PHIL 275B. Proseminar for First-Year Graduate Students: Metaphysics and Epistemology (4) Seminar, 3 hours; extra reading, 3 hours. Prerequisite(s): PHIL 275A; first-year standing in the graduate program in Philosophy. One course in a three-term sequence designed to introduce new graduate students to current issues and methods of research in additional areas of metaphysics and epistemology.

PHIL 275C. Proseminar for First-Year Graduate Students: Moral Philosophy (4) Seminar, 3 hours; extra reading, 3 hours. Prerequisite(s): first- year standing in the graduate program in Philosophy. One course in a three-term sequence designed to introduce new graduate students to current issues and methods of research.

PHIL 280. Seminar in Philosophical Problems (4) Seminar, 3 hours; outside research, 3 hours. Prerequisite(s): graduate standing or consent of instructor. Considers an important philosophical problem. Students who submit a term paper receive a letter grade; other students receive a Satisfactory (S) or No Credit (NC) grade. Course is repeatable.

PHIL 281. Philosophical Texts (1-4) Seminar, 1-3 hours; consultation, 1 hour. Prerequisite(s): graduate standing. Involves focused reading and discussion of common text on research topics in philosophy. Students who submit a term paper receive a letter grade; other students receive a Satisfactory (S) or No Credit (NC) grade. Course is repeatable.

PHIL 282. Seminar in Individual Philosophers (4) Seminar, 3 hours; outside research, 3 hours. Prerequisite(s): graduate standing or consent of instructor. Considers a major figure in the history of philosophy. Students who submit a term paper receive a letter grade; other students receive a Satisfactory (S) or No Credit (NC) grade. Course is repeatable.

PHIL 283. Seminar in Contemporary Philosophy (4) Seminar, 3 hours; outside research, 3 hours. Prerequisite(s): graduate standing or consent of instructor. Covers an aspect of contemporary philosophy. Students who submit a term paper receive a letter grade; other students receive a Satisfactory (S) or No Credit (NC) grade. Course is repeatable.

PHIL 290. Directed Studies (1-6) Term paper, 3-18 hours. Prerequisite(s): consent of instructor and graduate advisor. Directed study to meet special curricular needs. Course is repeatable.

PHIL 291. Individual Studies in Coordinated Areas (2-4) Prerequisite(s): graduate standing. A program of studies designed to advise and assist candidates who are preparing for the Comprehensive Examinations. Open to M.A. students only; does not count toward the unit requirement for the M.A. Graded Satisfactory (S) or No Credit (NC). Course is repeatable.

PHIL 292. Concurrent Analytical Studies in Philosophy (1-4) Prerequisite(s): consent of instructor. Each 292 course will be taken concurrently with some 100-series 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 College of Natural and Agricultural Sciences, Student Academic Office, Room 1140 Batchelor Hall, or call (951) 827-7294.

Physics and Astronomy

Subject abbreviation: PHYS
College of Natural and Agricultural Sciences

Harry W.K. Tom, Ph.D., Chair
John A. Ellison, Ph.D., Vice Chair
Department Office, 3047 Physics
(951) 827-5331; **physics.ucr.edu**

Professors
Robert B. Clare, Ph.D.
Bipin R. Desai, Ph.D.
John A. Ellison, Ph.D.
J. William Gary, Ph.D.
Gail G. Hanson, Ph.D.
Ernest S. Ma, Ph.D.
Allen P. Mills, Ph.D.
Umar Mohideen, Ph.D.
Richard K. Seto, Ph.D.
Jing Shi, Ph.D.
Harry W.K. Tom, Ph.D.
Chandra M. Varma, Ph.D.
Stephen J. Wimpenny, Ph.D.
Jose Wudka, Ph.D.
Jory A. Yarmoff, Ph.D.
Gary P. Zank, Ph.D.
Allen D. Zych, Ph.D.

Professors Emeriti
Frederick W. Cummings, Ph.D
Sun-Yiu Fung, Ph.D.
Peter E. Kaus, Ph.D.
Anne Kernan, Ph.D.
Nai-Li H. Liu, 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.

Associate Professors
Kenneth N. Barish, Ph.D.
Ward Beyermann, Ph.D.

Assistant Professors
E. Gabriela Canalizo, Ph.D.
Roland Kawakami, Ph.D.
Chun Ning "Jeanie" Lau, Ph.D.
Owen Long, Ph.D.
Leonid P. Pryadko, Ph.D.
Kirill Shtengel, Ph.D.
Shan-Wen Tsai, Ph.D.
Roya Zandi, Ph.D.

**

Adjunct Professors
John Browne, Ph.D.
Paolo Giacomelli, Ph.D.
Ann Heinson, Ph.D.
Cy Hoffman, Ph.D.
Zdnek Sroubek, 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.

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 for the B.S. and B.A. degrees in Physics are as follows:

1. Lower-division requirements (63–64 units)
   a) PHYS 040A, PHYS 040B, PHYS 040C, PHYS 040D, PHYS 040E
   b) MATH 008B or MATH 009A, MATH 009B, MATH 009C, MATH 010A, MATH 010B, MATH 046
   c) CHEM 001A, CHEM 001B, CHEM 001C, CHEM 01LA, CHEM 01LB, CHEM 01LC
2. Upper-division requirements (55 units)
   a) PHYS 130A, PHYS 130B, PHYS 134, PHYS 135A, PHYS 135B, PHYS 136, PHYS 156A, PHYS 156B
   b) PHYS 139L, PHYS 142L. An approved senior thesis (PHYS 195A, PHYS 195B, PHYS 195C, PHYS 195D) in experimental physics or an internship (PHYS 198-I) in experimental physics at a government or industrial laboratory can be used in place of up to 3 units of PHYS 142L.
   c) A student may take up to a maximum of 8 units of undergraduate research in pursuit of a senior thesis (PHYS 195A, PHYS 195B, PHYS 195C, PHYS 195D).
   d) During the junior or senior years, a Physics internship (PHYS 198-I) of up to 12 units can be taken at an approved government or industrial laboratory. A maximum of 3 out of the 12 units may be used to satisfy the major requirements.
   e) Three elective courses to be taken in consultation with a faculty advisor.

Specialized skills can be developed by taking physics electives from the following:

PHYS 111 (Astrophysics and Stellar Astronomy)

PHYS 150A, PHYS 150B (Introduction to Condensed Matter Physics)

PHYS 151 (Topics in Modern Condensed Matter Physics)

PHYS 163 (Atomic Physics and Spectroscopy)

PHYS 164 (Introduction to Nuclear Physics)

PHYS 165 (Introduction to Particle Physics)

PHYS 166 (Cosmology)

PHYS 168 (Environmental Physics)

PHYS 177 (Computational Methods for Physical Sciences)

Biophysics option (B.S. degree only)

1. Lower-division requirements (76-77 units)
   a) PHYS 040A, PHYS 040B, PHYS 040C, PHYS 040D, PHYS 040E
   b) MATH 008B or MATH 009A, MATH 009B, MATH 009C, MATH 010A, MATH 010B, MATH 046
   c) CHEM 001A, CHEM 001B, CHEM 001C, CHEM 01LA, CHEM 01LB, CHEM 01LC
   d) BIOL 005A, BIOL 005B, BIOL 005C, BIOL 05LA
2. Upper-division requirements (88 units)
   a) PHYS 130A, PHYS 130B, PHYS 134, PHYS 135A, PHYS 135B, PHYS 136, PHYS 145A, PHYS 145B, PHYS 145C, PHYS 156A
   b) STAT 155
   c) CHEM 112A, CHEM 112B, CHEM 112C
   d) BIOL 105
   e) BCH 110A, BCH 110B, BCH 110C. Students may substitute BIOL107A for BCH110C
   f) 4 units of experimental research in either special studies (PHYS 190, PHYS 190L), an approved senior thesis (PHYS 195A, PHYS 195B, PHYS 195C, PHYS 195D), undergraduate research (PHYS 197), or an internship (PHYS 198-I).
   g) 12 units of elective courses (chosen after consultation with a faculty advisor)

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.

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.).

Although no foreign languages are required for the B.S. degree, the student who is planning to proceed to graduate work is reminded that reading proficiency in one or more foreign languages is required in some physics graduate programs.

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 134
   c) PHYS 135A
   d) One 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. In addition, PHYS 401 is required.

   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 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.

   Core courses:

   PHYS 205 (Classical Mechanics)

   PHYS 210A, PHYS 210B (Electromagnetic Theory)

   PHYS 212A, PHYS 212B (Thermodynamics and Statistical Mechanics)

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

   PHYS 401 (Scientific Writing and Illustration)

   In addition, at least three elective graduate lecture courses must be completed. The program for each student must be approved by the graduate committee and by 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 and courses in addition to those in the elective 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, 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 Matter Physics and Field Theory)

   PHYS 242 (Physics at Surfaces and Interfaces)

   c) Astrophysics

   PHYS 208 (General Relativity)

   PHYS 211A (Radiative Processes in Astrophysics)

   PHYS 211B (Astrophysical Fluid Dynamics)

   PHYS 214 (Techniques of Observational Astrophysics)

   PHYS 215 (Galactic Dynamics)

   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 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)

   ENTX 244/CHEM 244 (Airborne Toxic Chemicals)

   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 Engineering.

2. **Written and Oral Qualifying Examinations** Students must have satisfactory performance on a comprehensive examination, to be taken at the beginning of the student's second year. The examination is given once each academic year at the beginning of the fall quarter. A make-up exam is offered at the beginning of the winter quarter. The comprehensive examination consists of a) a four-hour written exam that covers Mechanics, and Statistical and Thermal Physics at the undergraduate level; and Quantum Mechanics and Electromagnetism at the graduate level, and b) an oral exam covering the above material and various other areas of general physics. Following the examination, the department reviews each student's entire academic performance to recommend a pass at the Ph.D. level, a pass at the M.S. level, or a failure. The examination may be repeated once in the winter quarter following the initial attempt.
3. **Oral 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** Students must have satisfactory performance on a final oral examination conducted by the candidate's doctoral committee.

Normative Time to Degree 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).

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. For biological sciences students. 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 awarded for only one of PHYS 002A or PHYS 040A.

PHYS 002B. General Physics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 009B or MATH 09HB (may be taken concurrently), and a grade of "C-" or better in PHYS 002A. For biological sciences students. Topics in mechanics, thermodynamics, and electromagnetism including 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. Credit is awarded for only one of PHYS 002B or PHYS 040B.

PHYS 002C. General Physics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 002B with a grade of "C-" or better. For biological sciences students. Topics in waves and modern physics including harmonic oscillations; mechanical and electromagnetic waves; geometrical optics; reflection, refraction, interference, diffraction, and polarization; and quantum, atomic, and nuclear physics. Credit is awarded for only one of PHYS 002C or PHYS 040C.

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." Cross-listed with GEO 006.

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 012. The Big Bang: Forces in the Early Universe (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): none. Explores our current understanding of the origins of the universe in a nontechnical manner using basic scientific literature. Topics include the "Scientific Process - How a Theory Comes to be," the fundamental forces of nature and their unification, the structure of the vacuum, and the beginning and end of the universe.

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. Applies the fundamental physics of energy sources and energy balance in the environment and to models of weather and the "Greenhouse Effect." Explores the environmental impact of solar, fossil fuel, and nuclear energy. Covers thermodynamics, energy and mass flow, and the limitations of modeling. Helps in making informed decisions about environmental issues.

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 021. Kingdom of the Sun (4) Lecture, 3 hours; workshop, 3 hours. Prerequisite(s): none. An astronomy course for non-science students. The nearest star, our Sun, and its solar system of planets, moons, asteroids, and comets are presented in a descriptive manner. A historical astronomy of the solar system is traced from ancient concepts to modern space exploration. Special topics such as UFOs and colonization of space are discussed.

PHYS 022. The Science in Science Fiction (4) Lecture, 3 hours; screening, 1 hour; term paper, 1 hour; extra reading, 1 hour. Prerequisite(s): none. Covers the physics underlying various science fiction stories, books, television shows, and films. Provides a perspective for interpreting the (often misleading) information presented in the popular media, and highlights those aspects that are good science.

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): PHYS 002A (may be taken concurrently). Illustrates the experimental foundations of physics presented in PHYS 002A. Covers the basic principles of classical mechanics. Laboratory is helpful, but not required, for PHYS 002A.

PHYS 02LB. General Physics Laboratory (1) Laboratory, 3 hours. Prerequisite(s): PHYS 002A with a grade of "C-" or better, PHYS 02LA, PHYS 002B (PHYS 002B may be taken concurrently). Illustrates the experimental foundations of physics presented in PHYS 002B. Covers the basic principles of fluid and rotational mechanics, temperature, heat, and electromagnetism. Laboratory is helpful, but not required, for PHYS 002B.

PHYS 02LC. General Physics Laboratory (1) Laboratory, 3 hours. Prerequisite(s): PHYS 002B with a grade of "C-" or better, PHYS 02LB, PHYS 002C (PHYS 002C may be taken concurrently). Illustrates the experimental foundations of physics presented in PHYS 002C. Covers the basic principles of oscillations, waves, optics, and radioactivity. Laboratory is helpful, but not required, for PHYS 002C.

PHYS 039. Adventures in Physics (2) Seminar, 1 hour; discussion, 1 hour. Prerequisite(s): none. General introduction to frontiers of physics research. Introduces the outstanding issues in physics research, along with work of UC Riverside faculty. 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 in one, two, and three dimensions; friction; circular motion; work, energy, and conservation of energy; the dynamics of particle systems; collisions; rigid-body motion; torque; and angular momentum. Laboratories provide exercises illustrating the experimental foundations of physical principles and selected applications. Credit is awarded for only one of PHYS 002A or PHYS 040A.

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); a grade of "C-" or better in PHYS 040A. 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. Credit is awarded for only one of PHYS 002B or PHYS 040B.

PHYS 040C. General Physics (5) Lecture, 3 hours; discussion, 1 hour; laboratory, 3 hours. Prerequisite(s): MATH 009C or MATH 09HC; a grade of "C-" or better in PHYS 040B. 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 awarded for only one of PHYS 002C or PHYS 040C.

PHYS 040D. General Physics (5) Lecture, 3 hours; discussion, 1 hour; laboratory, 3 hours. Prerequisite(s): a grade of "C-" or better in PHYS 040C 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.

PHYS 040E. General Physics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 046 (may be taken concurrently), a grade of "C-" or better in PHYS 040D. 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.

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; PHYS 040C; PHYS 040D. 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 010B, MATH 046, PHYS 040A. Topics include vector calculus, single-particle motion, oscillations, Lagrangian and Hamiltonian dynamics, and central-forces motion and celestial mechanics.

PHYS 130B. Classical Mechanics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 040B, 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 134. Thermal Physics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 010B, PHYS 040A, PHYS 040B, PHYS 040C, PHYS 040D, PHYS 040E. Macroscopic properties of many-particle systems. Laws and applications of thermodynamics: entropy, thermodynamic potentials, ideal gases. Principles and applications of statistical mechanics: probability distributions; canonical, microcanonical, and grand canonical ensembles; specific heat of solids; paramagnetism; kinetic theory of gases; phase transitions; quantum statistics.

PHYS 135A. Electromagnetism (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): MATH 010B, MATH 046, PHYS 040C. 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 040D, PHYS 135B. 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; relativistic electrodynamics.

PHYS 139L. Electronics for Scientists (5) Lecture, 3 hours; laboratory, 6 hours. Prerequisite(s): PHYS 040C or consent of instructor. An introduction to basic analog and digital circuit designs emphasizing practical applications. Topics include 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 (1-4) Laboratory, 3-12 hours. Prerequisite(s): PHYS 040A, PHYS 040B, PHYS 040C, PHYS 040D, PHYS 040E; upper-division standing in Physics; consent of advisor. Consists of experiments chosen from areas in contemporary physics. Course is repeatable to a maximum of 8 units.

PHYS 145A. Biophysics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): CHEM 001C or CHEM 01HC; MATH 010B; MATH 046; PHYS 040E. 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): PHYS 040A, PHYS 040B, PHYS 040C, PHYS 040D, PHYS 040E; 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): PHYS 040A, PHYS 040B, PHYS 040C, PHYS 040D, PHYS 040E; consent of instructor is required for students repeating the course. Introduces cutting-edge physics research being undertaken in laboratories and institutes around the world. Focus is on a single research area (e.g., nanoscale physics, biological physics) chosen by the instructor and 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, PHYS 040E; or consent of instructor. MATH 113 is recommended. 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 046, PHYS 040E, PHYS 130A, PHYS 135A. Topics include wave-particle duality; the Schrodinger 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 163. Atomic Physics and Spectroscopy (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): CHEM 113 or equivalent; or PHYS 156A and PHYS 156B; or consent of instructor. Theoretical and experimental techniques of atom physics. 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 magnetic, electric, and coherent electromagnetic fields; the two-level atom; electron spin resonance spectroscopy; nuclear magnetic resonance spectroscopy; laser spectroscopy; fundamentals of chemical bonding in molecules.

PHYS 164. Introduction to Nuclear Physics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 040A, PHYS 040B, PHYS 040C, PHYS 040D, PHYS 040E. Discusses the basic nuclear properties, nuclear building blocks and structure, radioactivity, nuclear interactions, the strong force, the confinement and chiral phase transitions, the quantum chromodynamics (QCD) vacuum, matter at extreme temperatures and densities.

PHYS 165. Introduction to Particle Physics (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 040A, PHYS 040B, PHYS 040C, PHYS 040D, PHYS 040E. Explores topics such as the classification of particles in terms of the Standard Model; 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 040A, PHYS 040B, PHYS 040C, PHYS 040D, PHYS 040E. 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; either CHEM 110B or both PHYS 040D and PHYS 040E. Covers the application of physics to environmental problems including 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): PHYS 040A, PHYS 040B, PHYS 040C, PHYS 040D, PHYS 040E; or consent of instructor. Computer applications for solving problems in physical sciences. Symbolic manipulation languages such as Mathematica. Mathematical operations, plotting, and symbolic and numerical techniques in calculus. Numerical methods such as histogramming, Monte-Carlo method for modeling experiments, statistical analysis, curve fitting, and numerical algorithms. Prior knowledge of the computer is 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 3 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 3 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 3 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 3 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 3 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. The student is jointly supervised by an off-campus sponsor and a Physics faculty member. Requires a written, final report. 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 3 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.

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 electrostatics, Coulomb potential, method of images, and Laplace's equations in Cartesian, spherical and cylindrical coordinates. Also examines magnetostatics, boundary value problems, multipoles, and dielectric media. **Pyradko**

PHYS 210B. Electromagnetic Theory (4) Lecture, 3 hours; discussion, 1 hour. Prerequisite(s): PHYS 210A; graduate standing; consent of instructor. Covers electrodynamics, Maxwell's equations, electromagnetic waves, special theory of relativity, tensor analysis, radiation, and interaction of electromagnetic fields with charged particles. Also examines Lagrangian formulation, gauge transformation, and magnetic monopoles. **Pryadko**

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. **Wudka**

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

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 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 231. Methods of Theoretical Physics (4) Lecture, 3 hours; consultation, 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, nano-electromechanical 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.

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.

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.

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 251. Techniques of Observational Astronomy (2) Seminar, 2 hours. Prerequisite(s): graduate standing; consent of instructor. Covers major areas necessary for the successful completion of an observational program, from the choice and preparation of telescope time proposals, to the actual data acquisition and reduction, to the analysis and publication of results. 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. **Canalizo**

PHYS 252. Topological Phases in Condensed Matter and Their Applications to Quantum Computing (2) Seminar, 2 hours. Prerequisite(s): graduate standing; consent of instructor. A study of topological order and fractionalization emergent in the systems of strongly correlated electrons, as well as their applications, in particular those related to quantum information processing. Covers frustrated quantum magnets, fractional quantum Hall effect, and related gauge theories. Discusses use of topologically ordered states for performing fault-tolerant quantum computations. 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. **Shtengel**

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 254. Statistical Physics in Biology (2) Seminar, 2 hours. Prerequisite(s): graduate standing; consent of instructor. Introduces students to the evolving field of biological physics. Topics include random walks, self-assembly, nucleation theory, scaling laws in polymer physics, mechanical properties of biopolymers, protein-DNA, and protein-protein interactions. 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. **Zandi**

PHYS 255. Spin-Dependent Phenomena in Solids (2) Seminar, 2 hours. Prerequisite(s): graduate standing; consent of instructor. Topics include spin-dependent transport and tunneling in magnetic multilayers and tunnel junctions, spin injection and detection in inorganic and organic semiconductors, spin transfer torque in nanomagnets, and their technological applications. 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.

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 260. Selected Topics in Theoretical High-Energy Physics (2) Seminar, 2 hours. Prerequisite(s): graduate standing; consent of instructor. Topics include the physics of the Standard Model and its extensions; anomalies, spontaneous symmetry breaking, and phenomenology; and cosmological effects of new particles. Students who present a seminar or submit a paper receive a letter grade; other students receive a Satisfactory (S) or No Credit (NC) grade. Course is repeatable. **Wudka**

PHYS 261. Theory of Strongly Correlated Low-Temperature Systems (2) Seminar, 2 hours. Prerequisite(s): graduate standing; consent of instructor. Topics include quantum transport with disorder and interactions, quantum effect, high-temperature superconductivity, and low-dimensional systems. Students who present a seminar or submit a paper receive a letter grade; other students receive a Satisfactory (S) or No Credit (NC) grade. Course is repeatable. **Pryadko**

PHYS 262. Electron Spin and Magnetism in Nanostructures (2) Seminar, 2 hours. Prerequisite(s): graduate standing; consent of instructor. Topics include synthesis of new materials and hybrid nanostructures, molecular beam epitaxy and magnetism dynamics, ultrafast optical spectroscopy, spin transport in molecular electronic devices, and sample characterization by atomic force microscopy and transmission electron microscopy. 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. **Kawakami**

PHYS 263. The Yukawa Sector Beyond the Standard Model (2) Seminar, 2 hours. Prerequisite(s): graduate standing; consent of instructor. Covers recent research in determining the quark masses and weak mixing angles through the properties of the Yukawa mass matrices at scales higher than the Standard Model scale. Topics include texture zeroes and their possible origin, renormalization group equations, and the role of the condensate mechanism. Students who present a seminar or submit a paper receive a letter grade; other students receive a Satisfactory (S) or No Credit (NC) grade. Course is repeatable. **Desai**

PHYS 264. Strongly Correlated and Nanoscale Systems (2) Seminar, 2 hours. Prerequisite(s): graduate standing; consent of instructor. Discusses current topics of research, including properties of materials and nanostructures with strong electronic correlations. Covers theoretical approaches to the study of effects of interaction and disorder in quantum many-body systems and the additional effects of surfaces, interfaces, and constrained geometry in nanoscale systems. 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. **Tsai**

PHYS 265. DNA Computation (2) Seminar, 2 hours. Prerequisite(s): graduate standing; consent of instructor. Involves elementary manipulations on DNA molecules with use of various enzymes, separation techniques, and detection methods and their applications to simple DNA molecular analog neural networks and

autonomous reactions. Students who present a seminar or submit a paper receive a letter grade; other students receive a Satisfactory (S) or No Credit (NC) grade. Course is repeatable. **Mills**

PHYS 266. Theoretical Aspects of Fundamental Particle Interactions (2) Seminar, 2 hours. Prerequisite(s): graduate standing; consent of instructor. Covers electroweak symmetry breaking and the origin of mass; conservation laws and physics beyond the Standard Model; and new theoretical ideas and their possible applications. Students who present a seminar or submit a paper receive a letter grade; other students receive a Satisfactory (S) or No Credit (NC) grade. Course is repeatable. **Ma**

PHYS 267. Hadron Physics at Electron-Positron Colliders (2) Seminar, 2 hours. Prerequisite(s): graduate standing; consent of instructor. Covers phenomenology of electroweak and strong interactions in electron-positron collisions; experimental results; and techniques for investigating the properties and interactions of quarks, gluons, leptons, and the W and Z gauge bosons at high energy e^+e^- accelerators. Students who present a seminar or submit a paper receive a letter grade; other students receive a Satisfactory (S) or No Credit (NC) grade. Course is repeatable. **Gary**

PHYS 268. Electroweak Physics at Electron-Positron Colliders (2) Seminar, 2 hours. Prerequisite(s): graduate standing; consent of instructor. The study of the electroweak interaction at high-energy e^+e^- colliders. Covers properties of the Z and W bosons. Emphasis is placed on the high precision tests of the Standard Model. Includes comparisons with similar tests in other reactions. Students who present a seminar or submit a paper receive a letter grade; other students receive a Satisfactory (S) or No Credit (NC) grade. Course is repeatable. **Clare**

PHYS 269. Physics and Electronics in Nanoscale Systems (2) Seminar, 2 hours. Prerequisite(s): graduate standing; consent of instructor. Discusses current topics of research including electrical, mechanical, and magnetic properties of nanoscale systems and possible device applications. Examples include superconducting and semiconducting nanowires, carbon nanotubes, and molecule-based nanostructures. Students who present a seminar receive a letter grade; other students receive a Satisfactory (S) or No Credit (NC) grade. Course is repeatable. **Lau**

PHYS 270. Magnetic Resonance Techniques in Condensed Matter Physics (2) Seminar, 2 hours. Prerequisite(s): graduate standing; consent of instructor. Introduces research graduate students to two or three topics in the following areas: nuclear magnetic resonance, muon spin rotation (muSR), and heavy-fermion materials. Topics are selected to correspond to the experience and interests of the students. Students who present a seminar or submit a paper receive a letter grade; other students receive a Satisfactory (S) or No Credit (NC) grade. Course is repeatable. **MacLaughlin**

PHYS 271. Heavy Ion Physics (2) Seminar, 2 hours. Prerequisite(s): graduate standing; consent of instructor. A study of Heavy Ion collisions at high energies. Surveys experimental data and examines theoretical expectations for the production of the quark-gluon plasma. Students who present a seminar or submit a paper receive a letter grade; other students receive a Satisfactory (S) or No Credit (NC) grade. Course is repeatable. **Seto**

PHYS 272. High Transverse Momentum Physics at Hadron Colliders (2) Seminar, 2 hours. Prerequisite(s): graduate standing; consent of instructor. A review of current research in both the current and future generation of hadron colliders. Discusses experiments, with an emphasis on high transverse momentum and rare processes and the search for new particles. Students who present a seminar or submit a paper receive a letter grade; other students receive a Satisfactory (S) or No Credit (NC) grade. Course is repeatable. **Wimpenny**

PHYS 274. Experimental Relativistic Nucleon-Nucleon Collisions (2) Seminar, 2 hours. Prerequisite(s): graduate standing; consent of instructor. Survey of experimental methods used by current relativistic nucleon-nucleon collision detectors at Brookhaven National Laboratory and CERN. Students who present a seminar or submit a paper receive a letter grade; other students receive a Satisfactory (S) or No Credit (NC) grade. Course is repeatable. **Barish**

PHYS 275. Experimental Physics of Electromagnetic and Weak Interactions (2) Seminar, 2 hours. Prerequisite(s): graduate standing; consent of instructor. A systematic study of electromagnetic and weak interactions. Discussion of experiments with particular bearings on symmetry principle violations, selection rules, and higher symmetries. Students who present a seminar or submit a paper receive a letter grade; other students receive a Satisfactory (S) or No Credit (NC) grade. Course is repeatable.

PHYS 276. Experimental Aspects of Electroweak Symmetry Breaking (2) Seminar, 2 hours. Prerequisite(s): graduate standing; consent of instructor. Investigation of experimental techniques and current limits on the origins of electroweak symmetry breaking. Includes examination of the Standard Model and extensions of the Standard Model. Topics include comparison of various production schemes: hadron colliders, electron-positron colliders, and muon colliders. 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. **Hanson**

PHYS 277. Special Topics in the Theory of Condensed Matter (2) Seminar, 2 hours. Prerequisite(s): graduate standing; consent of instructor. Discusses current topics of research including the theory of high temperature superconductivity, the quantum Hall effect, spintronics, and singular Fermi liquids. Students who present a seminar receive a letter grade; other students receive a Satisfactory (S) or No Credit (NC) grade. Course is repeatable. **Varma**

PHYS 278. Surface Sciences (2) Seminar, 2 hours. Prerequisite(s): graduate standing; consent of instructor. Topics include geometrical and electronic structure at surfaces and interfaces; chemical reactions on surfaces; interactions of radiation with surfaces; mechanisms of film growth on surfaces; and development of novel surface science analytical techniques. Students who present a seminar or submit a paper receive a letter grade; other students receive a Satisfactory (S) or No Credit (NC) grade. Course is repeatable. **Yarmoff**

PHYS 279. Astrophysics (2) Seminar, 2 hours. Prerequisite(s): graduate standing; consent of instructor. Topics include measurements of gamma rays from pulsars and other cosmic sources, measurements of gamma rays and neutrons from the sun, and laboratory magnetosphere and comet experiments. Students who present a seminar or submit a paper receive a letter grade; other students receive a Satisfactory (S) or No Credit (NC) grade. Course is repeatable. **Zych**

PHYS 280. Space Physics and Astrophysics (2) Seminar, 2 hours. Prerequisite(s): graduate standing; consent of instructor. Topics include the large-scale structure of the heliosphere, the physics of the interplanetary and interstellar medium, and particle acceleration and transport. Students who present a seminar or submit a paper receive a letter grade; other students receive a Satisfactory (S) or No Credit (NC) grade. Course is repeatable. **Zank**

PHYS 281. Charge-Parity (CP) Symmetry Violation (2) Seminar, 2 hours. Prerequisite(s): graduate standing; consent of instructor. Provides an overview of charge-parity (CP) symmetry violation, mostly from an experimental point of view. Reviews the theoretical background and discusses experimental results and their implications. 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. **Long**

PHYS 282. Experimental Investigations of Strongly Correlated Materials (2) Seminar, 2 hours. Prerequisite(s): graduate standing; consent of instructor. Examinations of thermodynamic and transport properties in strongly correlated materials which often exhibit unusual broken-symmetry ground states. Topics include measurements of specific heat, resistivity, magnetoresistivity, thermopower, and the Hall effect of existing and previously uncharacterized compounds. Students who present a seminar or submit a paper receive a letter grade; other students receive a Satisfactory (S) or No Credit (NC) grade. Course is repeatable. **Beyermann**

PHYS 283. Techniques of Microscopy (2) Seminar, 2 hours. Prerequisite(s): graduate standing; consent of instructor. Explores current techniques of microscopy. Covers optical and electron microscopy and novel techniques of scanning microscopy such as scanning tunneling microscopy, near-field scanning optical microscopy, and atomic force microscopy. Students who present a seminar or submit a paper receive a letter grade; other students receive a Satisfactory (S) or No Credit (NC) grade. Course is repeatable. **Mohideen**

PHYS 284. Optical Techniques for Measurements in Physics (2) Seminar, 2 hours. Prerequisite(s): graduate standing; consent of instructor. Explores current topics in optical physics and the use of optical and nonlinear optical techniques to make measurements of interest in atomic, molecular, chemical, and condensed matter physics. Emphasizes advances in science enabled by advances in laser technology. Students who present a seminar or submit a paper receive a letter grade; other students receive a Satisfactory (S) or No Credit (NC) grade. Course is repeatable. **Tom**

PHYS 285. Experimental Techniques in Particle Physics (2) Seminar, 2 hours. Prerequisite(s): graduate standing; consent of instructor. Review of experimental techniques used in particle physics experiments, including tracking, calorimetry, and muon detection. Analysis of experiments at future super-colliders and their physics capabilities, focusing on the searches for the Higgs, top quark physics, and supersymmetric particles. Students who present a seminar or submit a paper receive a letter grade; other students receive a Satisfactory (S) or No Credit (NC) grade. Course is repeatable. **Ellison**

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 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 Pathology and Microbiology

Subject abbreviation: PLPA
College of Natural and Agricultural Sciences

Michael F. Allen, Ph.D., Chair
Department Office, 1463 Boyce Hall
(800) 735-0717 or (951) 827-4116
plantpathology.ucr.edu

Professors
Michael F. Allen, Ph.D. (Plant Pathology/Biology)
Katherine Borkovich, Ph.D.
Michael D. Coffey, Ph.D.
Donald A. Cooksey, Ph.D.
Shou-Wei Ding, Ph.D.
Howard S. Judelson, Ph.D.
A. L. N. Rao, Ph.D.
Michael E. Stanghellini, Ph.D. *Cy Mouradick Chair in Desert Agriculture*

Professors Emeriti
Salomon Bartnicki-Garcia, Ph.D.
J. Allan Dodds, Ph.D.
Joseph W. Eckert, Ph.D.
Robert M. Endo, Ph.D.
Donald C. Erwin, Ph.D.
Dennis D. Focht, Ph.D.
John A. Menge, Ph.D.
Donald E. Munnecke, Ph.D.
Howard Ohr, Ph.D.
Alberto O. Paulus, Ph.D.
Joseph S. Semancik, Ph.D.
James J. Sims, Ph.D.
Ivan J. Thomason, Ph.D. (Plant Pathology/Nematology)
Peter H. Tsao, Ph.D.
Seymour D. Van Gundy, Ph.D. (Plant Pathology/Nematology)
Lewis G. Weathers, Ph.D.

Associate Professors
James E. Adaskaveg, Ph.D.
James G. Borneman, Ph.D.

Assistant Professors
Greg Douhan, Ph.D.
Hailing Jin, Ph.D.
Wenbo Ma, Ph.D.
James Ng, Ph.D.

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Lecturers
Francis P. Wong, Ph.D.
Georgios Vidalakis, Ph.D.

Affiliated Faculty
Ellis F. Darley, Ph.D. (Plant Pathologist Emeritus)
Steven Garnsey, Ph.D. Citrus Virology

Undergraduate Curriculum

The Department of Plant Pathology and Microbiology participates in the Biological Sciences interdepartmental major, in which students may specialize in areas such as Microbiology, Plant Sciences, and Entomology. It also participates in the Botany and Plant Sciences major leading to the baccalaureate degree. See the Biological Sciences 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 domestic 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 normally includes as a minimum PLPA 200, PLPA 203, PLPA 204, PLPA 206/NEM 206, and participation in PLPA 250 for each term the student is registered.

Doctoral Degree

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