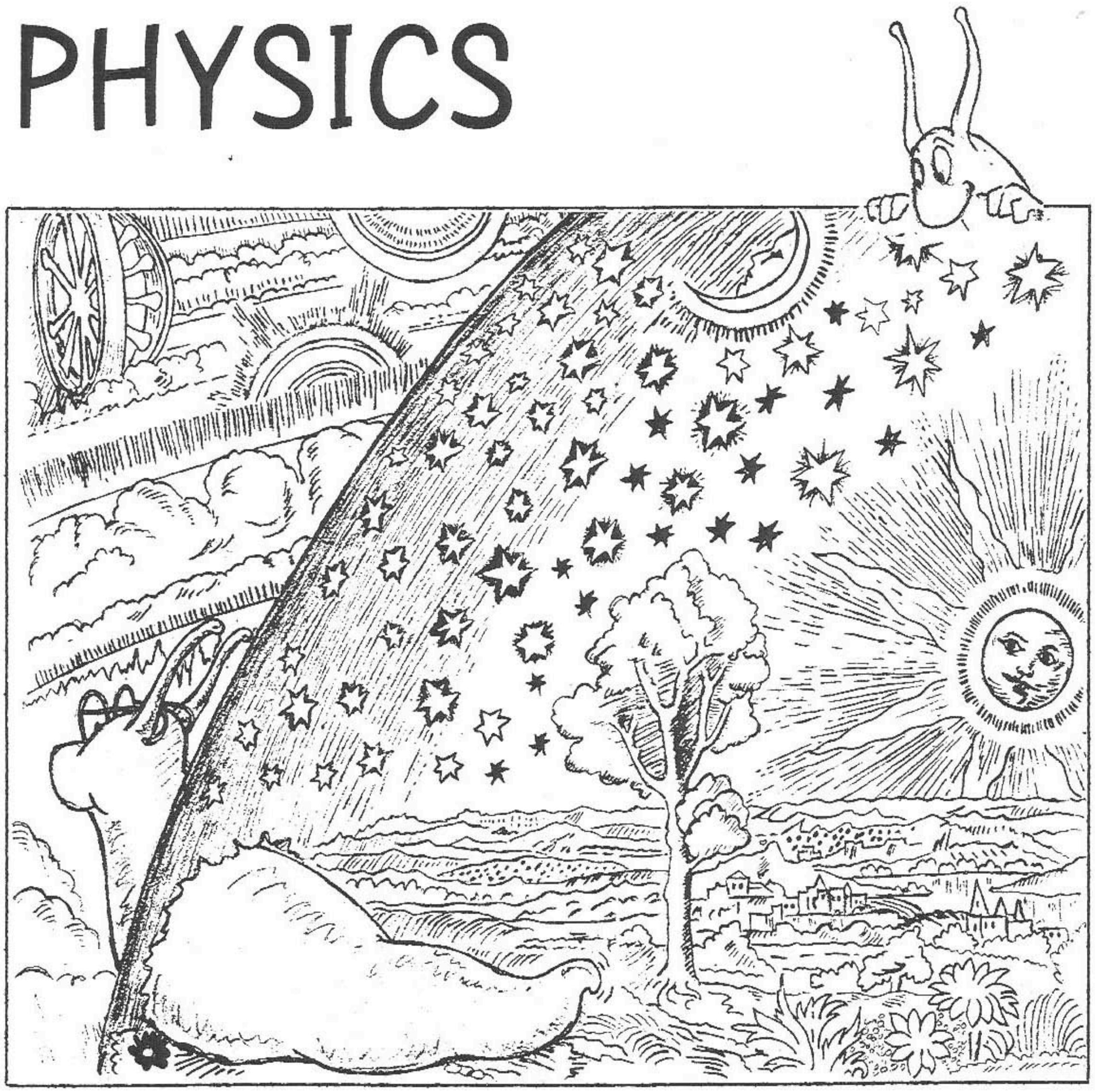
UC SANTA CRUZ

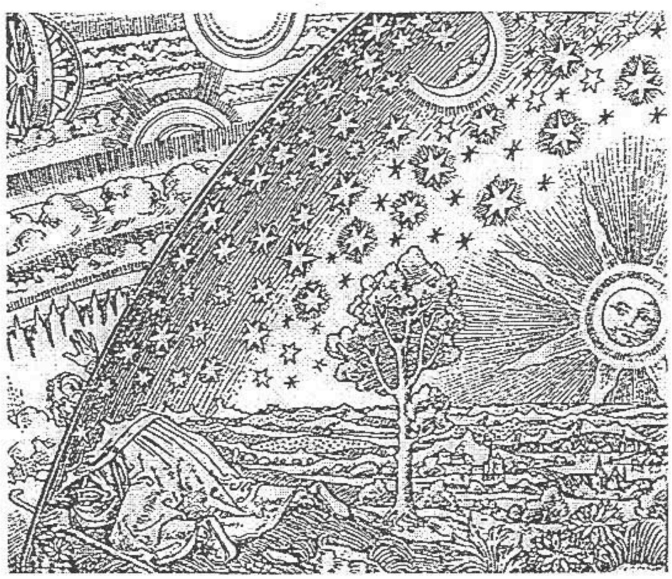
PHYSICS



A PHYSICS MAJORS' GUIDE

2006-2007

About the cover:



SPACE WAS FINITE and had a definite edge, according to the Aristotelian cosmology accepted during medieval times. Here a man is shown looking beyond the edge of space to the Empyrean abode of God beyond. The illustration is often said to be a 16th-century German woodcut; according to Owen Gingerich of Harvard University, it is more likely a piece of art nouveau that was apparently published for the first time in 1907 in *Weltall und Menschheit*, edited by Hans Kraemer. In either case the picture clearly demonstrates a dilemma posed by Immanuael Kant known as Kant's antinomy of space. Kant believed that the universe had to be finite in extent and homogeneous in composition, and that space had to obey the laws of Euclidean geometry. Actually, however, all those assumptions cannot be true at once.

C O N T E N T S

I N T R O D U C T I O N

This is a guide for students majoring in physics, physics (astrophysics)*, and applied physics at the University of California, Santa Cruz (UCSC). It provides a general description of the Physics Department, areas of research interest, background, photographs of our faculty, information about the physics program, career possibilities, and other information. Much of this guide is of particular relevance to the physics student in his/her upper division years. Nevertheless, students should at least browse through the handbook early on to get an idea of what might be in store for them before they approach graduation.

THE SANTA CRUZ PHYSICS DEPARTMENT

The UC Santa Cruz Physics Department has eighteen regular faculty and one lecturer. Additionally there are six adjunct faculty members who are involved in research and who occasionally teach undergraduate courses, several post-doctoral researchers, and approximately sixty graduate students. Historically, our faculty has shown a strong interest in the undergraduate program and has worked to maintain its quality and high standards. There are roughly forty students in each year of the Physics major at Santa Cruz, a remarkably large number for a school of this size.

The faculty is strongly involved in research and has achieved an internationally distinguished reputation. Our physics faculty is complemented by a close association, in the same building, with the astronomers of the Lick Observatory. The Interdisciplinary Sciences building is the headquarters of the University of California Observatories (UCO) supporting the operation of the 120-inch telescope on nearby Mount Hamilton and the new 10-meter telescopes in Hawaii. Additionally, we maintain a daily working relationship with the Santa Cruz Institute for Particle Physics (SCIPP), located in an adjoining building: Natural Sciences II. This area of physics research at Santa Cruz ("high energy physics") is devoted to investigations of the fundamental particles of nature. The Santa Cruz group is a major user of the Stanford Linear Accelerator Center (SLAC), the accelerator at Fermi lab, and major accelerators in Europe. Our faculty also use the Stanford Synchrotron Radiation Laboratory (SSRL) at Stanford and maintains scientific associations with various x-ray and neutron scattering centers at national laboratories. Other faculty members are involved in studies of the quantum behavior of atoms and electrons in solids and liquids (including living things), the cosmology of the Big Bang, and non-linear systems and chaos.

At the University of California, and at Santa Cruz in particular, we believe that students should be educated not only by good communicators of the material but by people who are also at the research frontier of their specialties. Introductory courses in physics demand attention to basic concepts. It is difficult for instructors in these courses to dwell explicitly on their research interests, but you will probably get a warm response if you ask an instructor about his or her research.

*Degree will read physics (astrophysics). Referred to subsequently as astrophysics.

THE FACULTY

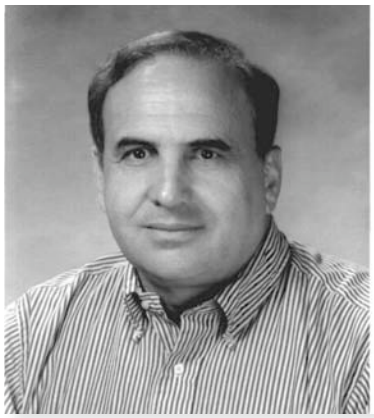
Below are listed both our regular and research faculty, with their research interests and a brief biographical sketch included. We do not mention the courses they teach as these vary from year to year. The emeriti faculty continue to participate in research and some of them occasionally teach courses.

ANTHONY AGUIRRE
Assistant Professor of Physics

Works on a variety of topics in theoretical cosmology. One strand of his work concerns the detailed comparison between theoretical models and observations of heavy elements in the intergalactic medium, in order to derive constraints on processes involved in galaxy formation, and on the cosmic star formation history. A second strand focuses on understanding the global structure of inflationary universes, cosmological boundary conditions, and related issues. He has also done work on (and occasionally revisits) other topics including dark matter and alternatives to dark matter, intergalactic dust, the cosmic background radiation. Ph.D. from Harvard University, 2003.

WILLIAM B. ATWOOD
Adjunct Professor of Physics

Primary research interest deals primarily with Particle Astrophysics. Of particular interest is his work in high-energy phenomena and cosmology. Work includes experiment simulations and analysis using Monte Carlo tools. Ph.D. from Stanford University, 2001.



TOM BANKS
Professor of Physics

Primary interest: high-energy theory with recent emphasis on string theory and quantum gravity. Recent work devoted to finding a complete formulation of string theory and the relation between the cosmological constant and the breaking of super-symmetry. Also actively interested in the interface between fundamental physics and cosmology. In the past, Banks has also worked on applications of quantum field theory to condensed matter physics. Ph.D. from Massachusetts Institute of Technology, 1973.

DAVID P. BELANGER
Professor of Physics,
Current Department Chair

Research deals primarily with the properties of magnetic systems close to their phase transitions with particular emphasis on the effects of randomness and frustration. The experimental work includes optical linear birefringence, Faraday rotation, specific heat, and neutron and x-ray scattering techniques. Each year several undergraduates work in his research lab. Ph.D. from UC Santa Barbara, 1981.

FRANK BRIDGES
Professor of Physics, Emeritus

Research deals primarily with the local structure of solids, including impurities in crystals, high T_C superconductors, colossal magneto-resistive and thermo-electric materials. Extended X-ray absorption fine structure (EXAFS) is used in these investigations. Bridges has also recently done experiments to investigate the collisional properties of the ice particles in Saturn's rings. Each year several undergraduates work in his research lab. Ph.D. from UC San Diego, 1968.

GEORGE BROWN
Professor of Physics

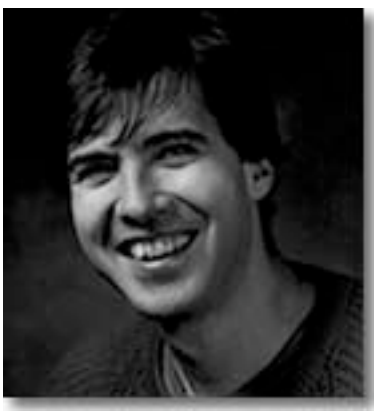
Has programs in the application of synchrotron radiation to condensed-matter physics, atomic physics, and diagnostic medical imaging. Brown has carried out collaborative programs with biologists, chemists, and earth scientists in fundamental studies of the structure of matter. Ph.D. from Cornell University, 1973.

SUE CARTER
Professor of Physics

Studies both fundamental and applied aspects of optical, magnetic, and electronic phase transitions in novel materials, such as organic LED's, polymer dispersed liquid crystals, transparent conductors and nano-crystalline oxides. Her research is interdisciplinary, combining physics, chemistry and materials science. Each year several undergraduates work in her research lab. Ph.D. from University of Chicago, 1993.

DONALD G. COYNE
Adjunct Professor of Physics, Emeritus

Research in experimental particle physics and astroparticle physics; the former done with e^+e^- annihilations at SLAC, the latter with the CYGNUS /MILAGRO collaborations in New Mexico. He also has an interest in the rapidly developing interface between particle physics and gravity, using the New Mexico experiment to search for exploding black holes. Ph.D. from Cal Tech, 1967.

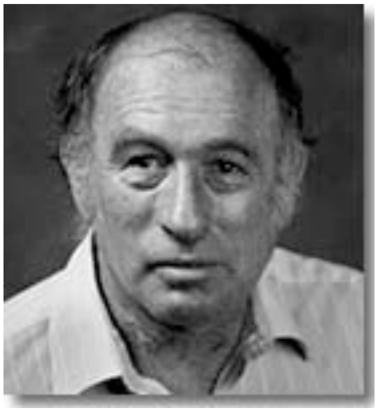


JOSHUA DEUTSCH
Professor of Physics

Interested in theoretical statistical mechanics. One area in which he is particularly interested deals with the properties of long macromolecules. Deutsch often uses computers as a tool in understanding these complex statistical systems. Ph.D. from University of Cambridge, 1983.

MICHAEL DINE
Professor of Physics

Primarily interested in elementary particle theory. Much of his work has been devoted to trying to resolve puzzles left unanswered by the Standard Model of strong, electro-magnetic, and weak interactions, particularly in the framework of super symmetry and superstring theory. Dine also works actively at the interface between particle physics and cosmology. Ph.D. from Yale University, 1978.



DAVID E. DORFAN
Professor of Physics, Emeritus

One of the leaders of our high energy physics experimental group. He has also worked in the area of nuclear safety and currently works on Tev x-ray astronomy and designs analog bipolar integrated circuits. Ph.D. from Columbia University, 1967.

STANLEY M. FLATTÉ
Professor of Physics, Emeritus

Studies the propagation of waves through random media, principally through the use of numerical simulations. Has applied his methods to ocean acoustics, atmospheric optics, and seismology. Works with experimenters in all those fields so as to keep contact with real data. Ph.D. from UC Berkeley, 1966.

GEORGE D. GASPARI
Professor of Physics, Emeritus

Works primarily on the theory of condensed matter. Ph.D. from UC Riverside, 1964.

GEY-HONG GWEON
Assistant Professor of Physics

Experimental condensed matter physics; research centers on materials that show novel properties due to electrons in them being strongly interacting with each other or being confined to low dimensional structures. His research has been providing sharp signatures of these novel physics, by using the state-of-the-art angle-resolved photo-electron spectroscopy (ARPES) and other electron spectroscopy tools. Ph.D. from University of Michigan, 1999.

HOWARD HABER
Professor of Physics

Works in theoretical elementary particle physics. His principal interest is the phenomenology of particle interactions at present and future high-energy colliders. His specialties include perturbative methods in field theory, super symmetry, electroweak symmetry breaking and the theory of Higgs bosons. Ph.D. from the University of Michigan, 1978.

CLEMENS A. HEUSCH
Professor of Physics

One of the leaders of our high energy physics experimental group, with active research programs at the Stanford electron-positron colliders, at the European Center for Particle Physics in Geneva, Switzerland and at the electron-proton collider HERA in Hamburg, Germany. Active in international science coordination and in planning for the next linear collider. Recently declared the top priority in the United States particle physics programs. He is the national as well as international convener for the electron-electron version of this machine. On occasion he has taught courses on pre-Columbian anthropology and science, as well as on musical criticism. On the apparatus side, Heusch is working on new calorimeter techniques and on high-density electronic readout technology. Ph.D. from the Technical University of Munich, Germany, 1959.

ROBERT JOHNSON
Professor of Physics

Working in experimental particle physics and high-energy gamma-ray astrophysics. Participated in the design of the silicon-strip readout system for the SLAC B-Factory detector. Presently managing the design and construction of the million-channel-silicon-strip tracking detector for the NASA/DOE Gamma-ray Large Area Space Telescope. Current interests include the physics of b-hadrons and CP violation, gamma-ray pulsars and active galactic nuclei, solid-state particle detectors, the design of the VLSI readout electronics. Ph.D. from Stanford University, 1986.

FRED KUTTNER
Lecturer in Physics

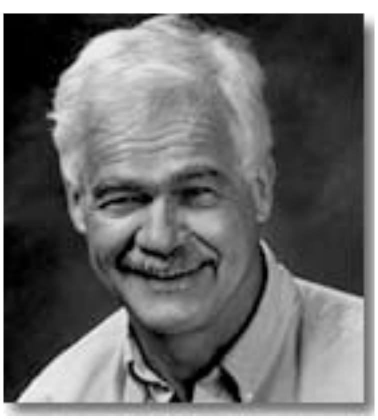
Current research interests include the foundations and implications of quantum mechanics and physics education. Ph.D. from UC Santa Cruz, 1977.

ALAN LITKE
Adjunct Professor of Physics

Interested in experimental particle physics; research work at CERN in Geneva, exploring the high-energy frontier with proton-proton collisions at the Large Hadron Collider. Also interested in understanding how neural systems process and encode information. He is applying techniques developed for high-energy physics to the experimental study of the retina, to understand the language used by the eye to send information about the visual world to the brain. Ph.D. from Harvard, 1970.

ONUTTOM NARAYAN
Professor of Physics

He is primarily working on the non-equilibrium behavior of disordered systems. These systems can take much longer to equilibrate than the duration of most experiments. In this field he has recently focused on understanding the properties of granular materials (such as sand or powders). Earlier work has been on the response of disordered systems to external forces, where the system moves only if the force is greater than the threshold value, close to which complex dynamics is seen. The work is analytical, supplemented by numerical calculations. He is also interested in pattern formation and in the theory of random matrices applied to small quantum systems. Ph.D. from Princeton University, 1992.



MICHAEL NAUENBERG
Professor of Physics, Emeritus

He does extensive and varied work in theoretical physics and the history of science in the 17th century. He has co-authored a book entitled *The Foundations of Newtonian Scholarship.* Ph.D. from Cornell University, 1960.

JASON NIELSEN
Assistant Professor of Physics

Studies the properties and interactions of elementary particles in high-energy collisions. His current interests are in the physics of the top quark and Higgs boson, as well as searches for new physics requiring extensions to the Standard Model. He has also collaborated on the ALEPH and CDF experiments on the energy frontier at CERN and Fermilab. Ph.D. from University of Wisconsin-Madison, 2001.

JOEL R. PRIMACK
Professor of Physics

Works on cosmology and elementary particle theory, especially on dark matter—its role in the formation of structure in the universe, and the possibility that it may be some sort of elementary particle. He uses super-computers and computer visualization in this work. He has also worked on energy and space policy. Ph.D. from Stanford University, 1970.

MICHAEL RIORDAN
Adjunct Professor of Physics

Involved in the History and Philosophy of Science Program at Stanford University. He has written and co-authored three highly acclaimed books on the discovery of quarks, dark matter and cosmology, and the invention and development of the transistor. He has recently received the prestigious American Institute of Physics Andrew Gemant Award for his efforts in communicating physics through his books, articles, and television programs. He is currently involved with a group of historians and physicists studying the history of the Superconducting Super Collider. For this work, he was awarded the Guggenheim Fellowship in 1999. He currently teaches a course called "The Quantum Century." Ph.D. from Massachusetts Institute of Technology, 1973.

BRUCE ROSENBLUM
Professor of Physics, Emeritus

Research has included molecular physics, semiconductors, superconductivity, the detection of magnetic fields by animals, and applied physics topics, but has now turned to fundamental aspects of quantum mechanics. Previously at RCA labs as head of the General Research Group. Ph.D. from Columbia University, 1958.

HARTMUT SADROZINSKI
Adjunct Professor of Physics

Works in experimental particle physics, e^+e^- annihilation at SLAC, e-p scattering at HERA and R & D for future colliders. Ph.D. from Massachusetts Institute of Technology, 1973.

TERRY SCHALK
Adjunct Professor of Physics

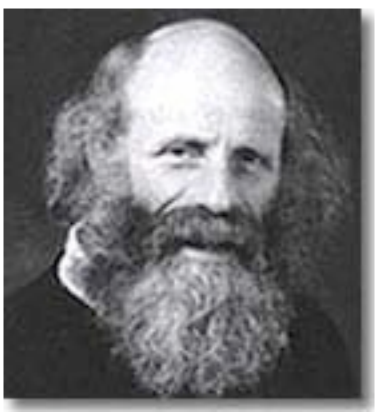
Currently working in experimental high-energy physics. His interests are in matter/anti-matter, asymmetry in the universe, phenomenology, polarized z^0 production in e^+e^- annihilation, and computational physics. Ph.D. from Iowa State, 1969.

ZACK SCHLESINGER
Professor of Physics

Experimental condensed-matter physics; uses optical infrared measurements and cryogenic techniques to probe the dynamics of electrons in strongly correlated systems. These include mixed-valent systems with unusual phase transitions, high temperature super-conductors, marginal metals, and systems with unusual magnetic behavior. Ph.D. from Cornell University, 1982.

BRUCE SCHUMM
Professor of Physics

Working in experimental particle physics, with the SLD and BABAR collaborations at the Stanford Linear Accelerator Center in Palo Alto. Current activities include electron beam polarity and detector electronics development, in pursuit of studies of symmetry violation in fundamental interactions. Ph.D. from the University of Chicago, 1988.



PETER L. SCOTT
Associate Professor of Physics, Emeritus

He is currently organizing a collection of physics songs and occasionally working on problems involving nonlinear dynamical systems. Ph.D. from UC Berkeley, 1962.

ABRAHAM SEIDEN
Professor of Physics

Director of the Santa Cruz Institute for Particle Physics, which coordinates theoretical and experimental research on particle physics at UCSC. His research deals with the design, coordination, and execution of experiments on fundamental particles, requiring the use of the world's largest accelerators in both the U.S. and Europe. Ph.D. from UC Santa Cruz, 1974.

B. SRIRAM SHASTRY
Professor of Physics

One of the leading figures in condensed matter theory in the world, Dr. Shastry's primary interests include: Strongly Correlated Matter, Mott Hubbard Physics, High Tc Superconductivity, Quantum Magnetism, Exactly Integrable Systems, Exactly Solvable models of Many Body Systems and in Statistical Mechanics, Quantum Chaos, Geometric Frustration. Ph. D. from the Tata Institute of Fundamental Research, India, 1976.

DAVID M. SMITH
Assistant Professor of Physics

Studies high-energy processes in astrophysical sources (supernova remnants, neutron star and black hole binaries, classical novae, etc.) and solar flares via their x-ray and gamma-ray emission. Participates in the design and construction of instruments to fly on spacecraft and stratospheric balloons as well as making observations with existing NASA satellites. Other interests include the use of gamma-ray observations to determine the composition of planetary surfaces and to study the fate of relativistic particles in the Earth's radiation belts. Ph.D. from UC Berkeley, 1993.

DAVID A. WILLIAMS
Adjunct Professor of Physics

Williams's research is on experimental questions at the frontier between particle physics and astrophysics. His main projects currently are the Milagro and STACEE very high-energy gamma-ray telescopes. Ph.D. from Harvard University, 1987.

A. PETER YOUNG
Professor of Physics

Research is on the theory of phase transitions. He has been particularly interested in applying computer simulation techniques to gain a qualitative understanding of phase transitions in highly disordered condensed matter systems. More recently Young has been looking at phase transitions in superconductors and transitions driven by quantum fluctuations. Ph.D. from Oxford University, 1973.

THE PHYSICS OFFICE

Room 211 Interdisciplinary Sciences Building

The Physics Office is the nerve center of the Physics Department and a valuable resource center. The office staff is happy to assist you with any questions or problems you may have.

Hua Vang, Undergraduate Program Advisor
Julie Reiner, Office Coordinator
Jennifer Hild, Graduate Program Advisor
Sarah Schuster, Department Manager

INTERNSHIPS AND OTHER JOBS FOR STUDENTS

A number of students have had interesting internships (REU, summer positions at Stanford, UC Leads, local companies, and in our labs in this department and in conjunction with Santa Cruz Institute of Particle Physics), which have helped them to develop their career perspectives. These internships can be during the summer and may be half-time or less during the school year. Such activity may possibly extend the time needed for graduation. Intern experiences have often served as the basis for a senior thesis. Contact Career and Internship Services (305 Baytree Building) at ext. 9-4420 and watch bulletin boards near the Physics Office for information. Or use your own contacts after a discussion with the Physics Department Undergraduate Advisor or a faculty member.

Occasionally, there are summer or part-time jobs available for students, usually upper-division students, in faculty labs. *How to get one?* Ask around. It pays to be well regarded on the basis of your course work. Persistence also pays. Recently, the work being done by a physics major was profiled in the UC Santa Cruz *Currents* newspaper. To see the story, please visit http://currents.ucsc.edu/03-04/04-19/wray.html.

Some jobs are also available assisting in the advanced labs, Charlie Crummer in the lower-division labs, or with demonstrations. Contact any of the above and/or watch the bulletin boards. During the school year, students are hired as readers to grade homework in physics courses. Applications for reader positions are available in the Physics Office (ISB 211). Good performance in the course in question—and in others—helps.

SOCIETY OF PHYSICS STUDENTS

The Physics Department hosts a chapter of the Society of Physics Students. The Society is a nationwide physics club whose aim is to enhance communication, leadership, and professional networking skills in ways that cannot be realized in course work alone. The acquisition of these skills can be realized through activities such as field trips or lectures given by professionals and faculty. Membership dues are $20 per year and once you become a member you will receive a subscription to *Physics Today*, a physics research publication. If you have any questions, please contact the Department office or visit the UC Santa Cruz SPS website: http://physics.ucsc.edu/sps

SPS activities are organized by a core group of officers along with active members. Elections are held every fall quarter to elect the club officers. Announcements for the election and general meetings will be sent via email. Signs will also be posted around the Department. Please watch for these messages if interested in keeping the club alive.

UCDC PROGRAM

DESCRIPTION OF UCDC PROGRAM

Spend Fall, Winter or Spring quarter studying and interning in Washington, D.C. Undergraduate juniors and seniors in all majors can now enroll full-time in the UCDC Program. Sophomores with special circumstances regarding their academic schedules, particularly those in the natural sciences or engineering, may apply as well. Students take classes and intern at one of the many organizations of agencies in the Washington D.C. area while fully enrolled as UCSC students. The cost for the quarter is comparable to a quarter on campus at UCSC (plus travel), and need-based scholarships are available to aid in the cost of airfare and additional living expenses. Students are housed in the UC Washington Center. Application materials are widely available throughout the campus during the months of October and March. Further information is available from the UCDC office. Send emails to ucdc@ucsc.edu, or visit their website at http://zzyx.ucsc.edu/Pol/ucdc/

CAREER POSSIBILITIES

The Physics Department offers majors in physics, astrophysics, and applied physics. These programs prepare students for graduate work in physics, astrophysics, and astronomy; for engineering and other technical positions in industry; and careers in education. With appropriate courses in another discipline, the physics and astrophysics majors provide excellent preparation for advanced study in technical subjects such as biology, chemistry, engineering, geophysics, and the philosophy of science. The applied physics major is excellent preparation for positions in industry directly upon graduation.

We are fortunate to have our Physics faculty so closely connected with the Astronomy and Astrophysics faculty. They share many of the same research areas of interest and both departments are located in or adjacent to the Interdisciplinary Sciences Building. UCSC is the headquarters for the University of California Observatories, which include Lick Observatory near San Jose and the Keck Observatory in Hawaii; these provide additional opportunities for collaboration between researchers in physics and astronomy. We also house on campus the Center for Adaptive Optics, the group who works with developing and creating the telescope mirrors and lenses for Keck Observatory.

The undergraduate education of a physics major is both basic and broad. The body of knowledge it covers is widely applicable, from quarks to galaxies and from transistors to neurons. A physics student becomes acquainted with this knowledge and also develops a range of skills for creating models and solving problems, often with the application of mathematics. It's not an easy major, but you don't have to be a genius.

The basic material studied for the physics major is well defined; it varies little from one institution to another throughout the world. Because physics is so fundamental, much of the material studied by undergraduates maintains a timeless quality and does not go out of date. A physics education provides a foundation not only for the research physicist but for the pursuit of other disciplines, such as Engineering and Biology.

According to recent statistics from the American Institute of Physics, 80% of physics bachelor's degree recipients, including those who go on to a master's degree in physics or other fields, make their careers in industry. The majority of those who go on to a Ph.D. in physics will also pursue careers in industry. The applied physics major is designed for those students who wish to make early preparation for this career path. Including chemistry, computer programming, three electives in an applied area, and an applied senior thesis, it is excellent preparation for direct entry into industry, or into graduate school in engineering or other applied disciplines.

Historically, almost half our physics graduates apply to Ph.D. graduate programs in Physics. Their acceptance rate at leading institutions is high, and almost all those accepted receive full financial support. Because of the broad nature of the physics curriculum and the respect it carries, physics majors with good undergraduate records are readily accepted into graduate programs in engineering and other disciplines or into professional schools of law or medicine. A physics major headed in such a direction should, of course, have at least some appropriately specialized course work and consider a relevant senior thesis (described in detail later in this handbook).

Unsure about majoring in physics? It is easier to change from a structured program such as physics to a less structured one. It is harder to go the other way. That reverse direction often requires extra years of study, permission for which is increasingly difficult to get. ***If physics might be for you, start here.***

ADVISING

If you have questions regarding becoming a Physics major or are ready to complete your declaration of major, your first contact should be with the Undergraduate Advisor in the Physics Department Office. You may also want to talk with any of the Physics faculty if you have particular questions about specific areas of research within Physics. It is a good idea to establish continuing contact with a faculty member early in your first year at Santa Cruz. Continue to do this as you advance to the upper division, where more options present themselves. ***Discuss your program and plans often.***

If you are transferring to Santa Cruz from a community college or other institution (usually as a junior), you should contact the Undergraduate Advisor in the Physics Department Office to begin your transfer-student advising. Make sure you see him/her immediately upon your arrival.

You can seek advice and information from a variety of resources. Go to any faculty member you wish. Graduate students are also good sources, and so are advanced undergraduates. Make contacts. Use them.

Students should be aware that fulfilling campus General Education Requirements requires careful planning early in a student's college career. These are spelled out in the Catalog, but are more completely described in ***The Navigator: The Undergraduate Campus Handbook of Academic and Student Services.*** In particular, note that Physics majors meet the "Code W" writing requirement while doing their senior thesis (195A/B series). The senior thesis is discussed in more detail later in this handbook.

PHOTOGRAPH BOARDS

Outside the Physics Office are two display cases with photographs. One has photos of all the Physics faculty. The other has photos of our undergraduate and graduate students. These pictures can help you get to know the people in the department and them to know you. It's an important advantage.

You will receive an e-mail notice from the Physics department for the date/time of our next group photo shoot. Please plan to attend and get your picture taken if you are in any upper-division classes. It definitely pays to be visible--to have your face associated with your name on the class lists or your name associated with the faces seen around the department. These pictures have helped students obtain job offers and better letters of recommendation.

THE COURSES

The Freshman/Sophomore Physics Courses

Physics 5 is the introductory course sequence for students considering a major in Physics. Prospective Physics majors need to start Physics 5A in the fall of their freshman year. The Physics 5 sequence begins in the fall quarter with Physics 5A, which covers Newtonian mechanics. Physics 5B in the winter quarter treats wave motion, optics, and fluids. Physics 5C in the spring quarter is devoted to the physics of electricity and magnetism. For each of these three quarters, there is an associated (once-a-week) laboratory course, respectively, Physics 5L, 5M, and 5N. Concurrent enrollment in the labs is required. The mathematics co-requisite for Physics 5A is Math 19A, for Physics 5B is Math 19B, and for Physics 5C is Math 23A. Students are encouraged to take Math 20A and 20B (Honors Calculus) instead of 19A and 19B. **Physics 6 is not intended for students majoring in physics.** In special cases, students who have completed phys 6A instead of phys 5A, and do very well in it may contact the department chair for permission to enter the major.

Physics 5D (*Heat, Thermodynamics, and Kinetics*) is a 2-unit course to be taken after completion of 5C. It is only offered fall quarter.

Physics 10 (*Overview of Physics*) is a "mini-course" of one lecture per week given by our faculty on current research being conducted in physics. No background in physics is assumed. This light overview of the field is suggested for Physics majors as a "fourth course" in their ***first quarter*** at Santa Cruz. Take it any other time if you missed it.

Physics 11 (*The Physicist in Industry*) is a 2-unit course strongly recommended for applied physics majors to take in their junior year. Topics include the roles of the physicist in industry, the business environment in a technical company, economic considerations, job hunting, and discussions with physicists with industrial experience.

Physics 14 (*Introduction to Vector Calculus with Applications*) covers vector calculus: partial differentiation, Jacobian determinants, vector functions, surface integrals and the divergence; line integrals and the curl; the theorems of Gauss, Stokes, and Green; and the gradient, including maxima and minima of multivariable functions. Physics 14 is not required for students who have completed Math 23B. Not offered in 06-07.

The Upper-Division Physics Courses for the major

The upper-division program offers a broad spectrum of fundamental and applied courses. There are twelve required courses in the physics and astrophysics majors and eleven required upper division courses in the applied physics major (this includes the two upper division laboratory courses). In addition, students must take two electives for physics majors, three electives for astrophysics majors, and three electives for applied physics majors. A listing of approved elective courses is available in the department office. Physics faculty are happy to advise students in their selections of the elective courses. Advanced students may be permitted to enroll in graduate courses.

A valuable and required feature of the physics program involves the preparation of a senior thesis (described in detail later in this guide). In addition to the regular upper division and elective courses, Physics 195A-B (Senior Thesis Research) are required in the senior year. See the section of this guide on the senior thesis for important information on the senior thesis and these courses.

Physics 101A-B (*Introduction to Modern Physics I and II*) is a two-quarter sequence in modern physics. The principles of special relativity and quantum mechanics are introduced and serve as the basis for concepts in atomic, molecular, and solid-state physics, including nuclear physics and elementary particle physics. Each of these topics is covered in more detail in further upper-division courses.

Physics 105 (*Mechanics*) covers particle dynamics in one, two, and three dimensions. Other topics include: conservation laws; small oscillations, Fourier series and Fourier integral solutions; phase diagrams and nonlinear motions, Lagrange's equations, and Hamiltonian dynamics.

Physics 110A-B (*Electricity, Magnetism, and Optics*) is a two-quarter sequence covering Maxwell's equations, electrostatics, magnetostatics, induction, electromagnetic waves, physical optics, and circuit theory.

Physics 112 (*Thermodynamics and Statistical Mechanics*) covers the first and second laws of thermodynamics, elementary statistical mechanics, and thermodynamics of irreversible processes.

Physics 116A-B-C (*Mathematical Methods in Physics*) is a three-quarter sequence, covering the following topics: A) probability, infinite series and power series, complex numbers, systems of differential equations, linear algebra, and matrix operations; B) Line vector spaces and coordinate transformations, tensor analysis, ordinary differential equations and boundary value problems, calculus of variations, Fourier series; and C) Legendre polynomials and Bessel functions, partial differential equations and boundary value problems, functions of a complex variable including the residue theorem, integral transforms, Green function techniques and the delta function.

Physics 133 (*Intermediate Laboratory*) is the first upper division laboratory course required of all physics, astrophysics, and applied physics majors. Objectives are demonstration of phenomena of classical and modern physics and development of a familiarity with experimental methods. Special experimental projects may be undertaken by students in this laboratory.

Physics 134 (*Physics Advanced Laboratory*) is only required for physics and applied physics majors. Objectives are individual experimental investigations of basic phenomena in atomic, nuclear, and solid state physics.

Physics 135(A-B) (*Astrophysics Advanced Laboratory*) is only required for astrophysics majors. Introduction to the techniques of modern observational astrophysics at optical and radio wavelengths through hands-on experiments. Offered in some academic years as a multiple-term course: 135A in fall and 135B in winter or spring, depending on astronomical conditions.

Physics 139A (*Quantum Mechanics*) is only required for physics and astrophysics majors. Topics include the principles and mathematical techniques of nonrelativistic quantum mechanics: the Schroedinger equation, Dirac notation, angular momentum, approximation methods, and scattering theory.

A complete listing of physics course descriptions can be viewed in the UCSC General Catalog.

THE PHYSICS UNDERGRADUATE LABORATORIES

Laboratory courses are essential and required components of the undergraduate physics program, starting with the Physics 5 lab course sequence. In these courses, each lab section meets once a week for three hours and is led by a graduate student teaching assistant ("TA"). The intermediate laboratory, Physics 133, is taken in the sophomore or junior year, and is a prerequisite to Physics 134, the Advanced Laboratory. Both courses are required of all Physics and Applied Physics majors. The laboratory requirements for Astrophysics majors are Physics 133 and Physics 135, the Astrophysics Advanced Laboratory.

Physics involves interpreting complex real-world phenomena in terms of models and idealizations; the process of observing the "messy" real world and connecting it with the theoretical models forms an essential element of the discipline.

The laboratory experience thus involves not only observing selected phenomena, but also their interpretation in terms of theoretical models. In doing this, the lab will help you develop skills in selecting and using apparatus, interpreting observations, and communicating your interpretations using mathematical expressions, graphs, and/or verbal explanations.

Occasionally, because lab work can be accompanied by confusion and frustration, students may start out seeing laboratory courses as unpleasant and irrelevant exercises. Ironically these same people often receive the most benefit from the labs and sometimes even discover them to be satisfying learning experiences. The Upper-Division Laboratories (Physics 133, 134 and 160) are managed by Fred Kuttner; the Lower-Division Labs (Physics 5, 6, and 7) are managed by Charlie Crummer. In addition, Alex Helman manages the Lecture/Demonstration laboratory.

THE PHYSICS MAJOR

Requirements for the major in physics include: Physics 5A/L, 5B/M, 5C/N, 5D; Math 19A or 20A, 19B or 20B, 23A, 23B or Phys 14; plus the twelve upper-division physics courses (and any prerequisites): 101A, 101B, 105, 110A, 110B, 112, 116A, 116B, 116C, 133, 134, and 139A. In addition, students must complete the senior thesis research sequence, 195A-B, and a senior thesis on a topic of their choice. Lastly, students must pass at least two upper-division electives: one elective chosen from Physics 129, 139B, 155, or 171 and one elective from any other upper division physics course or one of the following Astronomy and Astrophysics courses: 112, 113, 117, or 118. In very special cases, minor exceptions to these requirements may be granted to suit the specific programs of students. Before embarking on a program needing such waivers, plans should be discussed with a physics advisor and an approval must be obtained from the Physics Department.

Requirements for the minor in physics are Physics 5A/L, 5B/M, 5C/N, 5D (or Physics 6A/L, 6B/M, 6C/N with minimum GPA of 3.5); Math 19A or 20A, 19B or 20B, 23A, 23B or Physics 14; Physics 101A, 101B, 133, and one upper division elective (and any prerequisites) from Physics, or from a list of courses from other departments approved by the Physics Undergraduate Committee. See the Physics Department for the listing.

Listed below are courses required for a physics major:

	FALL	WINTER	SPRING
1st Year	Physics 5A/L Math 19A or 20A Physics10 (recommended)	Physics 5B/M Math 19B or 20B	Physics 5C/N Math 23A
2nd Year	Physics 5D Physics 101A Math 23B	Physics 101B Physics 116A	Physics 116B Physics 133*
3rd Year	Physics 105 Physics 116C Physics 134*	Physics 110A Physics 112	Physics 110B Physics 139A
4th Year	Physics 195A Physics Elective	Physics 195B Physics Elective	

*Physics 133 is offered winter and spring quarters. Physics 134 is offered in fall and winter quarters and may be taken junior or senior year after completing Physics 133.

THE ASTROPHYSICS MAJOR

Requirements for the major in astrophysics include: Physics 5A/L, 5B/M, 5C/N, 5D; Math 19A or 20A, 19B or 20B, 23A, 23B or Phys 14; plus the twelve upper-division physics courses (and any prerequisites): 101A, 101B, 105, 110A, 110B, 112, 116A, 116B, 116C, 133, 135, and 139A. In addition, students must complete the senior thesis research sequence, 195A-B, and a senior thesis on an astronomy-related topic. Lastly, students must pass at least three upper-division electives selected from the following upper division astronomy and astrophysics courses: 112, 113, 117, 118, or 171. In very special cases, minor exceptions to these requirements may be granted to suit the specific programs of students. Before embarking on a program needing such waivers, plans should be discussed with a physics advisor and an approval must be obtained from the Physics Department.

Note: The astrophysics minor is administered by the Astronomy Department. Please contact Roxanne Monnet at 831-459-3581 or roxannem@ucsc.edu. Physics majors are **not** encouraged to take an astrophysics minor.

Listed below are courses required for an astrophysics major:

	FALL	WINTER	SPRING
1st Year	Physics 5A/L Math 19A or 20A Physics10 (recommended)	Physics 5B/M Math 19B or 20B	Physics 5C/N Math 23A
2nd Year	Physics 5D Physics 101A Math 23B	Physics 101B Physics 116A	Physics 116B Physics 133*
3rd Year	Physics 105 Physics 116C Physics 135*^	Physics 110A Physics 112	Physics 110B Physics 139A
4th Year	Physics 195A Astr Elective	Physics 195B Astr Elective	Astr Elective

*Physics 133 is offered winter and spring quarters. Physics 135 is offered fall quarter and may be taken junior or senior year after completing Physics 133.
^Physics 135 is offered in some academic years as a multiple-term course: 135A in fall and 135B in winter or spring, depending on astronomical conditions.

THE APPLIED PHYSICS MAJOR

Requirements for the applied physics major include: Physics 5A/L, 5B/M, 5C/N, 5D; Math 19A or 20A, 19B or 20B, 23A, 23B or Phys 14; Computer Sciences 60N; Chemistry 1B; plus eleven upper-division physics courses (and any prerequisites): 101A, 101B, 105, 110A, 110B, 112, 116A, 116B, 116C, 133 and 134. In addition, students must complete the senior thesis research sequence, 195A-B, and a senior thesis on an applied physics topic. Lastly, students must pass at least three upper-division applied physics electives (and any prerequisites). Electives may be chosen from an approved list of courses in other departments in discussion with a faculty advisor. In special cases, minor exceptions to these requirements may be granted to suit the specific programs of students. Before embarking on a program needing such waivers, plans should be discussed with a physics advisor, and the approval of a petition to the Physics Department must be obtained.

Listed below are courses required for an applied physics major:

	FALL	**WINTER**	**SPRING**
1st	Physics 5A/L Math 19A or 20A Physics10 (recommended)	Physics 5B/M Math 19B or 20B	Physics 5C/N Math 23A Computer Sci 60N
2nd	Physics 5D Physics 101A Math 23B	Physics 101B Physics 116A Chemistry 1B	Physics 116B Physics 133*
3rd	Physics 105 Physics 116C Physics 134*	Physics 110A Physics 112	Physics 110B Apph Elective Physics 11 (recommended)
4th	Physics 195A Apph Elective	Physics 195B	Apph Elective

*Physics 133 is offered winter and spring quarters. Physics 134 is offered fall and winter quarters and may be taken junior or senior year after completing Physics 133.

GRADING

Students who wish to receive letter grades in physics courses, in addition to the narrative evaluations customary at Santa Cruz, may do so in all courses. Bear in mind that the Santa Cruz transcript has more than thirty-six independent comments on your performance, and it presents an informative and an accurate picture of your performance to the outside world. That transcript will stay with you for many years. ***It pays to make it a good one.***

HONORS

The department awards "honors" or "highest honors" to top graduating seniors each year. Recommendations for these awards are made by the department chair and are based upon excellence of academic performance, particularly in upper-division physics courses, as reflected in grades and the written evaluations.

The department also awards "honors" for outstanding work on the senior thesis, made upon the recommendation of the Senior Thesis Supervisor and the Thesis Technical Advisor.

DEPARTMENT AWARDS

The Marilyn Stevens Memorial Scholarship is an award designed to honor our former Department Manager, Marilyn Stevens. It is to be given to a current upper division physics undergraduate student and a current physics graduate student. Prospective students are nominated by fellow students, faculty, or staff. The awarding of the scholarship is based on both academic excellence and community service, service in and out of UCSC, and any outstanding contribution made to the Physics Department.

EDUCATION ABROAD PROGRAM

While studying abroad can add considerable cultural perspective, students should be aware that it takes very careful planning to do this and still graduate in four years. Problems sometimes arise with availability or level of appropriate courses. It is the responsibility of students considering education abroad to find out the details of course content and level at the institution they will be attending. This is often most readily accomplished by finding out which text is being used and which sections are covered.

THE PHYSICS DISCUSSION/COMPUTER ROOM

The Undergraduate Discussion/Computer Room is in ISB 207. We ask for your suggestions and possible contributions for turning this room into a user-friendly space. All suggestions and contributions are welcome.

Discussion plays an important role in physics research and in physics learning. (Physics is ***social*** science!) In this room physics discussions have priority over physics study. If you are seeking a quiet place to study, the Science Library has a great deal of available study space.

There is a computer in this room with very limited access and technical support. For this reason it is recommended that students visit the supported Instructional Computing Labs located throughout campus, available to students during drop-in hours. These labs are upgraded periodically each summer and have some of the latest hardware and software installed, fully equipped with printers, and can access the campus network. A listing of the labs, hours of operation, hardware and software programs can be accessed at the Instructional Computing website at http://ic.ucsc.edu.

Some physics homework may require the use of specialized software, such as Mathematica. Mathematica Version 5.0 is installed in the following Mac and PC Labs: BE 109, Cowell Apt, Kresge, Ming Ong, Porter and SS1.

EMPLOYMENT AFTER GRADUATION

Many physics majors, deciding to take jobs immediately after the bachelor's degree, find well-paid employment. They are usually called "R & D engineers" in the companies for which they work.

Students in their junior and senior years are encouraged to keep in touch with the *Career and Internship Services* (305 Baytree Building) for employment opportunities for the summer months and for permanent positions after receiving their bachelor's degree. Two items of importance when seeking employment:

1. Have a good resume ready to present. The Career Center can help you prepare one.

2. A good senior thesis on an appropriate topic can help convince an employer of the wide range of your knowledge and the focus of your scientific interests. A well-written introduction can be particularly useful as a stand-alone piece.

Meetings may be held by Joan Walker in the Career Center early in the winter or spring to go into more details about seeking employment. Announcement of these meetings will be on the bulletin board directly outside of the undergraduate lounge.

Faculty, staff researchers, and graduate students can be good sources of information about career possibilities after graduate school, particularly in the case of careers in academic physics.

The department owns three copies of the book, Landing Your First Job, published by the American Institute of Physics that can be checked out from the undergraduate advisor. This book is an excellent guide for students looking ahead at the job search process.

GRADUATE SCHOOLS

Which ones? How to get in? Financial support

Almost all of our students who apply to graduate school are admitted and receive enough support (e.g., a Teaching Assistantship) to be financially independent. Some advice: If in doubt about going to graduate school, apply anyway. Your mind can change. You can always decide not to go. Applying keeps your options open.

The Physics Office has a catalog, which you can check out for an hour or two, entitled Graduate Programs in Physics, Astronomy and Related Fields.

It pays to talk with as many people as possible, such as faculty and graduate students both at UCSC and elsewhere, about graduate schools and their programs. It also pays to visit graduate schools, where you can wander around, observe research labs, sit in on some graduate lecture courses, talk with graduate students and faculty, and generally get a feel for a program. Such visits can be helpful, informative, and fun.

Remember that a good senior thesis completed early enough can be used to help you get into graduate schools or obtain suitable employment. Even a completed introduction can help.

THE GRE (Graduate Records Examination)

Register for the GRE in the fall quarter of your senior year if you might want to go to graduate school. The Career and Internship Services (305 Baytree Building), keeps a supply of the Information Bulletin, which you should pick up and read carefully. Take the exam in November or December in order to take the exam early enough so that your scores can be mailed to the universities to which you apply for graduate study.

Much of the material on the GRE is of the level covered in the first two years of our physics program. It pays to review this before the exam. In particular, it is smart to look over any material of that level that is in books such as the Physics 5 texts and the Feynman Lectures[1]. The department may organize some review sessions and interesting workshops. Watch the bulletin boards for announcements. A group of interested students could also organize such activities themselves and ask the faculty for help. There are sample GRE exams in the Physics Department Office. Use them.

THE PHYSICS PICNIC

Each year the Physics faculty sponsors a picnic—usually in the spring quarter. This is an excellent time for faculty, research staff, graduate, and undergraduate students to get to know each other. Physics students ***at all levels*** are urged to attend. Watch and listen for the announcement.

COLLOQUIA/SEMINARS

The Weekly Colloquium

Thursday at 4:00 p.m. is colloquium time. Every week during the quarter a speaker talks on a subject of interest to upper-division physics majors, graduate students, and faculty. Speakers come from other universities, from research centers, and from industry. A few will be from UCSC. A wide variety of subjects related to physics are discussed. All students are welcome to attend.

Seminars

The various research groups in the Physics Department have seminars throughout the year. Check the Physics Bulletin Board each week to see what might be of particular interest. These seminars are generally quite advanced and specialized.

A current schedule of colloquium and seminar speakers, topics, and abstracts are posted at http://physics.ucsc.edu/sem_news/index.html.

[1] Every physics major should own and browse through this famous three-volume set.

THE SENIOR THESIS

What is it?

A major requirement for graduation as a UCSC physics, astrophysics, and applied physics major is the senior thesis. This thesis is a clear, logical presentation of some independent, physics-related work done by the student. Possible forms for the thesis include: (1) results of the student's experimental investigations, (2) results of the student's theoretical investigations, (3) results of numerical simulations of some physical problem (4) a review of some particular area related to physics, or (5) extension of some class material (possibly a Physics 134 or 135 experiment). The thesis may focus on a topic that is not generally considered to be in the mainstream of physics, but it must display the use and understanding of physics at the level of upper-division courses.

We require twenty-five pages of double-spaced text and equations. In only rare cases should the thesis exceed forty pages overall, nor should it have more than thirty-five pages of text and equations. The effort invested in the entire senior thesis may vary widely. It is reasonable to budget at least the amount of time and energy required for two regular upper-division physics courses (e.g., 110A and B) over the full course of the project. Copies of previous theses are available for your reference through the Physics Department Office.

Why do a senior thesis?

The senior thesis is designed both to complete your undergraduate physics experience and to provide a base from which to continue your future work related to physics.

Unlike the standard physics courses, which typically stress techniques for problem-solving and analysis, the senior thesis also includes independent decision-making, activity scheduling, synthesizing, and presenting scientific material in a well-written form. It allows you to explore and develop subjects of your own choosing. You not only acquire knowledge but you develop and demonstrate your ability to communicate it. You also can display considerable originality.

How do I do it?

The thesis supervisor (Physics 195A/B instructor) is responsible for coordinating all the theses for the year, for commenting on your early drafts, and for finally accepting your thesis. The thesis supervisor will be primarily concerned with a suitable professional level and presentation but will also have advice on how to get started and how to organize your endeavors.

In general you must also have a technical advisor, normally a faculty member who is knowledgeable about your thesis topic. Your technical advisor could be a faculty member of another department or a postdoctoral researcher. In some cases, especially where your thesis is connected to work done outside the campus—on an internship perhaps—your technical advisor could be a scientist with whom you have worked. You have a wide latitude in your choice, but he or she must be approved by the thesis supervisor. The thesis supervisor can often facilitate arrangements with appropriate advisors.

In your senior year you must enroll in Physics 195A/B (Senior Thesis Research) courses, which extends over the fall and winter quarters. In this course, students receive guidance on their thesis work, give progress reports on their work, and comment helpfully on the reports of others. Your technical advisor may be willing to sponsor a Physics 199 (Independent Study) should you require additional time to complete your thesis beyond these two quarters.

When is it due?

Senior theses must be submitted in final form in early May in order to graduate in June. The thesis must be approved in order for you to obtain your degree. Unfortunately, each year several otherwise successful students do not graduate because they leave too much work on the senior thesis to the last few months and are not able to meet the deadline and standards for the work required.

Before you leave campus for the summer before your senior year, it is an **extremely** good idea to have a general concept of your senior thesis topic and have at least a tentative agreement with an advisor. You should spend some time during that summer studying the general background of your thesis topic. Talk with the thesis supervisor and possible technical advisor and work out a summer reading list. A thesis proposal must be submitted to the thesis supervisor by mid-November of your senior year.

Drafts of specified parts of the thesis will be required at various times during the year in connection with the 195A/B sequence.

Expect drafts to be returned for revision a number of times. Revisions will include suggestions for improvement of presentation; these suggestions will cover your writing style as well as the technical aspects of your paper. An unbound copy of the final thesis is due in May, in order to graduate in June. You should also give a final copy to those who played an important role in the work.

Writing advice and critique

Physics 195A/B satisfies the campus "Code W" requirement for a writing-intensive course in a discipline. Since the Physics Department believes that writing skills are essential, the senior thesis is required to be a well-written document.

To assist students in acquiring writing skills, writing tutors may critique portions of early drafts and provide suggestions for improvement. Substantial improvement in technical writing skill can readily be achieved through practice. This is true independent of the skill-level at which the writer starts. An early start with writing critique is required, and a tentative version of the section "Introduction" of the thesis will be the first item critiqued.

Originality?

The thesis should comprise independent work, but not necessarily "original research." Many theses will be reports of extensive campaigns in the library, followed by an integration and simplification of the results. (Reference your work—refer to the various sources you used in each section of your thesis. For examples of references, see a typical physics journal.) There will be ample opportunity for originality in the selection and presentation of the material. Occasionally, there will also be new and original physical knowledge uncovered.

Evaluation

Campus wide rules specify that accepted theses be graded "Pass" or "Honors." A substantial fraction of physics theses are graded "Honors." A smaller number of outstanding theses will also receive a special "Departmental Commendation."

Collapse?

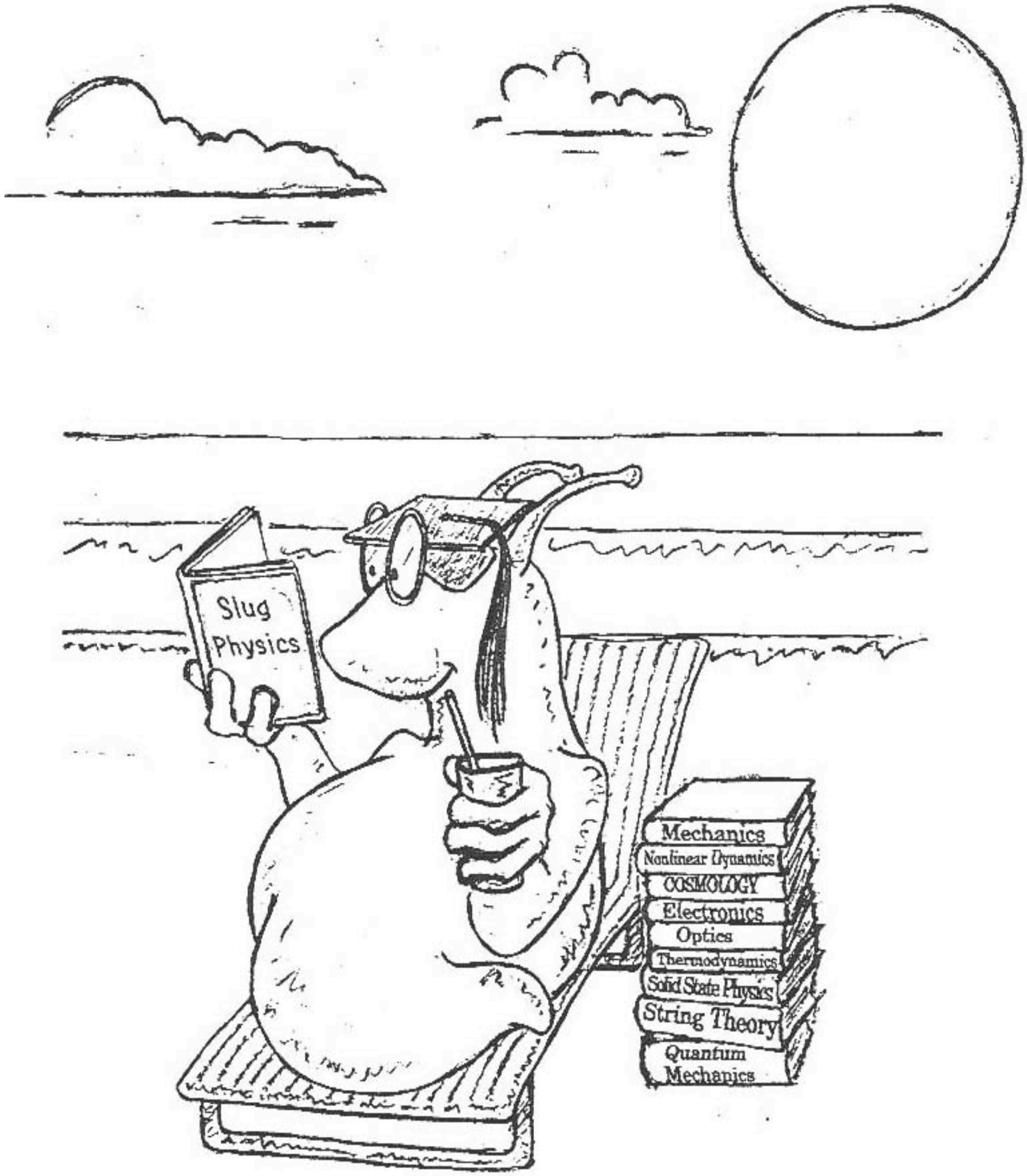
The best laid plans flop sometimes. Don't go too deep too fast. Don't leave a crucial part to the bitter end. Plan ahead. Seek advice.

Blank?

Can't think of anything? Look through back issues of *Scientific American, Science, Physics Today, and American Journal of Physics.* Talk to the supervisor of theses, to instructors in courses that particularly interested you, or to faculty members about their research field or peripheral interests. Also we have in the Physics Office, ISB 211, a library of theses written by our former students. You are welcome to read them to stimulate ideas for your own work.

Enthusiastic?

Great! The opportunities for an outstanding job are unlimited. Just remember you have other responsibilities this year, which should not be neglected. We hope to be able to help.



Slug
Physics
Mechanics
Nonlinear Dynamics
COSMOLOGY
Electronics
Optics
Thermodynamics
Solid State Physics
String Theory
Quantum
Mechanics