 120, PLPA 120L, PLPA 200, PLPA 206/NEM 206, PLPA 207, PLPA 234, PLPA 250 and PLPA 265.

Doctoral Degree

The Department of Plant Pathology and Microbiology offers the Ph.D. degree in Plant Pathology.

In accord with the student's preparation and specific interests, the departmental graduate advisory committee, in consultation with the student's major professor or curriculum advisor, prescribes areas where study is required. In addition to selected subjects in plant pathology, related fields in which some degree of competence may be expected is drawn normally from biochemistry, biology, chemistry, cell and molecular biology, entomology, genetics, mathematics, microbiology, nematology, plant physiology, soils, and statistics.