CALTECH

CATALOG

1986/87

CALTECH CATALOG
1986–87

California Institute of Technology
Pasadena, California 91125
(818) 356-6811

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September 23	Registration of entering freshmen—1:00 p.m.–4:30 p.m.
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California Institute of Technology

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GENERAL INFORMATION

1

INTRODUCTION

The California Institute of Technology, an independent, privately supported institution, officially classed as a university, is accredited by the Accrediting Commission for Senior Colleges and Universities of the Western Association of Schools and Colleges. Caltech conducts instruction on both undergraduate and graduate levels, and, including its off-campus facilities, it is also one of the world's major research centers. "Caltech has achieved international influence far disproportionate to its size," according to *Time* magazine.

The Institute is organized into six divisions: Biology; Chemistry and Chemical Engineering; Engineering and Applied Science; Geological and Planetary Sciences; The Humanities and Social Sciences; and Physics, Mathematics and Astronomy.

The primary purpose of the undergraduate school of the California Institute of Technology, as stated by the original trustees, is "to train the creative type of scientist or engineer so urgently needed in our educational, governmental, and industrial development." It is believed that this purpose is attained at the Institute for both undergraduate and graduate students because of the contacts between a relatively small group of students (approximately 820 undergraduate and 1,000 graduate students) with the members of a relatively large research staff (approximately 800 faculty members).

President Goldberger says, "Our small size enables us to form a community of scientists, a scholarly intimacy that cannot be found anyplace else." Advancement in understanding is best acquired by intimate association with creative workers who are, through research and reflection, extending the boundaries of knowledge.

Undergraduate Program

Caltech offers a four-year undergraduate course with options available in applied mathematics, applied physics, astronomy, biology, chemical engineering, chemistry, economics, electrical engineering, engineering and applied science, geochemistry, geology, geophysics, history, independent studies program, literature, mathematics, physics, planetary science, and social science. Each leads to the degree of Bachelor of Science.

All options require students to take courses in chemistry, humanities, mathematics, physics, and the social sciences. Course work is rigorous and students are encouraged to participate in research. The undergraduate program is thus designed to provide an intensive exposure to a wide spectrum of intellectual pursuits.

Near the end of the first year, students select an option, and during the second year they begin to specialize. However, the major concentration in chosen fields and professional subjects occurs during the third and fourth years.

Caltech also encourages a reasonable participation in extracurricular activities, largely managed by the students themselves. Three terms of physical education are required, and intercollegiate and intramural sports are encouraged.

In short, every effort is made to provide undergraduate students with well-rounded, integrated programs that will not only give them sound training in their professional fields, but that will also develop character, intellectual breadth, and physical well-being.

Graduate Program

In the graduate school Caltech offers courses leading to the degree of Master of Science, which normally involves one year of graduate work; the Engineer's degree in certain branches of engineering, with a minimum of two years; and the degree of Doctor of Philosophy. In all the graduate work, research is strongly emphasized, not only because of its importance in contributing to the advancement of science and thus to the intellectual and material welfare of mankind, but also because research activities add vitality to the educational work of Caltech.

The graduate options are: aeronautics, applied mathematics, applied mechanics, applied physics, astronomy, biology, chemical engineering, chemistry, civil engineering, computation and neural systems, computer science, electrical engineering, engineering science, environmental engineering science, geological and planetary sciences, materials science, mathematics, mechanical engineering, physics, and social science.

Graduate students constitute a comparatively large proportion (slightly over 50 percent) of the total student body. Engaged as they are in research problems of varying degrees of complexity, and taught by faculty members who are also actively engaged in research, they contribute materially to the general atmosphere of intellectual curiosity and creative activity that is generated on the Institute campus.

Standards

In order to utilize Caltech's resources most effectively, two general lines of procedure are followed. First, the Institute restricts the number of fields it offers for undergraduate and graduate study, believing that it is better to provide thoroughly for a limited number of curricula than to risk diffusion of personnel, facilities, and funds in attempting to cover a wide variety of fields. Second, and in line with this policy of conservation of resources, the student body is strictly limited to that number which can be satisfactorily provided for. Admission is granted after a careful study of the merits of each applicant, including the results of entrance examinations, school records, and interviews by members of the Caltech staff. These procedures result, it is believed, in a body of students of exceptional ability. A high standard of scholarship is also maintained, as is appropriate for students of such competence.

HISTORICAL SKETCH

The California Institute of Technology, as it has been called since 1920, developed from a local school of arts and crafts, founded in Pasadena in 1891 by the Honorable Amos G. Throop and named Throop University, later renamed Throop Polytechnic Institute. It enjoyed the local support of the citizens of Pasadena, and by 1908 the Board of Trustees had as members Dr. Norman Bridge, Arthur H. Fleming, Henry M. Robinson, J. A. Culbertson, C. W. Gates, and Dr. George Ellery Hale. It was the dedication, by these men, of their time, their minds, and their fortunes that transformed a modest vocational school into a university capable of attracting to its faculty some of the most eminent of the world's scholars and scientists.

George Ellery Hale, astronomer and first director of the Mount Wilson Observatory, foresaw the development in Pasadena of a distinguished institution of engineering and scientific research. Hale well knew that a prime necessity was modern well-equipped laboratories, but he stressed to his fellow trustees that the aim was not machines, but men. "We must not forget," he wrote in 1907, "that the greatest engineer is not the man who is trained merely to understand machines and apply formulas, but is the man who, while knowing these things, has not failed to develop his breadth of view and the highest qualities of his imagination. No creative work, whether in engineering or in art, in literature or in science, has been the work of a man devoid of the imaginative faculty."

The realization of these aims meant specializing, so the trustees decided in 1907 to separate the elementary department, the normal school, and the academy, leaving only a college of technology that conferred Bachelor of Science degrees in electrical, mechanical, and civil engineering.

In 1910 Throop Polytechnic Institute moved from its crowded quarters in the center of Pasadena to a new campus of 22 acres on the southeastern edge of town, the gift of Arthur H. Fleming and his daughter Marjorie. The president, Dr. James A. B. Scherer, and his faculty of 16 members, opened the doors to 31 students that September. When, on March 21, 1911, Theodore Roosevelt delivered an address at Throop Institute, he declared, "I want to see institutions like Throop turn out perhaps ninety-nine of every hundred students as men who are to do given pieces of industrial work better than any one else can do them; I want to see those men do the kind of work that is now being done on the Panama Canal and on the great irrigation projects in the interior of this country—and the one-hundredth man I want to see with cultural scientific training."

It would have surprised Roosevelt to know that within a decade the little Institute, known from 1913 as Throop College of Technology, would have again raised its sights, leaving to others the training of more efficient technicians and concentrating its own efforts on Roosevelt's "hundredth man." On November 29, 1921, the trustees declared it to be the express policy of the Institute to pursue scientific researches of the greatest importance and at the same time "to continue to conduct thorough courses in engineering and pure science, basing the work of these courses on exceptionally strong instruction in the fundamental sciences of mathematics, physics, and chemistry; broadening and enriching the curriculum by a liberal amount of instruction in such subjects as English, history, and economics; and vitalizing all the work of the Institute by the infusion in generous measure of the spirit of research."

Three men were responsible for the change in the Institute. George Ellery Hale still held to his dream. Arthur Amos Noyes, professor of physical chemistry and former acting president of the Massachusetts Institute of Technology, served part of each year as professor of general chemistry and research associate from 1913 to 1919, when he resigned from MIT to devote full time to Throop as director of chemical research. In a similar way Robert Andrews Millikan began, in 1916–17, to spend a few months a year at Throop as director of physical research. In 1921, when Dr. Norman Bridge agreed to provide a research laboratory in physics, Dr. Millikan resigned from The University of Chicago and became administrative head of the Institute as well as director of the Norman Bridge Laboratory.

The great period of the Institute's life began, then, under the guidance of three men of vision—Hale, Noyes, and Millikan. They were distinguished research scientists, and they soon attracted graduate students. In 1920 the enrollment was 9 graduate students and 359 undergraduates under a faculty of 60; a decade later there were 138 graduate students, 510 undergraduates, and a faculty of 180. At the present time there are about 830 undergraduates, 1,000 graduate students, and 780 faculty (including postdoctoral fellows).

The Institute also attracted financial support from individuals, corporations, and foundations. In January 1920 the endowment had reached half a million dollars. In February of that year it was announced that $200,000 had been secured for research in chemistry and a like amount for research in physics. Other gifts followed from trustees and friends who could now feel pride in the Institute as well as hope for its future. The Southern California Edison Company provided a high-voltage laboratory, with the million-volt Sorensen transformer. Philanthropic foundations bearing the names of Carnegie, Rockefeller, and Guggenheim came forth with needed help when new departments or projects were organized.

In 1923 Millikan received the Nobel Prize in Physics. He had attracted to the Institute such men as Charles Galton Darwin, Paul Epstein, and Richard C. Tolman. In 1924 the Ph.D. degree was awarded to nine candidates.

It was inevitable that the Institute would enlarge its fields; it could not continue to be merely a research and instructional center in physics, chemistry, and engineering. But the trustees pursued a cautious and conservative policy, not undertaking to add new departments except when the work done in them would be at the same high level as that in physics and chemistry. In 1925 a gift of $25,000 from the Carnegie Corporation of New York made possible the opening of a department of instruction and research in geology. A seismological laboratory was constructed, and Professors John P. Buwalda and Chester Stock came from the University of California to lead the work in the new division.

This same year William Bennett Munro, chairman of the Division of History, Government, and Economics at Harvard, joined the Institute faculty. Offerings in economics, history, and literature were added to the core of undergraduate instruction.

In 1928 Caltech began its program of research and instruction in biology. Thomas Hunt Morgan became the first chairman of the new Division of Biology and a member of Caltech's Executive Council. Under Morgan's direction the work in biology developed rapidly, especially in genetics and biochemistry. Morgan received the Nobel Prize in 1933.

The Guggenheim Graduate School of Aeronautics was founded at Caltech in the summer of 1926 and a laboratory was built in 1929, but courses in theoretical aerodynamics had been given at the Institute for many years by Professors Harry Bateman and P. S. Epstein. As early as 1917 Throop Institute had constructed a wind tunnel in which, the catalog proudly boasted, constant velocities of 4 to 40 miles an hour could be maintained, "the controls being very sensitive." The new program, under the leadership of Theodore von Kármán, included graduate study and research at the level of the other scientific work at the Institute, and GALCIT (Graduate Aeronautical Laboratories at the California Institute of Technology) was soon a world-famous research center in aeronautics.

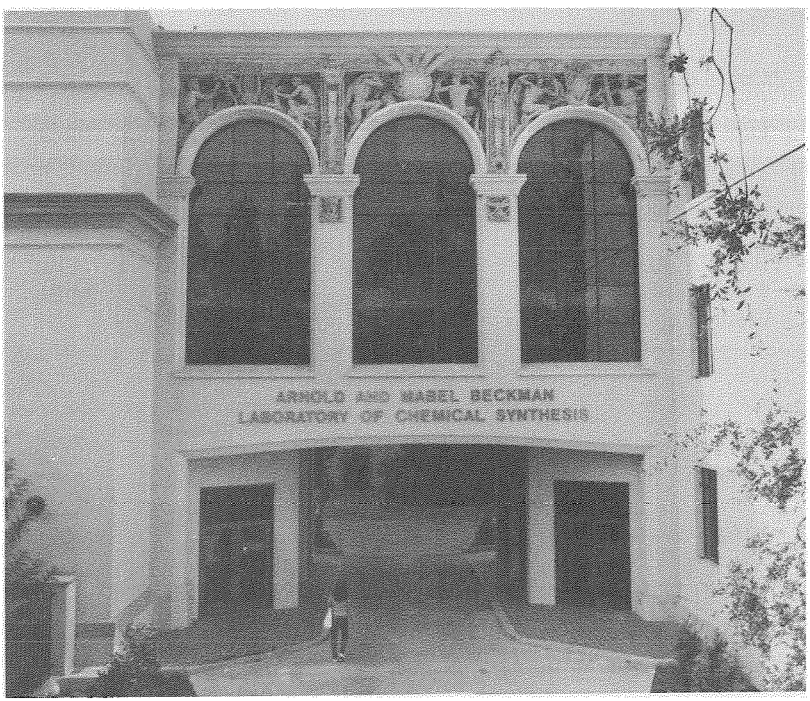
In 1928 George Ellery Hale and his associates at the Mount Wilson Observatory developed a proposal for a 200-inch telescope and attracted the interest of the General Education Board in providing $6,000,000 for its construction. The Board proposed that the gift be made to the California Institute of Technology, and Caltech agreed to be responsible for the construction and operation. The huge instrument was erected on Palomar Mountain. Teaching and research in astronomy and astrophysics thus became a part of the Caltech program.

From the summer of 1940 until 1945, Caltech devoted an increasingly large part of its personnel and facilities to the furthering of the national defense and war effort. Caltech's work during this period fell mainly into two categories: special instructional programs and weapons research. The research and development work was carried on, for the most part, under non-profit contracts with the Office of Scientific Research and Development. Rockets, jet propulsion, and antisubmarine warfare were the chief fields of endeavor. The Jet Propulsion Laboratory in the upper Arroyo Seco continues under Institute management to carry on a large-scale program of research for the National Aeronautics and Space Administration in the science and technology of unmanned space exploration. The Laboratory launched the first U.S. satellite, Explorer I, in 1958, and held major responsibilities for the Ranger, Surveyor, Mariner, Viking, and Voyager programs of lunar and planetary exploration for NASA, with the Galileo program now under way. The Infrared Astronomical Satellite (IRAS) has recently provided a wealth of data on the infrared sky. The Laboratory also operates the NASA worldwide deep-space tracking network and conducts a program of supporting research in space science and engineering.

In the 1950s, in response to the growing technological component of societal problems, the Institute began to expand the fields in which it had substantial expertise. In the late 1960s and early 1970s several economists and political scientists were added to the Institute faculty who initiated theoretical and applied studies of issues at the interface of their disciplines. A graduate program in social sciences was added in 1972. Caltech students could now engage their talents in the development of the basic scientific aspects of economics and political science, and begin to use the principles from these sciences together with those from the physical sciences to formulate and address public policies.

In 1945 Robert A. Millikan retired as chairman of the Executive Council but served as vice chairman of the Board of Trustees until his death in 1953. Dr. Lee A. DuBridge became president of Caltech on September 1, 1946. Formerly chairman of the physics department and dean of the faculty at the University of Rochester, he came to the Institute after five years as wartime director of the MIT Radiation Laboratory—and remained 22 years.

DuBridge was also committed to the concept of a small, select institution offering excellence in education. Facts and figures are only part of the story, but the statistical record of change during the DuBridge administration indicates how he held to that concept. The 30-acre campus of 1946 grew to 80 acres; the $17 million endowment grew to more than $100 million; the faculty of 260 became 550; the number of campus buildings increased from 20 to 64; and the budget went from something less than $8 million to $30 million. But enrollment remained relatively constant. In 1946 the total number of students, graduate and undergraduate, was 1,391. In 1968, the year DuBridge left, it was 1,492.



The arches created by Alexander Stirling Calder in 1910 for the facade of Caltech's first building, Throop Hall, were recently incorporated into the new Arnold and Mabel Beckman Laboratory of Chemical Synthesis.

Dr. Harold Brown came to Caltech as president in 1969. A physicist who received his Ph.D. from Columbia in 1949, he succeeded Dr. Edward Teller as director of the University of California's Lawrence Radiation Laboratory in Livermore in 1960. President Lyndon Johnson named Brown Secretary of the Air Force in 1965, and he came to the Institute from that office. Six new campus buildings were dedicated under Brown's administration, and a major development campaign for $130 million was under way when he resigned to become Secretary of Defense under President Carter in 1977.

Dr. Marvin L. Goldberger was appointed president by the Board of Trustees in March 1978. He received his B.S. at Carnegie Institute of Technology (now Carnegie-Mellon University) and his Ph.D. at The University of Chicago. He came to Caltech from Princeton University, where he was the Joseph Henry Professor of Physics.

As Caltech has developed in effectiveness and in prestige, it has attracted a steady flow of gifts for buildings, for endowment, and for current operations. The gifts invested in plant now total $223,000,000 and those invested in endowment about $275,000,000. Very substantial grants and contracts from the federal government support many research activities.

Today Caltech has about 15,000 alumni scattered all over the world, many eminent in their fields of engineering and science.

Caltech Nobel Laureates

Robert A. Millikan	physics	1923
Thomas Hunt Morgan	physiology or medicine	1933
*Carl D. Anderson, B.S. '27, Ph.D. '30	physics	1936
Edwin M. McMillan, B.S. '28, M.S. '29	chemistry	1951
Linus Pauling, Ph.D. '25	chemistry	1954
	Peace Prize	1962
William Shockley, B.S. '32	physics	1956
George W. Beadle	physiology or medicine	1958
Donald A. Glaser, Ph.D. '50	physics	1960
Rudolf Mössbauer	physics	1961
Charles H. Townes, Ph.D. '39	physics	1964
*Richard Feynman	physics	1965
*Murray Gell-Mann	physics	1969
Max Delbrück	physiology or medicine	1969
Leo James Rainwater, B.S. '39	physics	1975
Howard M. Temin, Ph.D. '60	physiology or medicine	1975
William Lipscomb, Ph.D. '46	chemistry	1976
Robert W. Wilson, Ph.D. '62	physics	1978
*Roger W. Sperry	physiology or medicine	1981
Kenneth G. Wilson, Ph.D. '61	physics	1982
*William A. Fowler, Ph.D. '36	physics	1983

*In residence

BUILDINGS AND FACILITIES

Gates and Crellin Laboratories of Chemistry: first unit, 1917; second unit, 1927; third unit, 1937. The first two units were the gifts of Messrs. C. W. Gates and P. G. Gates of Pasadena; the third unit was the gift of Mr. and Mrs. E. W. Crellin of Pasadena. Gates (first unit), which was retired after suffering extensive damage in the February 9, 1971, earthquake, was rebuilt in 1983 as the Parsons-Gates Hall of Administration. **The Arnold and Mabel Beckman Laboratory of Chemical Synthesis**, 1986, occupying portions of Crellin Laboratory (as well as portions of Church Laboratory for Chemical Biology) was built with funds provided by the Arnold and Mabel Beckman Foundation.

Norman Bridge Laboratory of Physics: first unit, 1922; second unit, 1924; third unit, 1925. The gift of Dr. Norman Bridge of Los Angeles, president of the Board of Trustees, 1896–1917.

High Voltage Research Laboratory, 1923. Built with funds provided by the Southern California Edison Company. Retired in 1959 with basic research completed and rebuilt in 1960 as the Alfred P. Sloan Laboratory of Mathematics and Physics.

Dabney Hall, 1928. The gift of Mr. and Mrs. Joseph B. Dabney of Los Angeles.

William G. Kerckhoff Laboratories of the Biological Sciences: first unit, 1928; second unit, 1939; annex, 1948. The gift of Mr. and Mrs. William G. Kerckhoff of Los Angeles.

Guggenheim Aeronautical Laboratory, 1929. Built with funds provided by the Daniel Guggenheim Fund for the Promotion of Aeronautics. A substantial addition was built in 1947.

Athenaeum, 1930. A clubhouse for the teaching, research, and administrative staffs of the Institute and the Huntington Library and Art Gallery, for The Associates of the California Institute of Technology, and for others who have demonstrated their interest in advancing the objectives of the Institute. The gift of Mr. and Mrs. Allan C. Balch of Los Angeles. He was president of the Board of Trustees, 1933–1943.

Undergraduate Houses, 1931:

Blacker House. The gift of Mr. and Mrs. R. R. Blacker of Pasadena.

Dabney House. The gift of Mr. and Mrs. Joseph B. Dabney of Los Angeles.

Fleming House. Built with funds provided by some 20 donors and named in honor of Mr. Arthur H. Fleming of Pasadena, president of the Board of Trustees, 1917–1933.

Ricketts House. The gift of Dr. and Mrs. Louis D. Ricketts of Pasadena.

W. K. Kellogg Radiation Laboratory (Nuclear Physics), 1932. The gift of Mr. W. K. Kellogg of Battle Creek, Michigan.

Henry M. Robinson Laboratory of Astrophysics, 1932. Built with funds provided by the International Education Board and the General Education Board, and named in honor of Mr. Henry M. Robinson of Pasadena, member of the Board of Trustees, 1907–1937, and of the Executive Council of the Institute.

Charles Arms Laboratory of the Geological Sciences, 1938. The gift of Mr. and Mrs. Henry M. Robinson of Pasadena, in memory of Mrs. Robinson's father, Mr. Charles Arms.

Seeley W. Mudd Laboratory of the Geological Sciences, 1938. The gift of Mrs. Seeley W. Mudd of Los Angeles, in memory of her husband.

Franklin Thomas Laboratory of Engineering: first unit, 1945; second unit, 1950. Funds for the first unit were allocated from the Eudora Hull Spalding Trust with the approval of Mr. Keith Spalding, trustee. Named in honor of Dean Franklin Thomas, professor of civil engineering and first chairman of the Division of Engineering, 1924–1945.

Alumni Swimming Pool, 1954. Provided by the Alumni Fund through contributions of the alumni of the Institute.

Scott Brown Gymnasium, 1954. Built with funds provided by the trust established by Mr. Scott Brown of Pasadena and Chicago, who was a member and director of The Caltech Associates.

Norman W. Church Laboratory for Chemical Biology, 1955. Built with funds provided through a gift and bequest by Mr. Norman W. Church of Los Angeles, who was a member of The Caltech Associates.

Eudora Hull Spalding Laboratory of Engineering, 1957. Built with funds allocated from the Eudora Hull Spalding Trust.

Archibald Young Health Center, 1957. The gift of Mrs. Archibald Young of Pasadena, in memory of her husband, who was a member and director of The Caltech Associates.

Physical Plant Building and Shops, 1959. Built with funds provided by many donors.

Gordon A. Alles Laboratory for Molecular Biology, 1960. Erected with the gift of Dr. Gordon A. Alles of Pasadena, research associate in biology at the Institute, an alumnus, and a member of The Caltech Associates, 1947–1963; and with funds provided by the Health Research Facilities Branch of the National Institutes of Health.

Undergraduate Houses, 1960. Built with funds provided by the Lloyd Foundation and other donors.

Lloyd House. Named in memory of Mr. Ralph B. Lloyd and his wife Mrs. Lulu Hull Lloyd of Beverly Hills. He was a member of the Board of Trustees, 1939–1952.

Page House. Named in honor of Mr. James R. Page of Los Angeles, a member of the Board of Trustees, 1931–1962, and chairman, 1943–1954.

Ruddock House. Named in honor of Mr. Albert B. Ruddock of Santa Barbara, a member of the Board of Trustees, 1938–1971, and chairman, 1954–1961.

Harry Chandler Dining Hall, 1960. The gift of the Chandler family, the Pfaffinger Foundation, and the Times Mirror Company of Los Angeles.

W. M. Keck Engineering Laboratories, 1960. The gift of the W. M. Keck Foundation and the Superior Oil Company of Los Angeles.

Alfred P. Sloan Laboratory of Mathematics and Physics, 1960. Formerly High Voltage Research Laboratory, 1923. Rebuilt in 1960 with funds provided by the Alfred P. Sloan Foundation.

Graduate Houses, 1961:

Braun House. Built with funds provided by the trustees of the Carl F Braun Trust Estate in his memory.

Keck House. The gift of Mr. William M. Keck, Jr., of Los Angeles.

Marks House. The gift of Dr. David X. Marks of Los Angeles.

Mosher-Jorgensen House. The gift of Mr. Samuel B. Mosher of Los Angeles and Mr. Earle M. Jorgensen of Los Angeles. Mr. Jorgensen is a member of the Board of Trustees.

Karman Laboratory of Fluid Mechanics and Jet Propulsion, 1961. The gift of the Aerojet-General Corporation, named in honor of Dr. Theodore von Kármán, professor of aeronautics at the Institute, 1929–1949.

Firestone Flight Sciences Laboratory, 1962. The gift of the Firestone Tire and Rubber Company.

Winnett Student Center, 1962. The gift of Mr. P. G. Winnett of Los Angeles, a member of the Board of Trustees, 1939–1968. Winnett houses the bookstore, Caltech Y, *California Tech,* and offices of theater arts and ASCIT.

Willis H. Booth Computing Center, 1963. Built with funds given by the Booth-Ferris Foundation of New York and the National Science Foundation. Named in memory of Mr. Willis H. Booth, a member of The Caltech Associates.

Beckman Auditorium, 1964. The gift of Dr. and Mrs. Arnold O. Beckman of Corona del Mar. Dr. Beckman, an alumnus, was a member of the Institute's faculty from 1928 to 1939, a member of the Board of Trustees since 1953, chairman of the Board from 1964 to 1974, and is now chairman emeritus.

Harry G. Steele Laboratory of Electrical Sciences, 1965. Built with funds provided by the Harry G. Steele Foundation and the National Science Foundation.

Central Engineering Services Building, 1966.

Robert A. Millikan Memorial Library, 1967. Built with a gift from Dr. Seeley G. Mudd and named in honor of Dr. Robert Andrews Millikan, director of the Bridge Laboratory of Physics and chairman of the Executive Council of the Institute, 1921–1945.

Arthur A. Noyes Laboratory of Chemical Physics, 1967. Built with funds provided by the National Science Foundation and Mr. Chester F. Carlson, an alumnus, and named in honor of Arthur Amos Noyes, director of the Gates and Crellin Laboratories of Chemistry and chairman of the Division of Chemistry and Chemical Engineering, 1919–1936.

Central Plant, 1967.

George W. Downs Laboratory of Physics and Charles C. Lauritsen Laboratory of High Energy Physics, 1969. The Downs wing was built with funds provided by Mr. George W. Downs and the National Science Foundation. The Lauritsen wing was built with Atomic Energy Commission funds and named in honor of Dr. Charles C. Lauritsen, a member of the Institute faculty, 1930–1968.

Keith Spalding Building of Business Services, 1969. Named in honor of Keith Spalding, Caltech trustee, 1942–1961.

Donald E. Baxter, M.D., Hall of the Humanities and Social Sciences, 1971. Built with funds provided by Mrs. Delia B. Baxter of Atherton and named in honor of her late husband, Donald E. Baxter, M.D. Additional funds were given by the U.S. Department of Health, Education and Welfare. Dr. and Mrs. Simon Ramo provided funds for the completion of **Ramo Auditorium**. Dr. Ramo is a member of the Board of Trustees.

The Earle M. Jorgensen Laboratory of Information Science, 1971. Built with the gift of Mr. and Mrs. Earle M. Jorgensen, with additional funds provided by the Booth-Ferris Foundation and other private donors. Mr. Jorgensen is a member of the Board of Trustees.

The Mabel and Arnold Beckman Laboratories of Behavioral Biology, 1974. The gift of Dr. and Mrs. Arnold O. Beckman of Corona del Mar. Dr. Beckman is chairman emeritus of the Board of Trustees.

Seeley G. Mudd Building of Geophysics and Planetary Science, 1974. Built with funds provided by Dr. Seeley G. Mudd, Mrs. Roland Lindhurst, Mr. and Mrs. Ross McCollum, Mr. and Mrs. Henry Salvatori, and the U.S. Department of Health, Education and Welfare.

Clifford S. and Ruth A. Mead Memorial Undergraduate Chemistry Laboratory, 1981. Built with funds allocated from the Clifford S. and Ruth A. Mead Memorial Building Fund.

Thomas J. Watson, Sr., Laboratories of Applied Physics, 1982. Built with funds provided by the Watson family and other private donors. Thomas J. Watson, Jr., is a member of the Board of Trustees.

Braun Laboratories in Memory of Carl F and Winifred H Braun, 1982. Built with funds provided by the Braun family, other private donors, and the National Cancer Institute. John G Braun is a member of the Board of Trustees.

Parsons-Gates Hall of Administration, 1983. Formerly Gates Laboratory of Chemistry, 1917. Rebuilt in 1983 with funds provided by The Ralph M. Parsons Foundation and The James Irvine Foundation.

Athletic Facility, 1984. Built with funds provided by the Carl F Braun Trust and the Braun Foundation.

Catalina Graduate Apartment Complex, 1984, 1986.

Infrared Processing and Analysis Center. 1986.

Off-Campus Facilities

Kresge Building, Seismological Laboratory, 1928 (of the Division of Geological and Planetary Sciences), 220 North San Rafael Avenue, Pasadena. Named in recognition of a gift from The Kresge Foundation of Troy, Michigan.

William G. Kerckhoff Marine Biological Laboratory, 1930, Corona del Mar. Rehabilitated with funds provided by the National Science Foundation in 1966.

Jet Propulsion Laboratory, 1944, 4800 Oak Grove Drive, Pasadena. Administered by the Institute; owned and supported by the National Aeronautics and Space Administration.

Palomar Observatory, 1948, San Diego County. Site of the 200-inch Hale Telescope, built by the Institute with funds from Rockefeller sources.

Owens Valley Radio Observatory, 1958, Big Pine. Built with funds provided by the Winnett Foundation, the Office of Naval Research, the National Science Foundation, and the Oscar G. and Elsa S. Mayer Charitable Trust.

Big Bear Solar Observatory, 1969, Big Bear Lake. Built with funds provided by the National Science Foundation and the Max C. Fleischmann Foundation of Nevada.

Submillimeter Observatory, Mauna Kea, Hawaii. Built with funds provided by the National Science Foundation and the Kresge Foundation. Under construction.

Keck Observatory, Mauna Kea, Hawaii. Built with funds provided by the W. M. Keck Foundation. Under construction.

Libraries

The Caltech library system is organized into 16 departmental or divisional libraries; six are in the Millikan Library and ten are distributed throughout the campus. The libraries collectively subscribe to 6,450 journals, contain 396,021 volumes, and have extensive collections of microfilm, government documents, archives, and maps.

The Robert A. Millikan Memorial Library includes the collections of biology, chemistry, mathematics, physics, engineering, and humanities and social sciences, each of which is organized as an individual unit complete with books, periodicals, reference works, and card catalog. The main card catalog, which includes the records of the books held in the major collections on campus, is located on the second floor of Millikan. The circulation and reserve operations are on the first floor, photocopy service and the Institute archives are in the basement, and the microfilm and government documents collections are on the fifth floor. The Millikan Library is open weekdays during the school year from 8 a.m. to 1 a.m., and weekends from 9 a.m. until midnight.

The library collections that are located elsewhere on campus include aeronautics, applied physics and electrical engineering, astrophysics, chemical engineering, computer science, earthquake engineering, environmental engineering, geology, management, and public affairs. Special services that are available through the Caltech libraries include computerized literature searches, document delivery, interlibrary loans, and intercampus transportation between the Caltech, UCLA, and USC libraries.

Campus Computing Organization

The Campus Computing Organization (CCO) was created in 1986 to address the dynamic and complex computing support needs of the distributed computing environment at the Institute. The CCO provides comprehensive support for the hundreds of personal computers in use on the campus. This includes system selection assistance, procurement, installation, maintenance, repair, and consulting.

The CCO provides resources to support educational computing. These include obtaining appropriate hardware and software, maintaining an IBM 4381, three DEC VAX11/750s, and a large number of personal computers for student use, and assisting in the development of effective use of computers in the educational processes.

The CCO manages and maintains CITNET, Caltech's campus-wide local area network. This activity includes the support of connections to off-campus national and international networks, the development of shared network resources, and the maintenance of a campus electronic mail system and common data bases.

The CCO supports super-computing by maintaining a local node with a high-speed link to a CRAY computer located in San Diego.

The CCO operates a Campus Computing Information Center for the Institute. This Center provides manufacturers' documentation, a software library, a monthly *Campus Computing Newsletter*, an on-line software repository, an on-line information system, an on-line document server, and access to various international teleconferences.

Industrial Relations Center

The purpose of the Industrial Relations Center is to increase and disseminate knowledge and understanding of the current practices, future trends, and critical issues in executive leadership and management in an era of rapid technological change. The seminar program emphasizes practical management skills and assists professionals, particularly technical professionals, in making career transitions to managerial ranks. The executive program consists of residential programs, briefings, and meetings that focus on the management of technology and innovation, entrepreneurship, and executive leadership. The courses are presented on campus for representatives of a variety of companies or off campus at specific companies. Courses do not carry academic credit but are open to Caltech students.

The office, library, and conference rooms of the Center are located on campus at 383 South Hill Avenue. Detailed information about the specific services of the Center can be secured from the Industrial Relations Center.

POSTDOCTORAL APPOINTMENTS

Caltech appoints each year a number of postdoctoral research fellows for definite terms, usually for one year. The postdoctoral program consists, generally, of fundamental research in one of the Caltech laboratories in close association with one or more regular faculty members. Caltech is subject to the requirements of Executive Order 11246 and is an affirmative action employer. All interested persons are encouraged to apply.

SHERMAN FAIRCHILD DISTINGUISHED SCHOLARS PROGRAM

The Sherman Fairchild Distinguished Scholars Program brings renowned scholars to Caltech from industry, government, and the academic community. Through this program, Caltech's faculty and student body have an opportunity to be influenced in both teaching and research by the wisdom and experience of eminent world leaders in various fields. The emphasis in the program is on giving faculty and students exposure to Fairchild Scholars in all academic divisions—through teaching, seminars, lectures, and research—and establishing a forum for the exchange of ideas among Fairchild Scholars, Caltech faculty, students, and industry. Appointments are usually from three months to one year.

UNDERGRADUATE RESEARCH

Each division offers the opportunity for qualified students early in their careers to engage in research under the supervision of a faculty member. Most options offer undergraduate research courses in order to encourage participation, and students should consult their listings and descriptions of opportunities. Students are encouraged to undertake research of such scope and caliber as to merit the preparation of a senior thesis. The requirements for such thesis research vary from option to option, and the individual option representatives should be consulted.

The Summer Undergraduate Research Fellowships (SURF) program provides continuing undergraduate students the opportunity to work on an individual research project in a tutorial relationship with a sponsor, a member of the Caltech/JPL research community. Beginning in January, students, in collaboration with their sponsors, develop research proposals that are then judged by members of the SURF administrative committee. The proposals are due early in March; awards are made in mid-April to the student authors of meritorious proposals. SURF students commit themselves to work on their projects on a full-time basis for ten weeks during the summer and finally to prepare a brief written report describing the project, the methods, and the results of their work. Early in October, students make oral presentations of their projects at SURF Seminar Day. About 20 percent of the students publish their work in the open scientific literature. In 1986, SURF students were paid $3,000. For further information regarding this program, call the SURF office, room 3 Dabney, (818) 356-3675.

STUDENT LIFE

Undergraduate Student Houses. The seven undergraduate student houses are situated on both sides of the Olive Walk near the eastern end of the campus. The original four—Blacker, Dabney, Fleming, and Ricketts—were built in 1931 from the plans of Mr. Gordon B. Kaufmann in the Mediterranean style to harmonize with the adjacent Athenaeum. The other three, designed by Smith, Powell and Morgridge, were completed in 1960, and are named Lloyd, Page, and Ruddock. Each of the seven is a separate unit with its own dining room and lounge, providing accommodations for about 75 students.

Each house has its own elected officers, and has wide power to arrange its own social events and preserve its own traditions. The immediate supervision of the activities of each house is the responsibility of the house Resident Associate, generally a married graduate student or younger faculty member. All houses are under the general supervision and control of a member of the faculty known as the Master of Student Houses.

In addition to the student houses, the Institute maintains two apartment buildings and 24 off-campus houses. Typically two or three students share an apartment. Depending upon size, the off-campus houses have a capacity for four to ten students. These residences are all within a short walking distance of the campus and offer students greater privacy, a different life style, and the opportunity to express their culinary creativity.

Mail is delivered daily to the student houses except on weekends. Students living in student houses should use their house name and mail code, California Institute of Technology, Pasadena, CA 91126, to facilitate the handling of their mail at the campus post office.

Interhouse Activities. The president of each undergraduate house represents that house on the Interhouse Committee (IHC). While the seven houses are generally autonomous, the IHC exists to ensure that conflicts between houses do not develop and to deal with matters that affect the houses in general. In particular, the IHC is responsible for the freshman selection process by which the houses choose their members.

In conjunction with the athletic department, the IHC conducts two intramural sports programs: the Interhouse and Discobolus trophy competitions. These are described below under *Athletics*.

Other interhouse activities include parties, usually involving two or three houses, which are held once or twice each term.

Faculty-Student Relations. Faculty-student coordination and cooperation with regard to campus affairs is secured through the presence of students on faculty committees, by faculty-student conferences, and by other less formal mechanisms, such as course ombudsmen.

Freshman Advisers. Each member of the freshman class is assigned a faculty adviser. The adviser takes an interest in the freshman's progress and provides advice on any questions or problems that the freshman may have.

Option Advisers. Each member of the three undergraduate upper classes is assigned an option adviser, a faculty member in the option in which the student is enrolled. The adviser takes an interest in the student's selection of courses, progress toward a degree, and, eventually, in assisting the student toward satisfactory placement in industry, or in graduate school. Normally, the association between student and adviser, which is primarily professional, is established before the beginning of the sophomore year and continues through graduation.

Athletics. Caltech supports a well-rounded program of competitive athletics. As a member of the Southern California Inter-Collegiate Athletic Conference, intercollegiate competition is carried on in 12 sports with such schools as Claremont-Harvey Mudd, La Verne, Occidental, Pomona-Pitzer, Redlands, and Whittier. Athletes who distinguish themselves locally are able to compete at regional and national levels.

The athletic facilities include a football field, a standard running track, a soccer field, baseball and softball diamonds, and eight tennis courts. The Scott Brown Gymnasium provides facilities for badminton, basketball, and volleyball, and is adjoined by two modern swimming pools. A well-equipped weight room completes the on-campus athletic facilities. In addition, Caltech owns six Flying Junior sailboats that serve both instructional and competitive interests.

The Institute sponsors a vigorous program of intramural competition in seven sports. The Interhouse Trophy is awarded annually to the house accumulating the most points in this competition. The Varsity Rating Trophy is awarded to the house having the greatest participation in intercollegiate sports. A third trophy, Discobolus, is a bronze replica of Myron's famous statue of the discus thrower. A challenge trophy, awarded for competition in any sport, it remains in the possession of a house only so long as that house can defeat the challengers.

The M. T. Davis Trophy is awarded each year to a student who has demonstrated outstanding achievement and leadership in track and field. This award was established in 1984 by alumnus Frank Davis in memory of his brother, a decathlon athlete during his Caltech career.

ASCIT. The undergraduate student body forms the membership of a corporation known as the Associated Students of the California Institute of Technology, Inc., or ASCIT. Governed by a board of directors consisting of nine elected officers, ASCIT is involved in many aspects of student life. It operates the coffeehouse, a casual nighttime spot near campus offering refreshment and diversion. ASCIT subsidizes the Friday night ASCIT movies, a weekly presentation of late vintage popular films, and partially subsidizes Cinematech, a Saturday night series of film classics. ASCIT also oversees publication of the newspaper, a directory, the yearbook, a research opportunities handbook, a course review, and a literary magazine.

Besides overseeing the many student publications and coordinating activities and policies, the ASCIT Board of Directors administers the corporation's finances. ASCIT sponsors a wide variety of special interest clubs and programs, such as the Student Space Organization, the student shop, and the Caltech Alpine Club.

The student government is active in campus affairs. The student members of each standing faculty committee ensure that undergraduate opinion is considered seriously. Excellent informal relations between students and faculty and between students and administration promote mutual concern and goodwill. Student-faculty conferences are held in alternate years, most recently in 1986. These serve a very useful purpose in promoting cooperation and communication between these groups.

Caltech is fortunate in that the faculty, staff, administration, and Board of Trustees take a genuine interest in students' welfare.

Graduate Student Council. The Graduate Student Council performs essentially the same functions for the graduate students that the Board of Directors of ASCIT does for the undergraduates.

Honor System. The Honor System, embodied in the phrase "No member shall take unfair advantage of any member of the Caltech community," is the fundamental principle of conduct for all students. More than merely a code applying to conduct in examinations, it extends to all phases of campus life. It is the code of behavior governing all scholastic and many extracurricular activities, relations among students, and relations between students and faculty. The Honor System is the outstanding tradition of the student body, which accepts full responsibility for its operation. The ASCIT Board of Control, which is composed of elected representatives from each of the seven houses, is charged with interpreting the Honor System for undergraduates, while the Graduate Review Board performs the same function for graduate students. If a violation should occur, the appropriate board investigates and recommends disciplinary measures to the deans.

Student Body Publications. The publications of the student body include a weekly paper, *The California Tech;* a yearbook; a literary magazine; a student handbook, which gives a survey of student activities and organizations and serves as a campus directory; an annual review of the quality of teaching in the various courses; and a handbook of available research opportunities. These publications are staffed entirely by students. Through them ample opportunity is provided for any student who is interested in obtaining valuable experience not only in creative writing, photography, art work, and in the journalistic fields of reporting and editing, but in the fields of advertising and business management as well.

Musical Activities. The Institute provides qualified directors and facilities for a wind ensemble, a jazz band, several choral music groups, a symphony orchestra (jointly with Occidental College), a number of small chamber ensembles, and a weekly interpretive music class. A series of chamber music concerts is given on Sundays in Dabney Lounge. There are other musical programs in Beckman and Ramo auditoriums.

Student Societies and Clubs. There are at the Institute more than 70 societies and clubs covering a range wide enough to satisfy most interests. The American Chemical Society, the American Institute of Chemical Engineers, and the American Society of Mechanical Engineers all maintain active student branches.

The Institute has a chapter (California Beta) of Tau Beta Pi, the national scholarship honor society of engineering colleges. Each year the Tau Beta Pi chapter elects to membership students from the highest ranking eighth of the junior class and the highest fifth of the senior class.

Special interests and hobbies are provided for by a broad and constantly changing spectrum of clubs, some informal but most formally recognized by either ASCIT or the Graduate Student Council.

Student Shop. The Student Shop is housed in the Winnett Student Center. It is equipped by the Institute, largely through donations, and is operated by the students. Here qualified students may work on private projects that require tools and equipment not otherwise available. All students are eligible to apply for membership in the Student Shop; applications are acted on by a governing committee of students. Members who are not proficient in power tools are limited to hand tools and bench work; however, instruction in power tools is given as needed. Yearly dues are collected to provide for maintenance and replacement.

The Caltech Y. The Y is located on the upper floor of Winnett Student Center. Run by undergraduate and graduate students and supported by endowments and Caltech's friends, it builds bridges between science and just about everything else: culture, politics, social consciousness, recreation, ethics, humanism, religious thought, exam week looniness.

Pluralistic and nonsectarian, too, The Caltech Y is open to everyone, and extends its hospitality to students, faculty, and staff, no strings attached. It makes interest-free loans, sets up low-cost ski trips and backpacking adventures, subsidizes theater and sports tickets, administers the annual $1,900 Studenski travel award, has a Xerox machine and a stereophonic lounge, provides free weekly outdoor campus concerts, runs the Lost & Found and a used-textbook exchange, offers personal counseling, loans out camping equipment, and sponsors guest speakers of national fame or local significance. No membership lists; no fees; no catches.

Human Relations Adviser. A human relations adviser is available to students, faculty, and staff for consultation about any intra-Caltech complaints, problems, or personal grievances, large or small, that have not been resolved by other campus offices. She provides a confidential, nonaligned source of assistance to help any member of the Caltech community with individual situations or, when necessary, with Institute policies.

Religious Life. In addition to several groups active on campus such as the Caltech Christian Fellowship, Newman Club, and Hillel, churches of many different denominations are within walking distance or are only a short drive from campus.

Public Events. Beckman and Ramo auditoriums serve as the home of the professional performing arts program on the Caltech campus. Each year, more than 150 public events, ranging from the traditional Earnest C. Watson Caltech Lecture Series to dramatic, film, and concert attractions (featuring world renowned artists), are presented at Caltech. The auditoriums also serve as the stage for the annual Caltech musical and the Caltech Glee Club Christmas and spring concerts. Tickets, often with discounts available, are offered to Caltech students for all events in Beckman and Ramo auditoriums. Located in the Office of Public Events are a ticket agency (handling tickets not only for Caltech events, but also for most southern California entertainment, sports, and cultural events) and the campus Audio-Visual Services Unit (where projectors, tape recorders, and video equipment may be obtained).

Bookstore. The student store serving students, faculty, and staff is located on the ground floor of the Winnett Student Center. The store, which is owned and operated by the Institute, carries a complete stock of required books and supplies, reference books, and such items as greeting cards, sweatshirts, and sundries. There is, on open shelves, an extensive collection of paperbacks and other books of general interest.

STUDENT HEALTH

Medical Examination. Before initial registration, each applicant is required to submit a Report of Medical History and Physical Examination on a form that is sent at the time of notification of admission. Students who have been absent from the Institute for two years or more may also be required to submit this report.

Student Health Services. The Archibald Young Health Center, which includes a dispensary and an infirmary, provides for undergraduate and graduate students the following services: (1) office consultation and treatment by a staff physician at prescribed hours; (2) laboratory tests, consultations, and radiographs as prescribed or ordered by the staff physician; (3) inoculations and treatments administered by nurses; (4) routine medications, prescription drugs, and other supplies at cost; (5) infirmary care; and (6) psychological counseling through the services of staff psychologists and psychiatrists. Services are available for faculty and staff on a limited basis, covering only emergency care, on-the-job injuries, and inoculations.

Student Health Insurance. In addition to services available at the Health Center, coverage under a comprehensive medical insurance plan is provided to all full-time students and, during the summer, to students registered for the previous term. This plan covers hospital and surgical costs, as well as costs of treatment as an out-patient for injury or illness. Benefits continue for 12 months, on campus and off campus, provided students remain enrolled through the school year.

Medical Coverage of Dependents. A student's spouse and all unmarried dependent children under 19 years of age are eligible for coverage under the medical insurance plan. In addition, student spouses may enroll for a modest fee in a plan that makes them eligible for all services offered at the Health Center. Children are not eligible for these services. Application for dependents' insurance should be made at the time of registration for any one school term. Rates for dependents' coverage are available at the Health Center.

Medical Responsibility of the Student. The responsibility for securing adequate medical attention in any contingency, whether emergency or not, is solely that of the student, whether the student is residing on or off campus. Apart from providing the opportunity for consultation and treatment at the Health Center as already described, the Institute bears no responsibility for providing medical attention.

Any expenses incurred in securing advice and attention in any case are entirely the responsibility of the student, except as already specified. To secure payment from the insurance plan and substantiate a claim for services rendered away from the Institute, the student is required to retain bills for such services and present them with appropriate documentation when medical claims are made. The Health Center office staff may be called upon for advice on the preparation of claim forms.

CAREER DEVELOPMENT

Career Services. The Career Development Center provides assistance to students, research fellows, and alumni in the areas of career and life planning and employment. Personal assistance in career choices, job search strategy, resume preparation, and interview techniques is available.

Campus Recruiting Program. Through the campus recruiting program, on-campus employment interviews are arranged with about 200 companies that seek full-time employees with B.S., M.S., or Ph.D. degrees. All graduating students, research fellows, and recent alumni are eligible to participate.

Career Day. Each February, between 35 and 40 different companies send representatives to campus for a day of informal discussion with students. Most bring informative displays and literature, and many of the representatives are Caltech alumni themselves.

Career and Employment Information Library. This resource library contains college and graduate school catalogues, scholarship and fellowship information, company literature, employer directories, career literature, audio-visual resources, and current employment opportunities.

Student Employment. Part-time and summer job listings both on and off campus are actively solicited to aid students seeking employment to help finance their education and to gain relevant work experience. In addition, several major employers arrange on-campus interviews for summer employment. (See also Student Employment under Financial Aid in Section 3.)

Annual Report. The office surveys all graduating students and compiles a detailed annual report that provides information on the plans of graduating students. Included are graduate schools attended, types of employers chosen, and salary statistics. (See Employment Experience of Recent Graduates below.)

All students are encouraged to visit and make use of the Career Development Center early in their student careers.

AUDITING COURSES

Persons not regularly enrolled in the Institute may audit courses, if they obtain the consent of the instructor in charge of the course and the Dean of Undergraduate Students or Dean of Graduate Studies, as appropriate, and pay the required fee. Auditing fees for non-academic staff members may be covered by the Institute Tuition Support Plan. Auditing cards may be obtained in the Registrar's Office.

Regularly enrolled students and faculty members of the Institute staff are not charged for auditing. Auditing cards are not required, but the instructor's consent is necessary in all cases. No grades for auditors are reported to the Registrar's Office, and no official record is kept of the work done.

LEAVE OF ABSENCE

Leave of absence must be sought by written petition. For undergraduates, the petition should be accompanied by a completed withdrawal card. Leave of up to one year can be granted by the appropriate dean for a student who is in good standing. A student in good standing is defined as a student who does not have to meet special academic requirements as a result of reinstatements. A petition for a *medical* leave of absence must carry the endorsement of the Director of Health Services or the Director of Counseling Services and may then be granted for a period of up to one year by the appropriate dean. Permission to return from a medical leave must also carry the endorsement of the Director of Health Services or the Director of Counseling Services. Other petitions should be addressed to the Undergraduate Academic Standards and Honors Committee or the Dean of Graduate Studies, as appropriate, and the student must indicate the length of time and the reasons for which absence is requested. All undergraduate leaves of absence may be reviewed by the Undergraduate Standards and Honors Committee.

The Institute may place a student on medical leave of absence if the Dean of Students or the Dean of Graduate Studies, as appropriate, is persuaded by medical opinion submitted to him that the student's continuation at the Institute would be seriously detrimental to the academic performance of other students or to the personal safety of the student or other members of the Institute. A decision by either Dean to place a student on medical leave of absence is subject to automatic review within seven days of the action by the Vice President for Student Affairs (or his designee). Nothing in this statement precludes access to the normal student grievance procedure.

GRADES AND GRADING

All permanent grades recorded for freshmen will be either P, indicating passed, or F, indicating failed. The temporary grade of I may be used as it is for other students. The temporary grade of E may be given to freshmen as described below for other students. It may also be used in a continuing course if the performance of the freshman concerned is not significantly below the current passing level, and if the student is maintaining a steady and substantial improvement; an E given for this reason will be automatically changed to a P if the freshman earns a P for the following term, and will change to an F if the student receives an F for the following term. The grade may not be used in this way for two successive terms nor for the last term of the course.

If a freshman is enrolled in a course in which the instructor gives letter grades, the Registrar will record P for all passing grades. No grades given to a freshman will be used in computing the cumulative grade-point average.

For all students beyond the freshman year, graduate and undergraduate, letter grades will ordinarily be used to indicate the character of the student's work: A, excellent; B, good; C, satisfactory; D, poor; E, conditional; F, failed; I, incomplete. P may also be used as described below under *Pass/Fail Grading*. In addition, grades of A+ and A−, B+ and B−, C+ and C−, and D+ may be used for undergraduates only. In any situation in which no grade is reported, the grade shall be assumed to be F.

The grade E indicates deficiencies that may be made up without repeating the course. The instructor giving the grade of E should state on the grade sheet the nature of the deficiencies and the time limit within which the work must be completed. At the end of this time period, the instructor should submit the appropriate letter grade, including P or F, and this will be placed on the student's record.

The grade I is given only in case of sickness or other emergency that justifies non-completion of the work at the usual time, and its use must be approved by the Dean of Graduate Studies or the Dean of Undergraduate Students. Any grade I not so approved will be recorded as an E. As with the grade E, the time period within which the grade I is to be made up should be indicated on the grade sheet.

Students receiving grades of E or I should consult with their instructors not later than the beginning of the next term in residence as to the work required and the time allowed. This time should, in most cases, coincide with the date fixed in the calendar for removal of conditions and incompletes (Add Day), and in fact if no other time is specified, this date will be assumed. Further, under no circumstances may the time for the completion of the work be extended for more than three terms in residence after the end of the term in which the grade of E or I was given. At the end of the specified time, unless there is a written request from the instructor to the contrary, or in any event at the time of graduation or at the end of three terms in residence, whichever occurs first, all Es and Is not otherwise reported will be changed to F. Grades of E and I shall not be considered in calculating a student's grade point average.

"Failed" means that no credit will be recorded for the course. The units, however, count in computing the student's grade-point average, unless the course was taken on a pass/fail basis. He or she may register to repeat the subject in a subsequent term and receive credit without regard to the previous grade, the new grade and units being counted as for any other course, but the original F and units for the course remain on the record. An F, once recorded, will be changed to a passing grade only on the basis of error. Such a change may be made only with the approval of the Undergraduate Academic Standards and Honors Committee or of the Graduate Studies Committee, whichever has jurisdiction.

Each course at the Institute is assigned a number of *units* corresponding to the total number of hours per week devoted to that subject, including classwork, laboratory, and the normal outside preparation. Credits are awarded as shown in the following table.

No. of Units	A+	A	A−	B+	B	B−	C+	C	C−	D+	D	F
1	4	4	4	3	3	3	2	2	2	1	1	0
2	9	8	7	7	6	5	5	4	3	3	2	0
3	13	12	11	10	9	8	7	6	5	4	3	0
4	17	16	15	13	12	11	9	8	7	5	4	0
5	22	20	18	17	15	13	12	10	8	7	5	0
6	26	24	22	20	18	16	14	12	10	8	6	0
7	30	28	26	23	21	19	16	14	12	9	7	0
8	35	32	29	27	24	21	19	16	13	11	8	0
9	39	36	33	30	27	24	21	18	15	12	9	0
10	43	40	37	33	30	27	23	20	17	13	10	0
11	48	44	40	37	33	29	26	22	18	15	11	0
12	52	48	44	40	36	32	28	24	20	16	12	0
13	56	52	48	43	39	35	30	26	22	17	13	0
14	61	56	51	47	42	37	33	28	23	19	14	0
15	65	60	55	50	45	40	35	30	25	20	15	0

Grade-Point Average is computed by dividing the total number of credits earned in a term or an academic year by the total number of units taken in the corresponding period. Units for which a grade of F has been received are counted, even though the course may have subsequently been repeated. Grades of P or F obtained in courses graded on a pass/fail basis are not included in computing grade-point average.

Pass/Fail Grading: The following regulations apply:

1) Freshmen receive pass/fail grades in all courses by virtue of their classification as freshmen by an admissions committee or, for students whose status after the first year is uncertain, by the Undergraduate Academic Standards and Honors Committee.

2) All other students, undergraduate and graduate, in courses with numbers under 200 will receive letter grades unless the course is designated "graded pass/fail" or unless, when it is allowed, the student files with the Office of the Registrar a completed Pass/Fail Course Selection Card not later than the last day for dropping courses.

3) In courses with numbers 200 or greater that are not designated either "graded pass/fail" or "letter grades only," the instructor may decide separately for each student what class of grades to use.

4) All research courses shall be designated "graded pass/fail." All reading courses, seminar courses, or other courses that do not have a formal class structure shall be designated "graded pass/fail" unless the option secures an exemption from the Curriculum Committee or the Graduate Studies Committee and from the Faculty Board.

5) A grade on the pass/fail system should be P if it would have been a D or better on the letter grade system. (Note that there is no D− grade.) The standards of failure in courses in which only pass/fail grades are used should be the same as they would be if the course were letter graded.

6) Any instructor may, at his or her discretion, specify prior to preregistration that his or her course, if not classified by the above regulations, is to be graded on a "letter grades only" basis or is to be graded pass/fail only, subject to possible review by the responsible option. The Registrar must be notified of such specification two weeks before the beginning of preregistration.

7) Each term any student may select, subject to such requirements as may be imposed by the option, one elective course in which he or she is to be graded on a pass/fail basis if it is not designated as "letter grades only" and is not specifically required for the degree in his or her option. To make this election, a completed Pass/Fail Course Selection Card must be submitted to the Office of the Registrar on or before the last day for dropping courses that term. This election may be reversed or reinstated at any time before the deadline. The election must be approved and the card signed by the student's adviser. The instructor must be notified and should sign the card to indicate that this has been done; the instructor must allow any eligible student to make this election.

8) Of the units offered to satisfy the requirements for the Bachelor of Science degree, no more than 81 may be in courses graded pass/fail because of the student's election.

NOTICES AND AGREEMENTS

Accreditations and Authorizations

The California Institute of Technology is accredited by the Accrediting Commission for Senior Colleges and Universities of the Western Association of Schools and Colleges. In addition, the Institute is authorized by the California State Department of Education, Office of Private Postsecondary Education, to operate as a private postsecondary educational institution and, by the same agency, to train veterans in the programs of the Veterans Administration.

In specific degree programs the Accreditation Board for Engineering and Technology has accredited our B.S. programs in chemical engineering and in engineering and applied science and our M.S. program in environmental engineering science. Further, the Committee on Professional Training of the American Chemical Society has approved our B.S. program in chemistry.

The documents describing these accreditations and authorizations are on file and may be inspected in the office of the Registrar, the Undergraduate Admissions Office, or the Graduate Studies Office.

Nondiscrimination

The California Institute of Technology is committed to the concept of equal educational opportunity for all. Individuals are considered for admission to student status, and all services, facilities, programs, and activities are administered in a nondiscriminatory manner without regard to (a) race, religion, color, sex, national or ethnic origin or nondisqualifying handicap in accordance with existing laws and regulations, including Title IX of the Education Amendments of 1972, Title VI of the Civil Rights Act of 1964, and Section 504 of the Rehabilitation Act of 1973 as amended; or (b) any other factor which is, in fact, irrelevant to student status or to the rendering of services, facilities, programs, or activities.

The grievance procedure described below is the Institute's official avenue for redress of grievances of alleged discrimination. The Vice President for Student Affairs is the Institute official responsible for investigating student complaints of discrimination.

Harassment

It is the policy of the Institute to maintain an environment free of harassment of any kind, including sexual harassment. Any member of the Caltech community who feels that he or she has been harassed is encouraged to pursue the issue, or lodge a complaint, in accordance with the Institute's stated policy. The official policy statement is available from the Dean of Students, the Dean of Graduate Studies, or the Vice President for Student Affairs. The Vice President for Student Affairs is the ombudsman for student grievances, procedures for which are summarized below.

Student Grievance Procedure

Caltech provides a variety of routes, most of them informal, by which student complaints are brought to consideration and resolution. These routes normally depend on the nature of the complaint. In academic matters, for example, they begin with teacher-student conversations and extend to the Deans, the Division Chairmen, the Registrar, and various committees having faculty and student members. Undergraduate housing matters relate primarily to the house government organizations, and to the Resident Associates and the Master of Student Houses. The Dean of Graduate Studies often serves as ombudsman in graduate student matters. The Graduate Student Council and the Associated Students of Caltech may become responsibly involved in important complaints. Sometimes *ad hoc* groups are formed to consider and make recommendations in particular areas.

The grievance procedure is intended to deal with complaints for which reasonable efforts by the available informal routes have not led to prompt and acceptable resolution and which do not fall within the jurisdiction of the Honor System.

The first step in this procedure is to submit the matter to the Vice President for Student Affairs, who is the ombudsman for student grievances. He will work with the grievant in attempting to resolve the matter. If the grievant is dissatisfied with the results, the grievant may appeal the case to the Grievance Committee. This committee consists of two members of each of the categories—undergraduate students, graduate students, faculty, and administration—appointed, respectively, by the ASCIT Board of Directors, the Graduate Student Council, the Chairman of the Faculty, and the President of the Institute. The Chairman of the Committee, non-voting except in the case of a tie, is also appointed by the President. The grievant may present the case to the Committee, present documents in support of the case, request that witnesses be called, and be assisted by another member of the Caltech community who is not an attorney. The Committee will present its conclusions and recommendations to the President of the Institute and the President's decision will be final. A complete statement of the student grievance procedure is available from the Vice President for Student Affairs, the Dean of Students, or the Dean of Graduate Studies.

Employment Experience of Recent Graduates

A survey was made at the end of June 1985 of the future plans of those students who had graduated at the commencement ceremony on June 14, 1985.

Of those receiving the B.S. degree about whom we have definite information, 49% had been accepted for admission to graduate school for further education, 37% had accepted employment, 11% had other plans and 3% were still seeking employment or graduate school admission. The average salary of those accepting employment was $2,433 per month. At the M.S. level, 58% were continuing in graduate school, 29% were employed at an average salary of $2,628 per month, 9% had other plans, and 4% were still seeking employment. Of those receiving the Ph.D. degree, 96% were employed at an average salary of $3,387 per month, 3% had other plans, and 1% were still looking.

Student Retention

Most undergraduates enter the Institute at the freshman level. Of those, over the last several years, 75% have graduated from the Institute with Bachelor of Science degrees in the options of their choice. Of students registering at the Institute for the first time as sophomores or juniors, 92% have graduated. At the graduate level, 91% of entering students graduate either with the degree of Master of Science or of Doctor of Philosophy or, occasionally, with both.

Student Patent and Computer Software Agreement

Students at Caltech have many opportunities to work in laboratories or in shops, or with computers, sometimes on individual projects and sometimes as part of a group activity. It is not unusual under these circumstances for inventions to be made, or computer software (including programs, data bases, and associated documentation) to be written, and it is important that the student's rights in patents on inventions and in computer software he or she may have made or written be protected. The Institute's policy generally is to reserve to itself rights in inventions and computer software made by faculty and staff members with the use of Institute facilities or in the normal course of their Institute duties. The student's position is different, however, and students generally retain all rights except in inventions or computer software made under circumstances such that rights clearly belong to the Institute or to the sponsor of the research. In order to clarify this situation and to protect the rights both of the student and of the Institute, each entering student is asked to sign the following agreement:

1. The Institute agrees that I shall retain all rights in inventions and computer software made or written by me except when such inventions are first conceived or reduced to practice or such computer software written:
   - 1.1 in the course of the performance of work as a paid employee of the Institute;
   - 1.2 in the course of independent student research financed by or otherwise obligated to an outside grant or contract to the Institute or financed by a grant from the Institute;
   - 1.3 or when they arise out of work in the research program of an academic staff member.
2. The Institute agrees that rights of all other inventions or computer software made or written by me with the use of Institute facilities are to be retained by me, except for computer software which is written in connection with or used in the educational program of the Institute (e.g., course work, homework, theses), for which the Institute shall obtain an

irrevocable royalty-free, non-exclusive license, with the right to grant sublicenses, for any purpose whatsoever.

3. I agree to notify the Institute promptly of any discovery, innovation, or invention which is first conceived or first actually reduced to practice, or computer software first written, under the conditions of paragraphs 1.1 or 1.2 or 1.3 above and computer software written in connection with or used in the educational program of the Institute under the conditions of paragraph 2 above.
4. I agree to assign to the Institute or its nominee all rights in the United States and foreign countries to inventions and computer software made or written under the conditions of paragraphs 1.1 or 1.2 or 1.3 above and to supply all information and execute all papers necessary for the purpose of prosecuting all patent applications, or registering copyrights in or otherwise protecting such computer software, and fulfilling obligations that may arise from such inventions or computer software. The Institute will bear the expenses for such patent applications or copyright registrations or for obtaining such other protection.

It is understood that the student will share in the same manner as a member of the academic staff such royalty income from patents or computer software as the Institute may receive on inventions assigned to it, or computer software assigned or licensed to it, as a result of this agreement.

It is also understood that the Institute relies on the foregoing agreement when it signs contracts with others and obligates itself with respect to discoveries, innovations or inventions or computer software made or written in the course of research conducted at the Institute under such contracts.

Access to Student Records

In accordance with Section 99.5 of Title 34 of the Code of Federal Regulations, the California Institute of Technology is using this means to inform students of their rights under Public Law 90-247, as amended.

1. The Institute maintains records for each student that include name, address, student identification number, information on parents, guardian, and spouse, general information on academic status at the Institute, previous school data, results of standardized admissions examinations, courses previously taken or being taken, credits, and grades. Applicants for Financial Aid have an additional file holding those records.
2. The Registrar of the Institute is responsible for maintaining all of these records, except for those involving Financial Aid. They are available to the Registrar, to the Vice President for Student Affairs, to the Dean of Graduate Studies, to the Director of Financial Aid, to the Faculty of the Institute, and to their respective staffs for the normal academic and business purposes of the Institute. Records involving Financial Aid are maintained by the Director of Financial Aid, and are available to the Director and staff, to the Dean of Graduate Studies and staff, to the Faculty Committee on Scholarships and Financial Aid, and to the Faculty Committee on Graduate Study for the purpose of granting and administering the Institute's Financial Aid program. All of these records are also available to such other organizations and persons as are entitled to them under Part 99 of Title 34 of the Code of Federal Regulations. None of these records nor any personally identifiable information contained therein, other than directory information (see below), will be made available to anyone else, other than the student, without written consent. Where consent is required and given, the student, upon request, will receive a copy of the records to be released. The Institute will keep a record, available to the student and kept with his or her file, of all persons and organizations, other than those authorized within the Institute, requesting or obtaining access to the files. This record will indicate specifically the legitimate interest that each person or organization obtaining access to the records has in such records.
3. Students are allowed access to their records as follows: A student may inspect his or her

academic transcript during normal working hours. To see other records, the student must provide a written request to the Registrar or to the Director of Financial Aid or to the Dean of Graduate Studies or their deputies, as appropriate. A mutually convenient time will be arranged within ten working days after receipt of the request for the student to examine the records in his or her file. At that time the student may examine all records in the file with the exception of those specifically exempted by Part 99 of Title 34 of the Code of Federal Regulations. The student may obtain copies of any of the records available to him or her; the cost will be $.44 for the first page copied and $.12 for each additional page. All reasonable requests for explanations or interpretations of the records will be honored, and if inaccurate, misleading or otherwise inappropriate data are found in the records, they will be promptly corrected or deleted. The student also has the right to insert into the records a written explanation respecting the contents of such records. If the student and the Registrar, or the Director of Financial Aid, or the Dean of Graduate Studies, or their deputies, do not agree on any item contained in the records, the student may submit a written request to the Provost for a hearing to challenge the content of the records. The Provost will schedule such a hearing within 30 days after receipt of the request and will notify the student at a time reasonably in advance of the hearing of its date, time, and place. The hearing will be before a Board composed of the Provost, the Vice President for Student Affairs, or their designated alternates, and at least one disinterested member of the Faculty who shall be appointed by the Chairman of the Faculty Board. None of those hearing the challenge may have a direct interest in the outcome. The student will be afforded a full and fair opportunity to present evidence relevant to the issues raised and may be assisted or represented by individuals of his or her choice at his or her own expense, including an attorney. The decision of the board on the correctness of the record, as determined by majority vote, will be in writing, will be rendered within ten days after the conclusion of the hearing, and will be final. This decision will be based solely upon the evidence presented at the hearing and will include a summary of the evidence and of the reasons for the decision.

If, as a result of the hearing, the Institute decides that the information in the files is inaccurate, misleading, or otherwise in violation of the privacy or other rights of the student, the Institute shall amend the records accordingly and so inform the student in writing. However, if, as a result of the hearing, the Institute decides that the information is not inaccurate, misleading, or otherwise in violation of the privacy or other rights of a student, it shall inform the student of the right to place in the records a statement commenting on the information in the records and/or setting forth any reasons for disagreeing with the decision of the Institute.

4. The Institute considers the following to be directory information: student's name, address, telephone listing, date and place of birth, major field of study, participation in officially recognized activities and sports, weight and height of members of athletic teams, dates of attendance, degrees and awards received, thesis title, home town, and the most recent educational agency or institution attended by the student. Directory information is made generally available to requestors. Any student may, however, have part or all of this information withheld by notifying the Registrar in writing no later than 30 days after the commencement of classes in the academic year. That information will then be withheld for the balance of that academic year. If the information is to be withheld in subsequent years, new requests must be filed.
5. No student can be required, nor will be asked, to waive rights under Part 99 of Title 34 of the Code of Federal Regulations. However, a student may voluntarily waive right of access to confidential statements made by third parties respecting admission to educational agencies or institutions, applications for employment, or the receipt of an honor or honorary recognition. In case of waiver, the confidential statements will be used solely for the purposes for which they were specifically intended, and the student will, upon request, be notified of the names of all persons making such confidential statements. If a student

should desire to so waive right of access, so as to facilitate the obtaining of a confidential statement of this nature, he or she should contact the Registrar for the necessary form.

6. The Institute reserves the right to destroy from time to time any and all records that it maintains on a student, except to the extent that the law requires their maintenance for a longer period of time. However, records, access to which has been requested under Part 99 of Title 34 of the Code of Federal Regulations, are not allowed to be and will not be destroyed until such access has been granted, or a decision to deny such access has been arrived at as described in (3) of this section.
7. The Institute also maintains for each student a medical record showing history, treatment, etc. These records are maintained at the Young Health Center and, while specifically excluded from Public Law 90-247, are still available for inspection by the individual student on request.

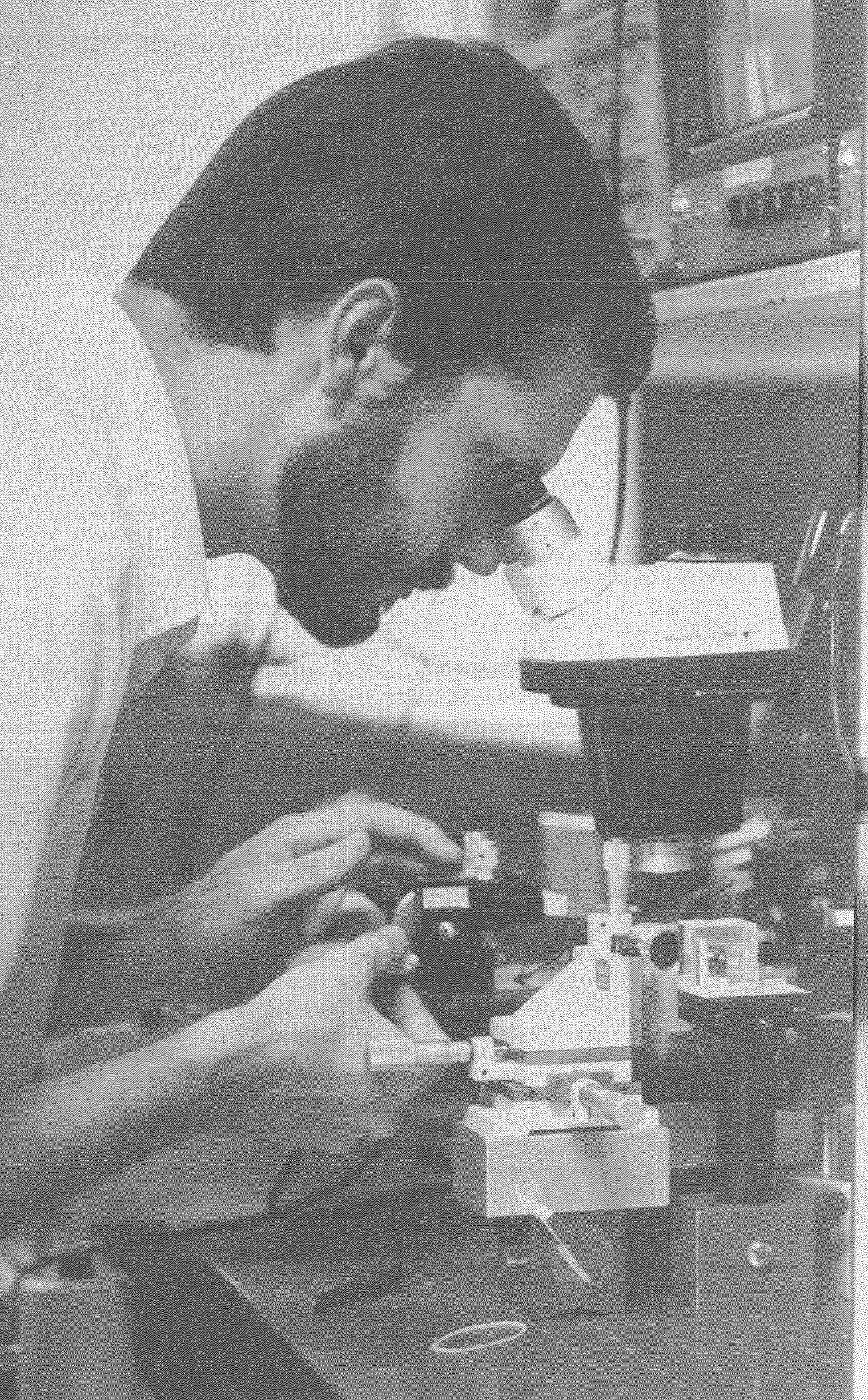
Academic Records of Veterans

The Institute maintains a written record of a student's previous education and training. This is part of the student's permanent record card, and included on this is a summary of any prior college-level education. A true copy of a transcript of college-level work at other institutions is maintained as part of the student's record. The amount of credit granted for prior training is indicated on the student's permanent record card and, where this results in the shortening of a required training period in the case of a veteran, the Veterans Administration is notified.

The Institute's permanent record card for each student shows the progress that student is making at the Institute. There is a record of each course enrolled in each term with a grade recorded for the course. The total number of units earned is kept so that the record will show continued progress toward the degree sought. The final grades are recorded at the end of each term of the school year, and the accumulative permanent record has on it grades for all subjects taken at the Institute. No student is allowed to enroll repeatedly in a course and withdraw without penalty. If a student enrolls in a course, he or she is expected to complete the course or receive a failing grade unless he or she withdraws from the course prior to the deadline for dropping courses. All students must maintain a minimum load equivalent to 12 quarter hours each term; no student may drop courses that would bring him or her below this level of effort. At any time when the student falls below the required number of units, fails to receive satisfactory grades, or engages in unsatisfactory conduct, the record is marked to indicate this, and the student is forbidden to continue at the Institute.

The grading system of the Institute is A (excellent) to F (failed). An A is equivalent to 4.0 and an F to 0.0. A student must maintain a grade point average of 1.4 in any term and at least 1.9 in each full year in order to be able to enroll in a successive term at the Institute. A minimum 1.9 overall grade point average is required for graduation. A student who drops below the required averages (1.4 for a given term or 1.9 for the year) is dismissed and must petition for reinstatement. A student may be reinstated by the Undergraduate Academic Standards and Honors Committee and, if so, is required to earn a 1.9 GPA during the immediately following term. The Veterans Administration is notified when a veteran is academically dismissed or is making unsatisfactory progress toward a degree. Since the Institute requires all students to carry a minimum full load that corresponds to 12 quarter hours each term, any student who finishes a term in good standing is considered to have made satisfactory progress. If a student withdraws from a course before the final date for withdrawal, no grade is given in that course. The time spent in school counts, however, and the student may be considered to have not made satisfactory progress in the event of such withdrawal.

In order to withdraw from any course a student must submit a withdrawal card. This shows the date on which the student was last in official attendance in that course. If a student reenrolls in that course and successfully completes it, that fact will be noted on his or her permanent record card. Since the Institute does not offer resident courses not leading to a standard college degree, no attendance records are maintained for such courses.



STUDY AND RESEARCH

2

AERONAUTICS

The Guggenheim Aeronautical Laboratory, the Karman Laboratory of Fluid Mechanics and Jet Propulsion, and the Firestone Flight Sciences Laboratory form the Graduate Aeronautical Laboratories, widely known as GALCIT. In this complex are housed the Applied Mathematics group, the Jet Propulsion Center, and the Hydrodynamics Laboratories, as well as the various disciplines making up the broad field known as Aeronautics.

Areas of Research

Aeronautics has evolved at Caltech from a field of basic research and engineering, primarily related to the development of the airplane, into a wide discipline encompassing a broad spectrum of basic as well as applied problems in fluid dynamics and structural mechanics. Research at GALCIT has traditionally pioneered exploration of new areas that have anticipated subsequent technological demands. Thus, for example, research in transonic, supersonic and hypersonic fluid mechanics began before the advent of supersonic flight and the development of vehicles re-entering the earth's atmosphere. Research in plasma dynamics began before the importance of controlled fusion was recognized; in turbulent mixing, before the appearance of the chemical laser, the need for optimizing combustion, and the drive to reduce jet noise. Similarly, research on problems of shell structures began before their widespread use in aircraft, and undoubtedly stimulated this development. Work in fracture mechanics of polymers was initiated before composite materials became an important component of aerospace structures. This tradition places a high premium on an in-depth understanding of fields both closely and remotely related to the behavior of fluids and structures such as physics, applied mathematics, geophysics, materials science, electronics, and even astrophysics. As a consequence, GALCIT students are known and sought after for their broad yet intense education and for their ability to deal with new and challenging problems.

Major areas of study and research currently pursued by aeronautics students at Caltech are briefly described below.

Physics of Fluids. Fluid dynamics as a discipline is as much a part of physics as of engineering. Physics of fluids refers to research in areas closer to applied physics than to direct technical applications. Present active research includes studies in gas dynamics, diffraction of shock waves, shock-induced Rayleigh-Taylor instability, and transient supersonic jets; work on the flow properties of liquid helium II, turbulence and shock wave propagation in the superfluid; the development of laser scattering diagnostic techniques for fluid-flow measurements; and studies of two-phase flows, vapor explosions, and dusty gases in transient flows and explosive volcanoes. Students in applied physics are also able to pursue various problems in the physics of fluids under the supervision of members of the aeronautics faculty.

Computational Fluid Dynamics. Computational fluid dynamics is a relatively new discipline in which fluid flows are investigated by computer simulation. Present active research areas include the study of structures and mechanisms in transition and turbulence, the study of flows with large-scale separation, and the design of new algorithms. Current computing machinery and computing techniques have improved to the point that they are a valuable complement to laboratory investigation.

Technical Fluid Mechanics. Research at GALCIT includes a long history of work on subsonic and supersonic turbulent boundary layers, shear flows, and separated flows. These areas are related to a variety of modern technological problems and, in addition, to the traditional aeronautical problems of drag, wing stall, and jet mixing. Additional areas of activity include the effects of winds on buildings, aerodynamics of automobiles and trucks, turbulent mixing in chemical lasers, turbulent combustion, laminar diffusion flames and their instabilities, fires in buildings (turbulent mixing and flow fields driven by fire-produced buoyancy), hydrodynamics and two-phase flows, and active and passive control of transition and turbulence.

Structural Mechanics. Structural mechanics research involves both the static and dynamic behavior of structures. Included are buckling in both the elastic and plastic range of the material. Fluid structure interaction under dynamic loading is studied experimentally and analytically. Other subjects include the failure of composite materials and the behavior of large space structures.

Mechanics of Fracture. An active effort is being made to understand the mechanisms of fracture. Aspects that are studied include quasi-static and dynamic crack growth phenomena in brittle solids, polymers and advanced composites, fatigue and failure of adhesive bonds. A research area adjunct to fracture studies in polymers is the non-linearly viscoelastic behavior of polymeric solids.

Aeronautical Engineering and Propulsion. Research work in the field of aeronautics includes studies of airplane trailing vortices and separated flows at high angles of attack. Research work in the propulsion area has centered on the fluid dynamic problems associated with gas turbine components (principally axial flow compressors and combustion chambers), rocket engine combustion chambers, and ramjet engines.

Aero-Acoustics. A number of topics in the broad field of aero-acoustics are actively under study at GALCIT. They include jet noise, combustion noise, and nonlinear acoustics and hydroacoustics. A particularly interesting problem is the generation of combustion-induced organ pipe oscillations in large burners of electric generating plants.

The Daniel and Florence Guggenheim Jet Propulsion Center conducts a large portion of its instruction and research in close cooperation with the aeronautics group. The fields of study covered are described under the separate heading of Jet Propulsion. Students in aeronautics are able to pursue studies and research leading to graduate degrees in aeronautics utilizing facilities, courses, and research supervision by the faculty of the Jet Propulsion Center.

Physical Facilities

The Graduate Aeronautical Laboratories contain a diversity of experimental facilities in support of the above programs. Low-speed wind tunnels include the Merrill Wind Tunnel, which can be operated by a single person, the GALCIT 10-ft. Wind Tunnel, and many special-purpose flow facilities. Both a High-Speed Water Tunnel (100 feet per second) and a Free-Surface Water Tunnel are housed in the Hydrodynamics Laboratory; they are used for studies of acoustics, laminar-turbulent flow transition, and the structure of turbulent shear flows. A smaller water channel for studies of wave motion and flow visualization is also available. For investigations of high-speed flows there is a supersonic wind tunnel with two different working sections.

Shock tubes, plasma tunnels, and other special facilities are available for the study of extreme temperatures, shock waves, acoustics, and cryogenic flow.

The solid mechanics laboratories contain standard as well as special testing machines for research in aircraft and spacecraft structures and materials under static and dynamic loads. Fatigue machines and photoelastic equipment are available, as well as special apparatus, including laser equipment and a line of high-speed cameras offering recording at rates from still to 250,000 frames per second, for study of elastic waves, dynamic buckling, and the mechanics of static and dynamic fracture.

State-of-the-art electronic instrumentation is being developed and used. Computer systems for real-time control of experiments, for data acquisition, processing and storage, and for digital image processing are used extensively.

APPLIED MATHEMATICS

The broad aim of the applied mathematics program at Caltech is to stimulate and explore the interplay between mathematics and the various non-mathematical disciplines. On the one hand, an active group of pure mathematicians devote themselves mainly to the more abstract and foundational branches of mathematics, and on the other hand, faculty members from other disciplines follow a wide diversity of research in physics, engineering, biology, chemistry, geophysics, and economics. Ideas travel in both directions, bringing mathematical tools to bear for synthesis and solution of practical problems in various fields and, of equal importance, generating new mathematical ideas and points of view that arise from physical problems. The research and educational program reflects this interdisciplinary aim in its structure.

In addition to the applied mathematics faculty, professors from other disciplines such as mathematics, physics, engineering, biology, etc. supervise research and offer courses of special interest. Close contact is maintained with experimental programs in fluid and solid mechanics and with research groups developing advanced computers. The applied mathematics group has access to super-computers, and has a variety of its own computers, graphics terminals, and other equipment. Library facilities are excellent, comprising all the journals, a complete general library, and a special research library in applied mathematics.

The present graduate program is one leading mainly to the Ph.D. degree. The curriculum consists of two types of courses: those that survey the methods used in applied mathematics, and those that have a special applied mathematics flavor and represent active research interests of the members of the faculty. Among the latter have been wave motion, perturbation theory, fluid mechanics, stochastic processes, mathematical programming, numerical analysis, computational fluid dynamics, and advanced elasticity. By study outside of applied mathematics, each student is expected to become competent in some special physical or non-mathematical field. In this way, subjects for research appear naturally, and a broad educational program is provided.

The present group primarily interested in applied mathematics consists of approximately 25 students and nine professors. Also, each year many distinguished visitors either come to present lectures or remain in residence for large parts of the academic year.

Areas of Research

Research is particularly strong in theoretical and computational fluid mechanics, elasticity, dynamical systems, numerical analysis, ordinary and partial differential equations, integral equations, linear and nonlinear wave propagation, bifurcation theory, perturbation and asymptotic methods, stability theory, variational methods, mathematical programming, large-scale scientific computing, and related branches of analysis.

APPLIED MECHANICS

Areas of Research

Advanced instruction and research leading to degrees of Master of Science and Doctor of Philosophy in Applied Mechanics are offered in such fields as elasticity, plasticity, wave propagation in solid and fluid media, fluid mechanics, mechanics of quasi-static and dynamic fracture, structural mechanics and stability, dynamics and mechanical vibrations, finite element analysis, stability and control, and certain areas in the fields of propulsion, heat transfer, and generation of energy.

Research studies in these areas that illustrate current interests include linear and nonlinear vibrations, structural dynamics and design for earthquake and wind loads, linear and nonlinear problems in static and dynamic elasticity, plasticity and viscoelasticity, wave propagation in elastic and viscoelastic media, mechanics of time-dependent fracture, buckling of shell structures, mechanics of fluid-structure interaction, diffraction of elastic waves by cavities and inclusions, boundary layer problems in plates and shells, stratified flow and unsteady cavity flow.

Physical Facilities

In addition to the regular facilities at the Division of Engineering and Applied Science, which include extensive computing facilities, and the special wind tunnel and water tunnel facilities for studies in solid and fluid mechanics of the Graduate Aeronautical Laboratories, certain special facilities have grown up in connection with applied mechanics activities. The vibration laboratory is equipped with a good selection of modern laboratory apparatus and instrumentation for experimental research in shock and vibration, and the earthquake engineering research laboratory contains specialized equipment for vibration tests of buildings, dams, and other structures, and for the recording and analysis of strong-motion earthquakes. The solid mechanics laboratory located in the Graduate Aeronautical Laboratories contains extensive testing equipment for the study of fracture and structural failure. Another specialized laboratory is the heat transfer laboratory, which contains a forced convection heat transfer loop and facilities for studying the performance of high-speed pumps.

APPLIED PHYSICS

An interdivisional program in applied physics for both undergraduate and graduate study was initiated in 1970. Like applied mathematics, applied physics at Caltech is in a fortunate position: The comparatively small size of Caltech coupled with its great strength in both the pure sciences and engineering makes it possible to have a faculty with a wide interest in the application of modern physics to technology, without losing close interaction with "pure subjects." At present, members of four divisions—Engineering and Applied Science; Physics, Mathematics and Astronomy; Chemistry and Chemical Engineering; and Geological and Planetary Sciences—participate in instruction and research in applied physics leading to a B.S. degree as well as to M.S. and Ph.D. degrees.

The program is designed for students who are deeply interested in physics but at the same time are fascinated by the interrelation of physical problems and technological development, i.e., students who like to work with problems in physics that originate from or result in applications. A sharp division between "pure" and "applied" physics or between applied physics and engineering cannot be drawn, and the option of applied physics should be considered a bridge rather than a divider. A student is expected to have a thorough background in physics, as well as a broad background in related fields of technology.

Members of the faculty involved with the educational and research activities in applied physics remain members of their respective divisions. Graduate students who choose the applied physics option similarly are admitted to one of the cooperating divisions.

In setting up the undergraduate curriculum, every effort has been made to facilitate the transition into and out of the option. In general an undergraduate student in applied physics will devote somewhat more time to the study of matter in bulk than will the "pure" physicist. Since it is expected that most students will be interested in experimental research, a special effort has been made to set up challenging laboratory courses and to provide an opportunity to do a senior thesis.

For first-year graduate students and adventurous seniors, a set of basic courses covering broad areas in applied physics is available, supplemented by a set of more specialized courses often closely related to a specific research effort.

Areas of Research and Physical Facilities

Research activities cover a broad spectrum, ranging from cryogenics to plasmas, from rarefied gas flow to high pressures and shock waves in solids, from neutron transport to planetary science. There is research in progress in the physics of solids, including solid-state electronics, ferromagnetic materials, quantum electronics, and superconductivity; in the physics of fluids, including plasmas and magnetohydrodynamics, liquids and superfluids; and in the physics of electromagnetic radiation, including linear and nonlinear laser optics and electromagnetic theory. The research program has been enriched recently by the construction of the 40,000-sq.-ft. Thomas J. Watson, Sr., Laboratories of Applied Physics. This attractive building contains offices around a central courtyard and laboratories in the balance of the two floors. Conference rooms and a large classroom occupy the single-story entrance wing.

ASTRONOMY

The astronomical observatories at Palomar, Las Campanas, and Big Bear and the Owens Valley Radio Observatory together constitute a unique and unprecedented concentration of scientific facilities in astronomy. In 1948, the California Institute of Technology and the Carnegie Institution of Washington recognized the advantages of creating a great astronomical center in which scientific programs could be pursued under favorable circumstances, with a variety of instruments. Such a center would also draw young men and women of ability to graduate studies, where they might familiarize themselves with powerful tools of exploration. Consequently, for more than 30 years the two institutions together have shared their facilities in optical astronomy—the Palomar Observatory and the Big Bear Solar Observatory, which are operated by Caltech, and the Mount Wilson and Las Campanas Observatories, which are operated by the Carnegie Institution. Within this collaborative arrangement, equipment and facilities are made available for the astronomical investigations of the Caltech and Carnegie astronomers, research fellows, and students. Academic activities and the operation of the Owens Valley Radio Observatory are the responsibility of the Institute's Division of Physics, Mathematics and Astronomy. The division also conducts work in theoretical astrophysics, laboratory astrophysics, gravitational-wave physics, infrared and sub-millimeter astronomy.

The radio astronomy group works in close collaboration with the optical astronomers in Pasadena; the program of graduate study in the two fields is essentially the same, except for specialized advanced courses. There also is close cooperation between these groups and the students and astronomers interested in planetary physics and space science.

As a result of the cooperation possible over a broad range of astronomy and theoretical astrophysics, unsurpassed opportunities exist at Caltech for advanced study and research. Courses of study depend upon a broad and thorough preparation in physics, mathematics, and other relevant subjects; the faculty offers advanced instruction in astronomy, astrophysics, solar physics, planetary physics, and astronomical instrumentation and techniques.

Areas of Research

Both observational and theoretical astrophysics are actively pursued. Topics of current interest in optical and infrared astronomy include observational cosmology; chemical abundances in normal and peculiar stars; spectroscopic and spectrophotometric studies of quasars and galaxies; studies of white dwarfs and other stars near the end-point of evolution; studies of the dynamics and composition of galaxies and clusters, nebulae and interstellar matter; statistical studies pertinent to the structure of the galaxy; and the physics of solar phenomena.

Research in planetary and solar system astronomy is pursued in cooperation with groups in the Division of Geological and Planetary Sciences.

The research in radio astronomy covers the physical properties of galactic and extragalactic radio sources, including quasars, radio galaxies, stellar envelopes, and the planets. The properties of the interstellar medium in our own and other nearby galaxies are investigated in spectroscopic studies of various atomic and molecular spectral lines.

Theoretical astrophysics is pursued not only in the astronomy department, but in physics and geology as well, and at Caltech includes work on supernovae, pulsars, stellar structure and evolution, stellar and planetary atmospheres, interstellar and intergalactic matter, the physics of radio sources, nucleosynthesis, relativity, and cosmology.

Physical Facilities

The Rockefeller Boards provided in 1928 for the construction by the Institute of an astronomical observatory on Palomar Mountain, equipped with a 200-inch reflecting telescope, 48-inch and 18-inch Schmidt wide-angle telescopes, and other auxiliary instruments, together with an astrophysical laboratory on the Institute campus. Graduate student thesis research may be conducted at any of these facilities or at the Mount Wilson and Las Campanas Observatories, operated by the Carnegie Institution of Washington. The great light-collecting power of the 200-inch Hale Telescope permits advanced studies of the size, structure, and motions of the stars of the galactic system; of the distance, motion, and nature of remote galaxies and quasi-stellar radio sources; and of many phenomena bearing directly on the constitution of matter. The 48-inch Schmidt has made possible a complete survey of the northern sky, as well as an attack upon such problems as the structure of clusters of galaxies, the luminosity function of galaxies, extended gaseous nebulae, and the stellar content of the Milky Way. These two unique instruments on Palomar Mountain supplement each other; the 200-inch Hale Telescope reaches as far as possible into space in a given direction, while the 48-inch Schmidt photographs upon a single plate an entire cluster of distant galaxies or a star cloud in our own Galaxy. At Palomar a 60-inch telescope owned jointly by Caltech and CIW was completed in 1969. It is used for photometry, spectroscopy, and photography. The Palomar telescopes have modern electronic detectors, some of which are constructed in Robinson Laboratory.

A multipurpose solar equatorial telescope has been installed at an observing station at Big Bear Lake. The unique atmospheric conditions in this area make possible investigations of the fine structure of the solar atmosphere. Emphasis is on high-resolution spectroscopy, magnetography, and cinematography. A major new effort is the study of solar oscillations.

Special apparatus for detection and measurement of radiation in the far infrared has been fitted to various telescopes for the study of planets, cool stars and dust clouds, as well as quasars and the energetic nuclei of galaxies.

The Owens Valley Radio Observatory is in a radio-quiet location 400 km north of Pasadena, near Big Pine, California. Its facilities include a 40-m parabolic antenna, a three-element millimeter-wave synthesis interferometer array, and a two-element interferometer for solar studies. The 40-m telescope is used in conjunction with other radio telescopes around the world for very long baseline interferometry (VLBI), a technique that permits mapping of compact galactic and extragalactic objects with angular resolution better than one millisecond of arc. The 40-m is also used alone for continuum and spectroscopic studies of radio sources and of the microwave background radiation. The millimeter-wave array consists of three high-precision 10-m antennas and is used at wavelengths of 1.3 to 4 mm to map the distribution of interstellar gas and dust in our own and other galaxies and for studies of planetary atmospheres, stellar envelopes and regions of star formation. These telescopes, which are equipped with very sensitive cryogenically-cooled receivers and sophisticated signal-processing and data-recording systems, give Caltech staff and students the widest range of observing opportunities available at any unversity-related radio observatory in the world.

Two major new facilities are under construction on Mauna Kea, in Hawaii. The Caltech 10-m submillimeter telescope will be completed in 1986. The Keck 10-m optical telescope, which is to be operated jointly with the University of California, will have four times the power of the Palomar 200-inch when it is completed about 1990.

Robinson Laboratory on campus houses the Astronomy Data Processing Facility. This contains two VAX 11/780 computers and special equipment for processing optical and radio images. Multi-baseline VLBI data processors are operated jointly with the Jet Propulsion Laboratory. A special laboratory for analysis of data from the Infrared Astronomical Satellite is also on campus.

BIOLOGY

Recent, dramatic progress in our understanding of the nature of life has revolutionized the science of biology. Applications of the methods, concepts, and approaches of modern mathematics, physics, chemistry, and information science are providing deep insight into basic biological problems such as the manner in which genes and viruses multiply themselves; the control of gene expression in cells; the regulation of cellular activity; the mechanisms of growth and development; and the nature and interactions of nerve activity, brain function, and behavior. Qualified experimental biologists will find opportunities for challenging work in basic research as well as in medicine and in biotechnology.

Because of the eminent position of the California Institute of Technology in both the physical and biological sciences and of the current expansion of our program in neurobiology, students at the Institute have an unusual opportunity to be introduced to modern biology.

Areas of Research

Research (and graduate work leading to the Ph.D. degree) is chiefly in the following fields: biochemistry, biophysics, cell biology, developmental biology, genetics, immunology, molecular biology, neurobiology, neurophysiology, and virology. Biochemical methodology plays an important role in many of these fields, and there is extensive interaction with related programs in chemical biology within the Division of Chemistry and Chemical Engineering.

The programs in cell and developmental biology are based upon approaches derived from biochemistry, biophysics, and genetics that offer new possibilities for expanded insight into long-standing problems. Some of this research involves the use of advanced physical techniques; such work benefits from close ties between Caltech's biologists and members of the Division of Physics, Mathematics and Astronomy.

Neurobiology and behavioral biology are receiving increasing emphasis within the Division of Biology. A comprehensive program of research instruction has been formulated to span the disciplines from neuron physiology to the study of animal and human behavior.

Physical Facilities

The campus biological laboratories are housed in five buildings: the William G. Kerckhoff Laboratories of the Biological Sciences, the Gordon A. Alles Laboratory for Molecular Biology, the Norman W. Church Laboratory for Chemical Biology, the Mabel and Arnold Beckman Laboratories of Behavioral Biology, and the Braun Laboratories in Memory of Carl F and Winifred H Braun. They contain classrooms and undergraduate laboratories, as well as research laboratories where both undergraduate and graduate students work in collaboration with faculty members. Special facilities include rooms for the culturing of the Institute's valuable collection of mutant types of Drosophila, scanning and transmission electron microscopes, containment facilities for recombinant DNA research, and a state-of-the-art microchemical facility for sequencing and synthesizing biologically important macromolecules.

About 50 miles from Pasadena, at Corona del Mar, is the William G. Kerckhoff Marine Laboratory. This laboratory provides facilities for research in cellular and molecular biology using marine animals and for collecting and maintaining these animals.

CHEMICAL ENGINEERING

The research and teaching interests of the chemical engineering faculty are directed toward the study of the fundamentals of chemical and transport principles and their application to the analysis and synthesis of complex chemical systems. These interests lead the faculty and students into problems as diverse as the chemical processes occurring in polluted atmospheres, the chemistry of coal conversion to synthetic fuels, the fluid mechanics of suspensions and non-Newtonian fluids, surface chemistry, the fundamentals of heterogeneous catalysis, their application in chemical and petrochemical processes and in the development of synthetic fuels, the mechanical properties of polymers, the control of chemical and biochemical reactors, and biotechnology and genetic engineering.

Areas of Research

The chemical engineering program is well equipped for instruction and research leading to the degrees of Master of Science and Doctor of Philosophy in Chemical Engineering. Major areas in which graduate research is currently concentrated include air pollution, aerosol dynamics, biochemical engineering, fluid mechanics, polymers, coal conversion and combustion, desulfurization of fuels, heterogeneous catalysis and surface chemistry, process control and estimation theory, and the physics and chemistry of two-phase systems. In particular, research includes:

1. Biochemical engineering: Dynamics of microbial populations in chemical reactors. Enzyme catalysis.
2. Chemical reaction engineering: Applied catalysis, dynamics of catalytic reactions. Gas solid reactions. Development of supported regenerable sorbents for gas cleaning.
3. Control: Modern control methods for chemical reactors and other distributed parameter systems. Interfacing process design and control systems design. Optimal control and estimation theory with application to petroleum reservoir engineering.
4. Design: Novel design tools for complex processes with recycle loops. Computer-aided process design.
5. Energy: Coal gasification and liquefaction. Coal pretreatment for clean combustion. Flue gas desulfurization. Petroleum reservoir engineering and recovery methods.
6. Environmental: Atmospheric chemical reactions and fluid mechanics. Computer simulation of the urban atmosphere. Application of tracer techniques. Chemistry and physics of aerosols, gas/particle conversion processes, and relationship of particulate pollution to sources.
7. Fluid mechanics: Rheology and transport properties of suspensions and polymer solutions. Mechanics of non-Newtonian fluids. Interfacial fluid mechanics and transport processes. Numerical simulation of fluid motion.

8. Heterogeneous catalysis and surface chemistry: Adsorption and catalytic reactions on well-characterized surfaces using low-energy electron diffraction, Auger-electron spectroscopy, x-ray and uv-photoelectron spectroscopies, characteristic electron energy loss spectroscopy, inelastic electron-tunneling spectroscopy, and mass spectrometry. Theoretical modeling of solids, solid surfaces, and gas-surface interactions.
9. Polymer science and engineering: Relationship between molecular constituents and macroscopic properties of polymers; synthesis of model polymeric materials; thermodynamics of multicomponent polymers.
10. Structure and dynamics of liquid systems: Macromolecular modeling and hydrodynamics. Rayleigh and Brillouin laser light-scattering studies of super-cooled liquids, macromolecular solutions and particulate suspensions; macromolecular dynamics and conformation in quiescent and flowing solutions; transport properties of liquids, molecular relaxation phenomena in liquids and amorphous solids. Structure of simple liquids by x-ray diffraction.

Physical Facilities

Chemical engineering laboratories, housed in the Eudora Hull Spalding Laboratory of Engineering, are particularly well equipped both for instruction and for research.

CHEMISTRY

Caltech's chemistry program offers exciting opportunities for study and research in many areas of chemical science. Eminent faculty and strong programs are available in structural chemistry, chemical dynamics and reaction mechanisms, synthesis, theoretical chemistry, biochemistry, and biophysical chemistry. Active interaction exists between chemistry and other disciplines at Caltech, especially applied physics, biology, chemical engineering, and geology. There is strong interest on the part of the faculty in both teaching and research, and the undergraduate and graduate programs are designed to encourage the greatest possible amount of freedom, creativity, and flexibility.

Areas of Research

Caltech has long had a reputation for excellence in chemistry in the areas of molecular structure and the nature of chemical bonding. This tradition is continuing. Work in structural chemistry ranges from x-ray crystallographic structural determinations of covalent compounds, transition metal complexes, and intermetallic compounds, to investigations of the stereochemistry of organic molecules, conformation of oligopeptides, and dynamical structures of lipid bilayers by NMR spectroscopy. Active programs in other areas of spectroscopy include laser Raman, electron impact and photoelectron spectroscopy, and solid state NMR.

Much of the current research in chemistry is directed at finding out how chemical reactions work in both chemical and biological systems. Chemical physics programs in this area include studies of gas phase reactions and processes using ion cyclotron resonance, molecular beam, and picosecond laser techniques. In organic chemistry, research focuses on the behavior of very reactive intermediates both in the gas phase and in solution. Catalysis by transition metals is receiving emphasis among researchers in the inorganic and organometallic areas. Research in progress includes mechanisms of electrode surface chemistry and electrocatalysis, uses of transition metal complexes as homogeneous and heterogeneous catalysts, solar energy conversion and storage, and nitrogen fixation. Reactions of molecules on surfaces are receiving increased attention. A number of biochemical projects are aimed at obtaining detailed information about reactions catalyzed by enzymes, including electron transfer reactions promoted by metalloproteins.

A significant amount of synthetic chemistry is involved in many of the above projects. In addition, several groups have chemical synthesis as a primary goal of their research. These include projects aimed at the synthesis of natural products and of molecules required for the testing of structural theories. Efforts are also directed at the development of novel and synthetically useful chemical transformations.

Research in biochemistry and molecular biology includes studies of the mechanisms of enzyme catalysis and allosteric transitions, interactions between proteins and nucleic acids, structural elucidations of nucleic acids, studies of membrane structure and function, protein-lipid interactions, and mechanisms of ion and electron transport in biological membranes. Other areas receiving emphasis include the chemistry of membrane proteins, glycoproteins and specific receptors for a variety of external stimuli and recognition processes, the fundamental processes of photosynthesis, immunology, and neurochemistry. Many of these studies make use of recombinant DNA and cloning to probe fundamental biochemical processes.

Current work in energy-related research comprises studies of laser isotope separation, photochemistry, catalysis, electrochemistry, and molecular processes for energy production, storage and transmission.

Our theoretical chemistry program encompasses work on the applications of quantum mechanics to the study of electronic states of molecules and solids. The emphasis of the work here is on excited states and reactions of molecules. Theoretical techniques are also being developed to facilitate detailed understanding of electron transfer processes, energy randomization processes within molecules, and the dynamics of reacting systems.

Physical Facilities

The laboratories of chemistry consist of five units providing space for about 250 graduate students and postdoctoral research fellows. Crellin and Gates laboratories house several research groups, the divisional computing facility, the Southern California Regional High Field NMR facility, and the divisional administrative offices. Several synthetic research groups occupy the Arnold and Mabel Beckman Laboratory of Chemical Synthesis. The Braun Laboratories in Memory of Carl F and Winifred H Braun are shared with the Division of Biology. The Arthur Amos Noyes Laboratory of Chemical Physics, one of the major research facilities, is adjoined by the Clifford S. and Ruth A. Mead Memorial Undergraduate Chemistry Laboratory.

CIVIL ENGINEERING

Civil engineering includes the research, development, planning, design, and construction associated with urban development, water supply, energy generation and transmission, water treatment and disposal, and transportation. Dealing with the function and safety of such public facilities as buildings, bridges, pipelines, dams, rivers, power plants, and harbors, it is concerned with the protection of the public against natural hazards of earthquakes, winds, floods, landslides, water waves, and fires.

Recent advances in technology and the escalation of urban problems have broadened the applications of civil engineering, increasing the scope of research. New problems have presented special challenges to the civil engineer well trained in the fundamentals of his or her profession. For this reason, in the advanced study of civil engineering at the Institute, the application of basic scientific principles and mathematics is emphasized for the solution of engineering problems.

Areas of Research

Graduate work leading to advanced degrees lies chiefly in the following fields: structural engineering and applied mechanics; earthquake engineering; soil mechanics and foundation engineering; finite element analysis; hydraulics, which includes hydrodynamics, hydraulic engineering, hydrology and coastal engineering; and environmental engineering (see also environmental engineering science). In the past few years, graduate students and members of the staff have pursued a variety of research programs, including analysis of structures subjected to earthquakes and other dynamic loadings; the use of finite element methods for structural analysis; soil deformation under stress; behavior of soil models in a centrifuge; investigation of laws of sediment transportation and dispersion in bodies of water; turbulent mixing in density-stratified flows; wave-induced harbor oscillations; tsunamis; design criteria for various hydraulic structures; aerosol filtration; radioactive waste disposal; water reclamation; and ocean outfalls for thermal discharges or sewage effluents.

Students whose interests are in environmental problems may enroll for graduate degrees in either civil engineering or environmental engineering science.

Physical Facilities

Civil engineering activities are housed in two buildings, the Franklin Thomas Laboratory, which contains the soil mechanics laboratory and centrifuge, the earthquake engineering laboratory, and the vibration laboratory, and the W. M. Keck Engineering Laboratories, which contain the laboratory of hydraulics and water resources and the environmental engineering science laboratories.

Excellent computing facilities are available through the campus computing network and in the specialized computing centers of various research groups.

COMPUTATION AND NEURAL SYSTEMS

A new interdisciplinary option has been established to study problems arising at the interface between neurobiology, electrical engineering, computer science, and physics. The unifying theme of this program is the relationship between the physical structure of a computational system (physical or biological hardware), the dynamics of its operation, and the computational problems that it can efficiently solve. The creation of this multidisciplinary program stems largely from recent progress on several almost unrelated fronts: the analysis of complex neural systems, the modeling of artificial neural networks, the development of massively parallel computer hardware, and recent advances in analog VLSI capabilities. Faculty in the program belong to the Divisions of Biology; Engineering and Applied Science; Physics, Mathematics and Astronomy; and Chemistry and Chemical Engineering. They have an interest in developing conceptual frameworks and analytical approaches for tackling seemingly disparate problems that share a common deep structure at the computational level. Students in the program will partake of a wide-ranging curriculum that will promote a broad understanding of neurobiology, computational hardware and software, and information theory.

Areas of Research

Areas of research include the functional organization of the visual cortex and modeling as a means for extracting key representational features; the circuitry, computational function, and modeling of olfactory cortex; the design and fabrication of analog VLSI for early stages in machine visual and auditory processing; the theory of collective neural and silicon circuits for biological and machine computation; the relation between problem complexity, communication, and computation in parallel machines; modeling and representation of physical objects for the general analysis of images; the use of optical devices in parallel computational hardware; the neuron as a computational device.

COMPUTER SCIENCE

Although computing is a ubiquitous tool in all areas of study and research at Caltech, computer science is directed at the theory and technology of computation itself. It is the science of information, and of the structures that communicate, store, and process information. Whether these structures are expressed in hardware, and called machines, in software, and called programs, or in nature or society, the fundamental concepts are similar. The student of computer science at Caltech does not specialize along traditional lines that divide hardware and software, systems and applications, or theory and experiment. Rather, in our courses and research we take a unified approach to the design and analysis of computing structures.

Unlike the physical and natural sciences, the objects of study by computer scientists are artificial systems, that is, structures that are purposefully designed. Thus design assumes a role equal in importance to analysis, and is a term found frequently in our curriculum and research. Design is a creative activity, but also a formal or at least systematic one. The management of the great complexity of useful systems requires that one represent computations in a way that is amenable to mathematical treatment, as well as to implementation.

Areas of Research

Research and advanced courses leading to M.S. and Ph.D. degrees in computer science are concentrated in the following areas: VLSI systems; concurrent computation; physics of computation; theory of computation; information theory; high-level programming languages; semantics; programming methods and correctness; the man-machine interface, including natural language; signal and image processing; graphics; and computer-aided design. Research projects frequently involve work in several of these areas, with both theoretical and experimental aspects, as well as connections with fields such as mathematics, physics, biology, linguistics, and electrical engineering.

Students have unusual opportunities at Caltech for research in very large scale integrated (VLSI) systems. VLSI is not only a powerful technology for implementing computing systems, but also an elegant medium for studying computing structures and for understanding their connection to the physical world. VLSI research at Caltech has many components, including formal design methods and theory, computer-aided design and analysis tools, and experiments with high performance VLSI architectures.

Caltech's computer science department is unique in that from our recent beginnings it was realized that programming and VLSI design should be treated as one science: the science of designing concurrent computing structures. Because of their great complexity, one cannot hope to construct reliable concurrent systems without rigorous design methods for deriving their implementation and proving their correctness. In our research in algorithms, programming notations, and semantics for concurrent computations, we are considering essentially two types of implementations: concurrent programs that run on large ensembles of communicating general purpose automata, and direct implementation in the VLSI medium. The scale and physical characteristics of either of these media pose many interesting problems of sequencing and synchronization, which may be addressed by design disciplines such as "self-timed" systems, in which sequencing does not depend on global timing assumption.

Computational complexity and information theory are two basic fields of research that are growing closer. The relation between different measures of complexity, the universal bounds on these measures, and the characterization of sequential and concurrent computing in terms of the combinatorial structure of data, are active fields of research.

Research in software system architectures for the support of the non-computer professional is a continuing part of computer science at Caltech. The primary language of these systems is natural English, with emphasis on the users' abilities to tailor their systems to their own interests. This research includes strong experimental components, using real life task environments.

Research in computer graphics and in digital signal and image processing is a recent and rapidly developing area of emphasis. The graphics group is conducting research in several areas, including advanced image synthesis, computer animation, CAD/CAM, and the simulation of natural phenomena. The graphics group is also investigating the design of specialized hardware to perform large-scale computations in graphics.

Physical Facilities

Most of the computer science department's computing facilities are interconnected by a department ethernet that includes a gateway to the ARPAnet. All department faculty, graduate students, research staff, secretaries, and the librarian, have terminals, personal computers, or workstations for access to these computing facilities.

Many of the department computers, including four VAXes, 15 SUN workstations, and an AT&T 3B20S, run Unix. An IBM 4341 with an FPS 160 array processor is used for many demanding computations. Our rapidly growing graphics laboratory includes two Symbolics 3600s with color frame buffers and video digitization capability, several 68020-based HP workstations, an Evans and Sutherland picture system, and several full-color raster and vector display controllers. There are also numerous smaller machines in use, such as HP 9836Cs and IBM PCs, most with color displays. The Cosmic Cube, an experimental concurrent computer with 64 computing nodes, and a 128-node model of its commercial descendant, the Intel iPSC, are on the department network for system and application experiments. Imagen laser printers and color plotting devices are concentrated on VAX servers.

These computing facilities support a diverse collection of software used both in courses and research activities. This software includes compilers and/or interpreters for more than 20 programming languages, extensive VLSI computer-aided design and analysis tools, TeX typesetting software, and libraries of advanced computer graphics routines.

Our digital systems laboratory is equipped with complete facilities for the construction and testing of experimental systems, including probing, testing, and packaging integrated circuits.

The computer science library subscribes to and maintains a collection of 80 journals in the computer science field. The library also includes collections of technical reports from our department and from the computer science departments of other universities, and text and reference books.

ELECTRICAL ENGINEERING

Electrical engineering at the Institute comprises physical electronics, electronic circuits, and communication. Closely allied with the computer science program and the applied physics option, it offers students the opportunity for study in the more technological aspects of a wide variety of subjects including plasma dynamics, electromagnetic radiation, quantum electronics, modern optics, new solid-state materials and devices, computer systems, control theory, signal processing, and information theory. This broad spectrum of subjects complementing the program in electronic circuits and circuit function design provides exceptional and challenging opportunities for both experimental and theoretical work.

Areas of Research and Physical Facilities

Laboratory facilities are available for a wide variety of research activities. Electrical engineering activities are housed mainly in one building, the Harry G. Steele Laboratory of Electrical Sciences.

Research in the solid-state electronics laboratories extends over a variety of subjects. They range from electrical transport properties of semiconductors to the atom movements occurring at interfaces during semiconductor device construction. Thin films and near-surface layers, in particular, are investigated from an electrical and a metallurgical point of view. Subjects currently under investigation are thin-film reactions, diffusion barriers, amorphous and metastable crystalline films, solid-phase epitaxial regrowth, and ion mixing. Conventional experimental tools are used for experimentation, as well as ion implantation and backscattering spectrometry. The properties, limitations, and ranges of application of these two techniques are the subjects of additional investigations performed with a 1 MV tandem Van de Graaf accelerator and a 400 keV ion implantation system in Steele Laboratory.

The quantum electronics laboratory and the laser laboratory are engaged in research in the area of generation and control of coherent radiation and in the study of related physical phenomena. Research projects in progress include the generation and control of ultrashort pulses, integrated optoelectronic semiconductor circuits, semiconductor injection lasers, molecular beam epitaxy growth of sub-micron GaAs/GaAlAs structures for optoelectronics and electronics, phase conjugate optics and applications of nonlinear optics, laser isotope separation, submillimeter wave techniques, dielectric waveguides, and electron beam devices.

The antenna laboratory is a center for the theoretical study of antennas, radio wave propagation, gravitational electrodynamics, particle beams, electric and magnetic suspensions, imaging radar, and lightning.

The power electronics laboratory deals with modern problems in analysis, design, and synthesis of electronic circuits as applied to efficient conversion, control, and regulation of electrical energy. The analysis techniques developed are extensively verified by experiments. Projects now in progress include the design and optimization of new switching dc-to-dc converters for regulated power supplies, dc-to-ac inverters for motor drives, resonant converters, and basic studies in integrated magnetics. A firm theoretical and experimental foundation is established for investigation in a number of research areas opened up by the current studies.

The Pierce communications laboratory conducts theoretical and computer experimental work in a wide range of information, communication, and signaling problems, including coding and modulation for channels and memories, communications switching and traffic, channel and memory capacity, digital filtering, and signal processing for speech, music, images, and radar. Current research emphases are in coding for new kinds of channels that occur in radio and guided communication, in jamming, and in magnetic recording; fundamental limits of information storage; information content of graphics, video, and radar; capacity and behavior of associative neural network memories; efficient design of rear-rangeable switches; traffic capacities of mobile services, enhanced switches, and integrated services digital networks; distribution architectures for combined fiber-copper subscriber loop in telephone networks; and design and simulation of single-rate and multi-rate digital filters and filter banks to minimize the number of computational operations for a given accuracy. Possibilities of joint work in communications with the digital microsystems laboratory also exist.

The digital microsystems laboratory is engaged in both theoretical and experimental research in advanced information processing, much of which interacts with the communications group. The laboratory supports its theoretical work with hardware and VLSI design facilities on networked Unix workstations, and chip fabrication via the MOSIS system. Current projects include bit serial arithmetic architectures for cryptography, error correcting code chips, expert systems for texture recognition, data flow architectures for digital signal processing chips, and object-oriented computer architectures.

In the control laboratory, theoretical work is conducted in the analysis and design of linear, multivariable, and sampled-data control systems. A computer-aided control system design facility is used to implement new analysis and design techniques and to simulate the performance of control systems. The objective is to develop new methods that enable the design of control systems for increasingly complex aerospace, electrical, mechanical, and chemical systems.

Research in the integrated circuits laboratory is oriented toward millimeter- and submillimeter-wave integrated circuits. The current projects involve gallium-arsenide and indium-phosphide detector diodes, imaging-antenna arrays, plasma holograms, and millimeter-wave radars and sources.

The optical information processing laboratory is engaged in research to develop optical techniques and devices for information processing. Current areas of interest include acoustooptic devices and systems, photorefractive crystals, synthetic aperture radar, image processing, pattern recognition, optical associative memories, and optical computers.

ENGINEERING SCIENCE

Advanced programs of study leading to the degrees of Master of Science and Doctor of Philosophy in Engineering Science are offered by the Division of Engineering and Applied Science. The need for these programs has developed as new frontiers of engineering have advanced to coalesce with major disciplines of science. It is possible to pursue programs of graduate study in geophysical fluid mechanics and biofluid mechanics under this option.

Areas of Research
The study program of the engineering science student at Caltech emphasizes physics, applied mathematics, biology, and those scientific disciplines that underlie the current development of technology. Its scope contains a broad range of subjects and continues to evolve and develop. Fields of study may include such topics as fluid mechanics with applications to geophysical and biomechanical problems; physics of fluids; aerosol physics; rheology of biological fluids; transport in biological systems; mechanophysiology of swimming, flying, and animal locomotion; free-surface flows; naval hydrodynamics; jets, cavities and wakes; stratified and rotating flows; tsunami and long waves in the ocean; and physical oceanography.

Physical Facilities
Laboratories are equipped with several microscope systems, laser illuminator and fluorescent imaging facilities, and high-speed-cinephotomicrographic sets for biophysical and mechanophysiological studies. It is also equipped with a versatile towing tank and flow measuring devices for investigating free surface flows, propulsive devices, and fluid energy engineering.

ENVIRONMENTAL ENGINEERING SCIENCE

This interdisciplinary graduate program is concerned with protection and control of man's environment. Research and instruction stress basic studies that aim to answer such questions as: How can we improve the air quality in our urban and industrial centers while maintaining clean air in pristine rural areas? How can we ensure the supply of water of adequate quality and quantity for population centers and industry? How can we safeguard our marine environment from pollution? What are the environmental consequences of alternative modes of energy production?

The academic disciplines of importance to the program include chemistry of natural waters and atmospheres; physics and chemistry of particulates; marine biology and ecology; fluid mechanics of the natural environment; hydrology; pollutant formation and control in combustion systems; theory and design of complex environmental control systems; environmental modeling and monitoring systems; processes of erosion, coagulation, and sedimentation. Courses are offered in the environmental engineering science program and in other related programs of the Institute. Faculty members participating in this interdisciplinary program are from the Divisions of Engineering and Applied Science, Chemistry and Chemical Engineering, and Geological and Planetary Sciences.

Areas of Research
Examples of recent and current research are theoretical and experimental studies on fates of trace metals in the environment; coagulation and settling of particles in seawater; chemistry of aerosols; acid rain and fog; interactions between toxicants and marine kelp; kinetics of oxidation processes in aqueous systems; dilution in turbulent shear flows; role of buoyancy forces in turbulent mixing; buoyant discharges in coastal waters; pollutant formation and control in combustion; regional air pollution modeling and control; and effects of air pollutants on art works.

Physical Facilities
The laboratory experimental work in environmental engineering science is primarily carried out in the W. M. Keck Laboratories with a wide variety of modern instrumentation used in air and water studies.

The air quality laboratory includes a facility located on the roof of Keck that has been specially designed for studies of gaseous and particulate pollutants both in the ambient atmosphere and in smog chambers. Bench and pilot scale combustors are housed in a laboratory devoted to the study of pollutant formation and control in combustion of pulverized coal and other fuels. These laboratories are equipped with a wide variety of instruments for the measurement and chemical analysis of gaseous and particulate pollutants. Instruments are interfaced with a computer data acquisition system for on-line data analysis. Cascade impactors and filter samplers are available for collecting samples of particulate matter for chemical analysis, while on-line analyzers continuously monitor ozone, nitrogen oxides, sulfur oxides, total sulfur, turbidity, and other ambient parameters. An electron microscope and associated equipment for sample preparation are used for particulate characterization. Meteorological variables, including wind speed, relative humidity, and temperature, can be measured with instruments on hand.

The water quality laboratory is equipped for trace element analysis (atomic absorption, polarography, electrometry, high performance liquid chromatography, fluorescence spectroscopy, multi-wavelength, multi-component UV-VIS spectroscopy, ion-chromotagraphy), carbon compound identification and determination, radiologic measurements, particle size determinations (conductance, electron microscopy, ultracentrifuge), microbiological measurements, and kinetic measurements (T-jump and stopped-flow kinetics, ion-potentiometry), PDP 11 instrumentation control and analysis.

The hydraulics laboratory has a variety of water channels and basins appropriate for waves, sediment, and turbulent diffusion studies. A 40-meter-long glass-walled flume is equipped with dual circulating water systems for density-stratified shear flow studies. Two wave flumes and a wave basin have computer-controlled wave generators that can produce waves of specified profiles for special wave studies. Three multi-beam laser-Doppler velocimetry systems are available for velocity measurements in turbulent flow studies or for wave-induced fluid velocity measurements. One of these systems is particularly designed for use in sediment-laden fluid flows. High resolution laser-induced fluorescence is used for simultaneous concentration measurement, and mass flux and dispersion studies. The laser systems can be directly coupled to a DEC 11/60 laboratory computer system that can accomplish real time multi-user processing and experiment control with data presentation by video graphics or hard copy plotter. VAX 730 and 11/84 computers are available for additional data analysis.

The Kerckhoff Marine Laboratory of the Division of Biology, at Corona del Mar, is the base for work in marine ecology and coastal oceanography. A research vessel is available for field work in neighboring coastal waters. The laboratory is equipped for both kelp reproduction and growth studies, and has an extensive range of diving equipment.

An excellent library with a wide variety of current materials in environmental engineering and science, and hydraulics is centrally located in the Keck Laboratories building.

The department provides students with access to scientific computing and word processing through various departmental computers and peripheral devices and the CADRE network of VAX's operated by the Division of Engineering and Applied Science.

ENVIRONMENTAL QUALITY LABORATORY

The Environmental Quality Laboratory is a research center for multidisciplinary, policy-oriented studies of problems related to natural resources and environmental quality. Administered within the Division of Engineering and Applied Science, the organization consists of faculty, students, staff, and consultants from various disciplines in engineering, and natural and social sciences. Since EQL is an independent research unit, faculty and students who participate in EQL activities are also associated with the appropriate degree programs. EQL research projects provide the framework for a comprehensive view of alternative solutions to natural resources and environmental control problems.

EQL research includes technical assessments, computer modeling, studies of environmental control options, policy analyses, and laboratory and field studies of important components of large-scale systems. Areas of current or recent work include:

(a) *Air quality, especially in the South Coast Air Basin of California* (control of sulfate and nitrate air pollutants; sources and distribution of carbon particles; visibility; development of advanced photochemical oxidant air quality models; reactive plume models; indoor air quality; effects of ozone on art works).
(b) *Water resources and water quality* (pollution control for coastal waters; sewage sludge disposal; acid depositions; water usage by energy industries; sediment management for streams and coastlines in southern California).
(c) *Control of hazardous substances and residuals management* (toxic substances in air and water; economics and regulation).
(d) *Energy policy, with emphasis on environmental tradeoffs* (energy pricing; energy demand and conservation; load management; risk taking by regulated firms in the energy industry).

EQL contributes to the education and training for multidisciplinary environmental and natural resources research by involving predoctoral students, postdoctoral fellows, and visiting faculty members in EQL research projects. Students who desire to work in EQL apply through an appropriate degree program, such as environmental engineering science, chemical engineering, civil engineering, mechanical engineering, geological sciences, or social science.

GEOLOGICAL AND PLANETARY SCIENCES

In the Division of Geological and Planetary Sciences, faculty members study the earth and planets in order to understand their origin, constitution, and development, and the effect of the resulting physical and chemical environments on the history of life, and on man. The approach to these problems is made with strong reliance on the basic sciences; close contact and interaction with the other divisions of the Institute are cultivated. Programs of study and research are pursued in geology, geobiology, geochemistry, geophysics, and planetary science.

The geographical position and geologic setting of the Institute are favorable for year-round field access to a wide variety of earth problems and materials. Current advances in understanding the dynamic motions of the earth's crust and the structure of the interior have opened up new opportunities for research into the processes responsible for the earth's development and activity. Seismic activity in the southern California area presents stimulus and research material for the study of earthquakes, which are of great practical concern and are intimately related to the earth's development on a global scale. Human records of seismic activity are put into long-term perspective by studies of surface and bedrock geology, which reveal the history of motion on fault systems. Major events in the chemical and physical evolution of the earth can be identified by studying the structure and chemistry of rocks formed or modified in these events, and their absolute chronology can be established by measurements of radioactive isotopes. A wide variety of studies focus on the origins of igneous and metamorphic rocks in planetary interiors. These include radiogenic and stable isotopes and experimental petrology in addition to field and petrographic studies. The earliest history of the solar system can be approached by studies of lunar samples and meteorites. Further breadth in our understanding of the earth and its place in the cosmos is being gained by comparative study of the other planets—their atmospheres, surfaces, and internal structures.

Physical Facilities

The Arms and Mudd laboratories are modern five-level buildings well equipped for instruction and laboratory research in geology and geochemistry. They also house the division library; paleontologic, rock, and mineral collections; x-ray and electron microprobe facilities, and other facilities required for comprehensive studies in the earth sciences. Laboratories for trace-element studies and mass spectrometric and counting facilities for isotopic work are available to apply the techniques of nuclear chemistry to problems in the earth sciences. Equipment includes mass spectrometers, ultraclean chemical laboratories, and extensive mineral separation facilities.

Conditions for field study and research in the earth sciences in southern California are excellent. A great variety of rock types, geologic structures, active geologic processes, physiographic forms, and geologic environments exist within convenient reach of the Institute. The relatively mild climate permits field studies throughout the entire year; consequently, year-round field work is an important part of both the educational and research programs.

The Seeley G. Mudd Building of Geophysics and Planetary Science, adjacent to the Arms and Mudd laboratories, provides research and teaching facilities for seismology, experimental geophysics, and planetary science. The Seismological Laboratory of the Institute, with excellent facilities including computers and extensive shops, is also located in the Seeley G. Mudd Building. The Kresge Laboratory is located about three miles west of the campus on crystalline bedrock affording firm foundation for the instrument piers and tunnels. These laboratories, together with a dozen portable and 17 permanent outlying auxiliary stations in southern California, which were built and are maintained with the aid of cooperative companies and organizations, constitute an outstanding center for education and research in seismology. In addition, special facilities are available at the Seismological Laboratory for the study of the behavior of rocks and minerals in the pressure and temperature environments of planetary interiors. These facilities include laboratories for performing ultrasonic and Brillouin scattering measurements of elastic constants of rocks and minerals at high pressures and temperatures. Ultra-high-pressure equations of state and shock effects in minerals are being studied in a shock wave laboratory.

Special, moderate-sized telescopes designed specifically for planetary work are available. A wealth of photographic information on the surfaces of Mars and Mercury is available from the Mariner missions and on the surfaces of Jupiter, Saturn, and their satellites from the Voyager missions. Radio and radar observations of the planets are made at the Owens Valley Radio Observatory and the JPL radar facility.

HUMANITIES

Literature at Caltech spans the major periods of American, English, and European writing. Students can pursue interests ranging from Greek and Latin literature to a survey of drama; from Shakespeare to romantic and modern poetry; from the novel as such to "The Self in Literature."

History at Caltech examines the Western and non-Western past to understand the evolution of culture, science, institutions, and behavior. Courses span the medieval, Renaissance, and modern periods; the United States, Europe, and Asia; and special topics such as religion, radicalism, and demography. In certain courses, quantitative methods drawn from the social sciences are applied to historical studies, and Caltech has become a major center of social scientific history, one of the most rapidly developing fields in history today.

Philosophy is concerned with the most fundamental issues involving the nature of human knowledge and judgment. At Caltech particular emphasis is placed on moral and political philosophy, the philosophy of history and the social sciences, and the philosophy of the physical sciences. Members of the faculty have a variety of other interests, including legal philosophy, philosophical problems of policy analysis, the history of philosophy, and the understanding of human action. Courses are given at both introductory and advanced levels.

Areas of Research

The faculty, interested in new approaches to studying literature, engage in active research directed to important issues in the humanities—the relationship between literature and psychology, literature and the pictorial arts, and literature and history.

Research in history covers a wide range of historical fields and specialties, including an examination of the political and economic effects of the disenfranchisement of blacks and poor whites in the American South after reconstruction; Anglo-American law as it applies to women's rights; the social, political, and intellectual development of science, particularly physics and genetics; and the confrontation of Asian and Western cultures.

The proximity of the Henry E. Huntington Library and Art Gallery, one of the great research libraries in the world, offers rich opportunities for staff and students, and a close but informal relationship is maintained between the Institute and visiting scholars at the Library. Art history classes make use of the resources of the Huntington Art Gallery and other museums in the area.

INDEPENDENT STUDIES PROGRAM

Independent studies is an educational alternative for undergraduates whose goals cannot be satisfied with a normal undergraduate option. The student gathers a three-person faculty committee, representing at least two divisions of the Institute, and chooses his or her own scholastic requirements under this committee's supervision. Approval must also be obtained from the Independent Studies Committee, a standing committee of the faculty. The independent studies program has no facilities of its own. Areas of study and research may be selected from any part of the Institute. *(For complete description see page 106.)*

MATERIALS SCIENCE

The field of materials science is concerned with the properties and behavior of materials of every kind. This field at the California Institute of Technology is largely restricted to metallic and polymer materials, essentially in the solid state. Faculty specifically in the field of materials science are concerned with the mechanical, physical, and chemical properties of solids. Some members of the faculty in electrical engineering are concerned with the behavior of electric and magnetic materials. Work in the general fields of polymers is carried on by faculty in chemical engineering and aeronautics.

Areas of Research
Current areas of research by the faculty and graduate students in materials science include:

A. Mechanical Properties
   1. Dislocation dynamics
   2. Theoretical and experimental deformation studies
   3. Behavior of metals under dynamic loading
B. Physical Properties
   1. Magnetic properties
   2. Electrical properties
   3. Electron transport properties
   4. Radiation effects
C. Chemical Properties
   1. Kinetics of phase transformations
   2. Diffusion in solids
   3. Metastable phases
D. Structure
   1. Theoretical and experimental transmission electron microscopy and diffraction studies of crystal defects and alloy phases
   2. X-ray studies of crystal defects and alloy phases

Physical Facilities
Research by the faculty and graduate students in materials science is conducted in the W. M. Keck Laboratory of Engineering Materials. Facilities are provided for crystal growth and alloy preparation, strain-free machining, annealing with atmosphere control, rapid quenching, optical metallography, X-ray diffraction, electron microscopy, and systems to control the application of stress (from load pulses of a few microseconds duration to static loading). Specialized

equipment is available for measuring low- and high-temperature specific heat, thermoelectric power, superconductivity, and mechanical properties. Computing facilities are available.

Other facilities in the field of materials science are available in the Spalding Laboratory of Engineering, the Firestone Flight Sciences Laboratory, and the Steele Laboratory of Electrical Sciences.

MATHEMATICS

Areas of Research

Graduate students in mathematics may find opportunities to select areas of research from the following list of fields and subfields of mathematics that are areas of current research interest of the mathematics faculty. *Algebra:* finite group theory, matrix algebra, quadratic forms; *Analysis:* classical real and complex analysis, ordinary and partial differential equations, harmonic analysis, integration theory and functional analysis, dynamical systems and ergodic theory; *Combinatorics:* block designs, coding theory and combinatorial matrix theory; *Mathematical Logic:* recursion theory, set theory and nonstandard analysis; *Mathematical Physics:* Schrödinger operators; *Mathematical Statistics:* sequential analysis; *Number Theory:* analytic number theory; *Geometry and Topology:* low-dimensional and algebraic topology, Riemannian manifolds, analysis on manifolds.

Physical Facilities

The mathematics department occupies three floors of the Sloan Laboratory of Mathematics and Physics. In addition to offices for the faculty and graduate students, there are classrooms, seminar rooms, a lecture hall, and a lounge for informal gatherings of the students and staff. Sloan Laboratory also houses a reference library in mathematics. The main mathematics library with its outstanding collection of journals is housed nearby in the Robert A. Millikan Memorial Library.

The Willis H. Booth Computing Center central computing facility serves the entire campus. Computing equipment is also available in the mathematics computer laboratory on the third floor of Sloan Laboratory.

MECHANICAL ENGINEERING

The way in which the term "mechanical engineering" is being used today embraces essentially all of those engineering aspects of a project that have to do with fluid flow, heat and mass transport, combustion, power, propulsion, structural integrity, mechanical design, robotics, optimization, and systems analysis. Projects in which mechanical engineers play a large role include nuclear and fossil-fuel power plants, as well as all types of energy production and conversion installations, transportation systems, propulsion devices, and pollution control. At the Institute, many of the basic disciplines are offered that are required for such applications. They are described in the following paragraphs under the headings of Design, Mechanics, Thermal and Fluids Engineering, and Jet Propulsion.

Mechanical Systems and Engineering Design. In the abstract, engineering design is the rigorous application of theory and analysis from traditional engineering disciplines to new problems. It marshals the principles and tools learned elsewhere to the synthesis of novel solutions. Design is mutifaceted, including applications from a variety of specialized branches of engineering. An imaginative, practical approach is emphasized for the solution of real problems involving many areas of technology. General areas of interest include engineering system design in the broad sense; mechanical systems, including system modeling, analysis and control; robotics and manipulators; computer-aided design and simulation. Opportunities exist for analysis as well as for the design, testing, evaluation, and fabrication of prototypes. A close relationship with design activities at the NASA Jet Propulsion Laboratory, as well as those in local aerospace industries, is maintained through seminars, visits, and exchange of ideas on current design problems.

Mechanics. Studies in the broad field of mechanics may be undertaken in either the applied mechanics option or the mechanical engineering option. In general, work pursued within the mechanical engineering option will have a more physical orientation. The specific areas available for advanced study closely parallel the research interests of the faculty.

Thermal and Fluids Engineering. Instruction and research are offered in these fields of mechanical engineering. Typical areas of research include free and forced convection heat transfer, boiling heat transfer and two-phase flow, friction and heat transfer in complex fluids and granular media, as well as studies in cavitation, turbomachinery, and some related areas of hydrodynamics.

Laboratory facilities are available for research in a large number of areas, especially heat transfer, pump dynamics, cavitation, hydrofoil analysis, flow visualization, and internal combustion engines.

Jet Propulsion. The Daniel and Florence Guggenheim Jet Propulsion Center was established at the California Institute of Technology in 1948 to provide facilities for postgraduate education and research in jet propulsion and rocket engineering. Students wishing to pursue courses of study and research in jet propulsion take degrees in aeronautics or mechanical engineering. The program generally emphasizes basic subjects (such as combustion, two-phase flow, turbomachinery, fire research, acoustics) that are applicable to a wide variety of engineering problems. The experimental facilities of the Jet Propulsion Center are located in the Karman Laboratory of Fluid Mechanics and Jet Propulsion. Some of the facilities of the Jet Propulsion Laboratory have also been used under special arrangement.

PHYSICS

Areas of Research

Graduate students in physics will find opportunities for research in the following areas where members of the staff are currently active.

High-Energy Physics. Experiments in elementary particle physics are carried out with accelerators at the Stanford Linear Accelerator Center (SLAC), the Deutsches Elektronen-Synchrotron (DESY) in Hamburg, and the Fermi National Accelerator Laboratory near Chicago. Current activities include the study of ψ and charmed particle decays at SLAC, and probes of fundamental theory at the shortest possible distances at DESY and SLAC. Caltech will be part of experiments approved for the new e^+e^- colliding beam accelerator SLC at SLAC. Work toward a large magnetic monopole detector is also under way.

A phenomenology group carries on an active program concentrating on the comparison of theories and experimental data. Current interests involve quantitative tests of quantum chromodynamics (QCD) for lepton and high transverse momentum processes.

Kellogg Radiation Laboratory. Studies of the structure and interactions of nuclei currently include experiments in the few MeV energy range, carried out with Caltech's in-house tandem electrostatic accelerators, and a new, expanding program of experiments in the GeV range, carried out at the Stanford Linear Accelerator Center (SLAC) and the Los Alamos Meson Physics Facility (LAMPF). The lower-energy experiments are designed to determine those properties of nuclei that result from their nucleonic structure, while the high-energy studies emphasize the effects of the quark structure of nucleons on the structure and properties of nuclei. Nuclear astrophysics is another major component of the laboratory's research program. Measurements of nuclear reaction cross sections and the strength distributions of nuclear weak interactions supply essential ingredients for understanding both cosmological and stellar evolution, and the synthesis of the Universal inventory of nuclei.

Nuclear and Particle Physics. This laboratory is engaged in the study of elementary particles and nuclei at low energies. At present the research emphasizes neutrino physics and the question of time reversal invariance in nuclear processes. A search for neutrino oscillations is currently being conducted at a power reactor in Switzerland. On campus, another experiment is searching for double beta decay in the nucleus ^{76}Ge. This search not only has implications for the mass of the neutrino, but also will provide evidence for another property of neutrinos, that of their symmetry when particles are replaced by antiparticles.

Cosmic Rays and Gamma Ray Astronomy. Measurements of energy and mass spectra of charged particles in space are carried out with sophisticated detectors carried on spacecraft and balloons. The data obtained are of interest for astrophysical phenomena such as element building in stars, astrophysical particle accelerators, and supernovae explosions. The gamma-ray astronomy program carries out astrophysical observations of solar, galactic, and extragalactic phenomena in the energy range 30 keV to 10 MeV. Studies have been undertaken with the HEAO and SMM spacecraft, and with newly developed imaging gamma-ray telescopes.

Infrared Astronomy. Astrophysical observations from 1 μm to 1mm wavelengths are carried out with ground-based telescopes at Palomar and other observatories. This group is heavily involved in making preparations for the new ten-meter Keck observatory on Mauna Kea. Caltech has been a major participant in a recent survey of the infrared sky conducted by the IRAS satellite, from which data are now being analyzed.

Submillimeter Astronomy. The research carried out in this group involves studies of star formation, interstellar gas, galaxies, and quasars. A new millimeter interferometer has been brought into operation at Caltech's Owens Valley Radio Observatory. It consists of three 10-meter antennas, each containing superconducting tunnel junction detectors. A fourth 10m antenna of very high surface accuracy is being placed in a dome on 14,000-foot Mauna Kea in Hawaii and will function as Caltech's Submillimeter Observatory. A shorter wavelength far-infrared astronomy program is also carried out from NASA's Kuiper Airborne Observatory.

Low Temperature Physics. Applied research includes work on high voltage and high frequency superconducting devices, superconducting electronic and digital devices, and heat transport at interfaces. Areas of fundamental interest are two-dimensional matter, phase transitions in two and three dimensions, phonon physics, and nonequilibrium aspects of the Josephson effect and type II superconductors.

Applied Physics. This group is engaged in the application of the techniques of theoretical and experimental physics to problems in surface physics, planetary science, and materials science. Experimental work is conducted on campus with low-energy particle accelerators. There is also an active program of off-campus work using the facilities of both industrial and other academic laboratories. Some recent studies have involved thin films, spatial distribution of trace materials near surfaces, sputtering phenomena, track damage by high energy ions, and the flow of granular material.

Gravity. The program of gravitational physics shows a close interplay between theory and experiment. The limits imposed by quantum measurement theory are being explored together with ways of reaching these limits by experiment. A new 40-meter interferometer for the detection of gravitational waves is now in operation and design work on a multikilometer-long detector is in progress.

Theoretical Physics. The principal areas under theoretical investigation are the nature of elementary particles and their high-energy interactions, the structure of atomic nuclei and their reactions, various problems in the area of general relativity and cosmology, the physics of the interplanetary and interstellar media, problems of stellar structure and stellar evolution, the synthesis of elements in stars, the nature of quasistellar radio sources and pulsars, condensed matter physics, and various areas of mathematical physics, including quantum field theory, statistical mechanical models, and the structure of non-relativistic quantum mechanics, especially atomic physics. A new trend is the use of the computer in theoretical physics, and Caltech is in the forefront of this activity. Arrays of microprocessors with up to 128 nodes have been built and used to solve astrophysics, condensed matter, and quantum field problems. A major new machine with up to 1,024 nodes is under construction.

Physical Facilities
The physics department is housed in six buildings grouped together on the south side of the campus: Norman Bridge Laboratory, Alfred P. Sloan Laboratory of Mathematics and Physics, W. K. Kellogg Radiation Laboratory, George W. Downs Laboratory of Physics, C. C. Lauritsen Laboratory of High Energy Physics, and the Synchrotron Laboratory. Members of the staff also carry out research at the Palomar Observatory and at the Owens Valley Radio Observatory. Several computers—typically PDP11s and VAXs—are available for use in research.

SOCIAL SCIENCE

Social science at Caltech offers a unique program closely integrating the fields of economics, law, political science, quantitative history, and anthropology. The program takes a practical but rigorous approach to social science—designing institutions to solve problems—and involves extensive use of scientific methods and mathematical modeling. Students can use their considerable quantitative talents to great advantage in this area.

The application of experimental methods in economics and political science was pioneered at Caltech. An exciting innovation in teaching as well as in research, experimentation enables the student to observe the operations of simplified economic and political systems and to discover how outcomes are constrained by the institutional environment in each context. The program offers a comprehensive knowledge of these economic, political, and legal institutions. Particular emphasis is placed on studying the relationships among economics, politics, and public policy in a vigorous scientific manner.

Areas of Research
The social science program is characterized by collaborative, multidisciplinary research. Often using innovative experimental methods, the faculty in economics, political science, and law explore such areas as group decision making, voting procedures, and market behavior.

Among the areas of basic and applied research are government regulation of business, the effect of consumer information on the prices and quality of goods and services, the design of institutions to solve environmental problems, the relationship between the structure and operating rules of a market and its performance, the adaptation of auction mechanisms to nonmarket as well as market situations, and the choice of strategies of candidates and voters in democratic elections.

INFORMATION FOR UNDERGRADUATE STUDENTS

3

REQUIREMENTS FOR ADMISSION TO UNDERGRADUATE STANDING

The undergraduate school of the California Institute of Technology is coeducational; there is no set ratio of men to women. Undergraduates are admitted only once a year—in September. All undergraduates at Caltech are expected to carry the regular program leading to the degree of Bachelor of Science in the option of their choice. Special students who wish to take only certain subjects and are not seeking a degree cannot be accepted.

ADMISSION TO THE FRESHMAN CLASS

The freshman class of approximately 215 is selected on the basis of (a) high grades in certain required high school subjects, (b) results of College Entrance Examination Board tests, and (c) recommendations and personal qualifications. The specific requirements in each of these groups are described below. Personal interviews with applicants and two or three of their teachers are held at their schools whenever feasible. An application fee of $25 is due at the time an application for admission is submitted. The fee is not refundable whether or not the applicant is admitted or cancels application, but it is applied on the first-term bills of those who are admitted and register in September. Checks or money orders should be made payable to the California Institute of Technology.

Application for Admission

An application form may be obtained by writing to the Office of Admissions, California Institute of Technology, Pasadena, CA 91125. It is to be returned directly to the Institute.

Completed admission application blanks and the $25 application fee must reach the Admissions Office not later than January 15. (Application to take entrance examinations must be made directly to the College Board at an earlier date.)

Transcripts of records covering three years of high school or secondary school should be submitted as soon as possible following the application. Students should arrange for a supplemental transcript covering the first semester of the senior year, or the first quarter if they attend a school operating on the quarter system, to be sent as soon as such records are available, but not later than March 1.

High School Credits

Each applicant must be thoroughly prepared in at least 15 units of secondary school work, each unit representing one year's work in a given subject in a high school at the rate of five periods weekly. Each applicant must offer all of the units in Group A and at least five units in Group B.

Group A:	English	3
	Chemistry	1
	Mathematics	4
	Physics	1
	United States History and Government	1
Group B:	Foreign Language, Shop, additional English, Geology, Biology or other Laboratory Science, additional History, Drawing, Commercial subjects, etc.	5

The three units of English are a minimum and four units are strongly recommended.

The four-year program in mathematics should include the principal topics of algebra, geometry, analytic trigonometry, and the elementary concepts of analytic geometry and probability. The program should emphasize the principles of logical analysis and deductive reasoning and provide applications of mathematics to concrete problems. A course in calculus is recommended if it is possible to arrange.

Entrance Examinations

In addition to the above credentials, all applicants for admission to the freshman class are required to take the following College Entrance Examination Board examinations: the Scholastic Aptitude Test, the Level II Achievement Test in Mathematics, and the English Achievement Test (with or without essay), plus any one of the following achievement tests: Physics, Chemistry, or Biology. The Level II Mathematics Test is designed for students who are in their fourth year of a mathematics program of the type outlined above. The Level II test does not presuppose an advanced placement course in mathematics. Note that the Scholastic Aptitude, the English Composition, and the Level II Mathematics tests must be taken, and that the choice lies only among Physics, Chemistry, and Biology—of which one must be taken. No substitution of other tests can be permitted. Very rarely the applications of those who have taken the Level I instead of the Level II Mathematics Test will be considered. It should be pointed out, however, that the Institute feels it can better judge the qualifications of an applicant who has taken the Level II test, and those who have not taken it will be handicapped in the competition for admission.

The Scholastic Aptitude Test and achievement tests must be taken no later than the January College Board Series. *It is important to note that no applicant can be considered who has not taken the required tests by January, but tests taken on any prior date are acceptable.* Students should have their test results sent to the Institute as soon as they are available. Students taking the January tests should submit the results from earlier tests by February 1. A student seriously interested in the Institute would be well advised to take the Level II Mathematics Test by the December administration if possible. No exception can be made to the rule that all applicants must take these tests.

Full information regarding the examinations of the College Entrance Examination Board is contained in the *Bulletin of Information,* which may be obtained without charge at most high schools, or by writing to the appropriate address given below. The tests are given at a large number of centers, but if any applicant is located more than 75 miles from a test center, he or she can make special arrangements to take the tests nearer home.

Applicants who wish to take the examinations in the western United States or Canada, or in Mexico, Australia, or the Pacific Islands should address their inquiries by mail to College

Entrance Examination Board, P.O. Box 1025, Berkeley, CA 94701. Check the *Bulletin of Information* for the exact dividing line.

Candidates applying for examination in other areas should write to College Entrance Examination Board, P.O. Box 592, Princeton, NJ 08540.

All applications to take examinations in the United States should reach the appropriate office of the Board at least four weeks in advance of the test date. Applications for examinations to be taken abroad must arrive at least six weeks in advance. Please note that requests to take the examinations and all questions referring exclusively to the examinations are to be sent to the College Entrance Examination Board at the appropriate address as given above and not to Caltech.

Personal Interviews and Recommendation Forms

Enclosed with the Institute's application form are three recommendation forms, which the applicant should distribute to three teachers at the applicant's high school who are well acquainted with his or her capabilities and preparation, with the request that they be filled out and returned directly to Caltech. These recommendation forms provide valuable information on candidates. The College Board scores, the last of which will be received by about February 15, provide further important data. Since there are many more applicants to Caltech than our facilities can accommodate, as much information as possible is desired on each candidate for admission. Wherever preliminary information shows that an applicant has a chance of gaining admission, the Institute will attempt to hold a personal interview at the school he or she is attending. It is not possible to visit all of the schools involved. If a personal interview cannot be held, this in no way prejudices an applicant's chances of admission. The applicant has no responsibility with regard to the personal interview unless and until a notice is received giving the time and date when a representative will visit the school. These visits occur generally between March 1 and April 6.

Notification of Admission

Final selections will ordinarily be made and the applicants notified of their admission or rejection well before May 1. Most College Board member colleges have agreed that they will not require any candidate to give final notice of acceptance of admission or of a scholarship before this date. Upon receipt of a notice of admission an applicant should immediately send in the registration fee of $100, which will be applied to the first term's bill. In the event he or she subsequently cancels the acceptance, $50 of the registration fee will be refunded if the cancellation occurs before August 1. Places in the entering class will not be held after May 1, if the applicant could reasonably be expected to have received notice at least ten days before that date. Otherwise, places will be held not more than ten days after notification. When the registration fee has been received, each accepted student will be sent an acknowledgement. It is assumed that any academic work in progress will be completed in a satisfactory manner.

Deferral of Entrance

The Institute will consider requests from newly admitted freshmen for a year's deferral of entrance for such purposes as studying abroad, working, or maturing. It is possible that not all requests will be granted: the seriousness and appropriateness of the purpose and the number of requests received will be determining factors.

Students who wish to request a year's deferral of entrance must (1) pay the registration fee by May 1 in the normal manner; (2) make a written request stating the purpose of postponement and the plans for using the extra year.

Early Decision Plan

The Institute will consider a few outstanding candidates who wish to make Caltech their first choice under an early decision plan. Such candidates must have taken the required College Board tests by the end of their junior year or at the following June administration, must have an excellent school record, and must have the thorough backing of their high school.

An applicant for admission under the early decision plan must have his or her credentials on file by October 15 of the senior year. (If the candidate is applying for financial aid, the financial aid application should be filed with the College Scholarship Service by the same date.) Early decision applicants will be notified by December 10 whether or not they have been accepted. An accepted applicant is then expected to withdraw all applications to other colleges. An applicant who is not accepted under the early decision plan will be considered without prejudice for admission at the regular time in April, unless final rejection is received in December.

Advanced Placement Program

A number of high schools and preparatory schools offer selected students the opportunity to accelerate and to take in the senior year one or more subjects that are taught at the college level and cover the material of a college course. The Institute encourages students to take advantage of such courses or to supplement their high school courses with mathematics and science courses at a local college. Credit for such work completed will be granted as appropriate by the faculty at the Institute at the time the student enrolls. Credit is not awarded automatically for Advanced Placement Examinations, International Baccalaureate Examinations, or for college courses completed.

Chemistry. Students with a particularly strong background in chemistry may elect to take Chemistry 2, Advanced Placement in Chemistry (or, in exceptional cases, Chemistry 21, The Physical Description of Chemical Systems, or Chemistry 41, Chemistry of Covalent Compounds), rather than Chemistry 1, General and Quantitative Chemistry. It is assumed that such students have reasonable competence in the following areas: 1) *elementary* theories of atomic structure and electronic theories of valence, 2) chemical stoichiometry, 3) computations based upon equilibrium relationships, and 4) elementary chemical thermodynamics. For those students who qualify for Advanced Placement in Chemistry, the Institute requirement of 18 units of Ch 1 abc can be satisfied by completing with passing grades two terms of (i) Ch 2 ab (9 units each term), (ii) Ch 21 abc (9 units each term), or (iii) Ch 41 abc (9 units each term). The student's qualification for Advanced Placement in Chemistry will be determined in a personal interview with the Ch 2 instructor.

Mathematics. Normally, an entering freshman will take Ma 1 abc, Freshman Mathematics. This course will cover the calculus of functions of one variable; an introduction to differential equations; vector algebra; analytic geometry in two and three dimensions; infinite series. The course will be divided into a lecture part, discussing primarily the mathematical notions of the calculus and the other topics listed above, and a recitation part, providing active practice in the application of mathematical techniques.

During the summer, entering freshmen will be invited to outline their advanced training in mathematics and take a placement examination. The appropriate course and section for each student will be determined on the basis of this information. Those students whose preparation permits them to begin with Ma 2 a will receive credit for Ma 1 abc. Exceptionally well-prepared students may receive additional credit for Ma 2 abc.

Physics. The required freshman physics course, Ph 1 abc, is quite unlike most advanced placement work, and entering freshmen are encouraged to take Ph 1, whatever their high school preparation. Students with unusually advanced backgrounds who do well on the Caltech placement test may, however, be given the option of advanced placement.

New Student Orientation

All freshmen are expected to attend the New Student Orientation as a part of the regular registration procedure. Upperclass transfer students are not required to attend.

The orientation, usually off campus, takes place during three days immediately following freshman registration for the fall term. A large number of faculty members and upperclass student leaders participate to help introduce the new student to the Caltech community. The orientation period provides an opportunity for the new student to become acquainted with the campus, the Honor System governing personal conduct, and other aspects of life at Caltech. In addition, he or she can meet classmates and a number of the upperclass students and faculty. Thus the new student can begin to feel at home at Caltech and share in the common agreement on intellectual and moral standards before the pressure of academic work begins.

ADMISSION TO UPPER CLASSES BY TRANSFER

The Institute admits to its sophomore or junior class a small number of students who have made satisfactory records at other institutions of collegiate rank and who do satisfactorily on the transfer entrance examinations. Transfer students are not admitted to the senior year. In general only students whose grades, especially those in mathematics and science, are well above average are permitted to take the entrance examinations. Students who have completed more than two years of college work will not be authorized to apply.

No application fee is charged in the case of transfer students, but applicants should not come to the Institute expecting to be admitted to the examinations without first receiving definite permission to take them.

Students will be allowed to apply for transfer admission only if they have completed elsewhere the equivalent of the courses required of students at the Institute. This means that applicants for transfer into the sophomore class must have completed at least one full year of calculus and one full year of physics at the college level. For transfer to junior level standing, two years of each of these subjects are required. A student planning to major in chemistry or chemical engineering should also have completed one year of college-level chemistry. Students with two years of mathematics and one year of physics would not be granted full standing as a junior.

An applicant for admission as a transfer student must write to the Office of Admissions of the California Institute of Technology stating his or her desire to transfer, the choice of engineering or one of the options in science or humanities, and the number of years of calculus and of physics that will have been completed by the date of transfer. A postage-free return postcard for this purpose may be obtained from the Admissions Office upon request. At the same time the applicant must present a transcript of his or her academic record to date, showing in detail the character of his or her previous training and the grades received in college. Transcripts should also clearly indicate courses in progress in the latter half of the year. After the postcard has been received and the transcripts have been evaluated by the Admissions Office, an application blank will be sent, provided the grades and subjects on the transcripts meet the transfer requirements.

Please note that an application blank is not sent until a preliminary letter or the postcard provided by the Admissions Office and transcripts have been received and evaluated. Transcripts are held in the files until such a letter or postcard is received.

Applications must be on file in the Admissions Office by April 1. Transcripts should, therefore, be sent no later than March 15. Applicants living in foreign countries must have applications and transcripts on file by March 1 at the latest.

Information with regard to acceptance or rejection for all candidates is sent before June 20. Candidates who are admitted to the Institute must send a second transcript of their work showing final grades received for any work in progress during the spring.

All transfer applicants must arrange to have sent in their scores on the Scholastic Aptitude Test (SAT) of the College Entrance Examination Board. If they have taken the SAT in previous years, these scores will be acceptable; but applicants must instruct the College Board (see address on page 61) to send the scores to the Institute. If the SAT has not been taken previously, it must be taken by the March series at the latest. College Board Achievement Tests are not required of transfer applicants. Before their admission to the upper classes of the Institute, all students are required to take entrance examinations in mathematics and physics covering the work for which they desire credit. In addition, an examination in chemistry is required for those planning to major in chemistry or chemical engineering.

Two examinations of a comprehensive character are offered in mathematics and physics. One examination in each subject covers the work of the first year; the other examination, that of the first and second years. Representative examination papers will be sent to approved applicants along with application materials. The Institute courses for which those admitted will receive credit will be determined by the Committee on Upperclass Admissions and the departments concerned, on the basis of the applicants' previous records and the results of their examinations.

It is not possible to give definite assurance that a transfer student entering the sophomore year will graduate in three years or that one entering as a junior will graduate in two years. Much depends on the amount and nature of the credit granted at the time a student registers in September and on the possibility of fitting deficiency make-ups into the regular schedule.

The first-year chemistry course at Caltech differs from those given at many other colleges because of the inclusion of a substantial amount of quantitative analysis in the laboratory work. A transfer student who has had a one-year college course in inorganic chemistry and qualitative analysis will be considered to have met the first-year chemistry requirements, provided, of course, that grades have been satisfactory. Those wishing to major in biology, chemistry, or geology will be required to take certain portions of freshman chemistry if they have not had the equivalent laboratory work elsewhere.

The transfer examination in chemistry is required only of those wishing to major in chemistry or chemical engineering. This examination is the same for both sophomore and junior standing and covers general chemistry. Transfer students entering the junior year in chemistry will be able to take the sophomore organic chemistry course during their first year at the Institute.

Examinations for admission to upper classes are given in the first two weeks in May. No other examinations for admission to upper classes will be given.

Applicants residing at a distance may take the examinations under the supervision of their local college or university authorities, provided definite arrangements are made well in advance.

Students whose native language is not English and who attend schools abroad will be required to take the Test of English as a Foreign Language (TOEFL). This test is an Educational Testing Service test and is given all over the world, including the United States, four times a year. This test must be taken by the February series at the latest. Full information on how and where to take the test should be obtained from ETS.

It is not possible to answer general questions regarding the acceptability of courses taken elsewhere. The nature of the work at the Institute is such as to demand that all courses offered for credit be scrutinized individually. In case the standard of the work taken elsewhere is uncertain, additional examinations may be required before the question of credit is finally determined.

Transfer students are required to pay a registration fee of $10 upon notification of admission to the Institute. If the application is cancelled, the registration fee is *not* refundable unless cancellation is initiated by the Institute.

The 3-2 Dual Degree Plan

The California Institute of Technology has an arrangement whereby students enrolled in certain liberal arts colleges may follow a prescribed course for the first three years and then transfer into the third year of the engineering option at the Institute without further formality, provided that they have the unqualified recommendation of the officials at the liberal arts college that they are attending. After two full years' residence at the Institute and after satisfactorily completing all the remaining work required for a bachelor's degree in engineering, they will be awarded a Bachelor of Arts degree by the college from which they transferred and a Bachelor of Science degree by the Institute. Application for admission at the freshman level under this dual degree plan should be made to the liberal arts college.

The colleges with which these arrangements exist are Bowdoin College, Brunswick, Maine; Bryn Mawr College, Bryn Mawr, Pennsylvania; Grinnell College, Grinnell, Iowa; Occidental College, Los Angeles, California; Ohio Wesleyan University, Delaware, Ohio; Pomona College, Claremont, California; Reed College, Portland, Oregon; Wesleyan University, Middletown, Connecticut; Whitman College, Walla Walla, Washington.

EXCHANGE PROGRAMS

Exchange programs exist with Occidental College, Scripps College, and Art Center College of Design, permitting Caltech students to receive credit for courses taken at these colleges. Students from these colleges also may receive credit for courses taken at the Institute. Tuition payments are not required, but the student may have to pay any special fees. The student must obtain approval from the instructor of the exchange course. Exchange courses taken by Caltech students must have prior approval by the student's option, by the division providing courses most similar to the proposed course, and by the Registrar. Students wishing to take such courses should obtain the appropriate form at the Registrar's Office, get the required signatures as above, and return it to the Registrar. Freshmen at Caltech ordinarily cannot participate in this exchange.

In addition, through the office of the Dean of Students, informal exchange programs are conducted with several colleges and universities throughout the country. The colleges currently in the program include Antioch, Pomona, Swarthmore, and Williams. Under these programs, a student can visit another campus for a period ranging from one term to a full academic year, without the formalities of transfer proceedings or written applications. Any student interested in the informal program should check with the Dean of Students for details.

ROTC

Through arrangements with the University of Southern California, an Air Force Reserve Officers' Training Corps is available to qualified full-time Caltech students on a competitive basis, and an Army Reserve Officers' Training Corps program is available through the extension program of the University of California at Los Angeles. The Air Force Reserve (AFROTC) program is a two- or four-year program available to juniors or freshmen. Successful completion of this program leads to a commission as a Second Lieutenant in the Air Force Reserve. The four-year program for freshmen must be applied for by December 1 of the year prior to entering college. The deadline for the other program is in the year prior to entering the program. All scholarship recipients receive full tuition, required fees and books, uniforms, and $100 a month. Academic units earned in this program count toward fulfillment of graduation requirements. Students desiring this credit should request that an official transcript be forwarded to Caltech. The Air Force ROTC program has a compulsory summer component. For additional information on this program, contact the Department of Aerospace Studies (AFROTC) at the University of Southern California, Los Angeles, CA 90007, (213) 743-2670. The Army ROTC offers four-, three-, and two-year scholarships that range from $200 to $5,000 a year, depending on type of award and tuition costs. High school seniors must complete applications for national competition before December 1 prior to the year they plan to attend. Completion of the program leads to a commission as a Second Lieutenant in one of seventeen specialties in the Army Reserve, National Guard, or Regular Army. For additional information, contact the Department of Military Science, UCLA, Mens's Gym, Room 142, Los Angeles, CA 90024, (213) 825-7381.

REGISTRATION REGULATIONS

Procedures

Students must register in person on the dates specified in the academic calendar. Registration material is to be picked up at a location designated by the Registrar and returned to the registration area when completed. Students are not registered until they have both

a. turned in a signed registration card with their approved study list, and
b. made satisfactory arrangements with the Office of Student Accounts for the payment of all fees due the Institute.

Any student who has not completed both phases of registration within one week after registration day will be removed from the Institute rolls.

Students are required to maintain continuity of registration until the requirements for the Bachelor of Science degree are fulfilled, except in the case of an approved leave of absence. If continuity is broken by withdrawal without leave, reinstatement is required before academic work may be resumed.

Changes of Registration

All changes in registration must be reported to the Registrar's Office by the student prior to the published deadlines. A grade of F will be given in any course for which a student registers and which he or she does not either complete satisfactorily or drop. A course is considered dropped when a drop card is completed and returned to the Registrar's Office. A student may not at any time withdraw from a course that is required for graduation in his or her option without permission of the Dean.

A student may not add a course after the last day for adding courses, or withdraw from a course after the last date for dropping courses, without the approval of the Undergraduate Academic Standards and Honors Committee. Registration for added courses is complete when an add card, signed by the instructor and the student's adviser, has been filed in the Registrar's Office. No credit will be given for a course for which a student has not properly registered. The responsibility for submitting drop cards and add cards to the Registrar's Office before the deadlines for dropping or adding courses each term rests entirely with the student. Failure to fulfill the responsibility because of oversight or ignorance is not sufficient grounds to petition for permission to drop or add courses after the deadline. It is the policy of the Undergraduate Academic Standards and Honors Committee that no petitions for the retroactive dropping or adding of courses will be considered except under very extenuating circumstances.

Withdrawal from the Institute

Formal separation from the Institute is effected by filing a completed withdrawal card with the Registrar. The effective date of withdrawal is the date of the signature of the Dean or Associate Dean of Students. Unless the student withdraws with an approved leave of absence (see next section), he or she must petition for reinstatement. Reinstatement rules are the same as those listed under scholastic requirements. No courses or grades will appear on the permanent record card of a student who withdraws on or before drop day of any term. The card of a student who withdraws with a leave of absence during the period between drop day and the end of the term will show the list of registered courses with W in place of grades. Students withdrawing without a leave of absence during that period will receive grades as reported by the instructors. If no grade is reported, an F will be recorded.

A student withdrawing at any time during a term without filing a formal withdrawal card will be considered to have withdrawn at the end of the term. Any grades reported by the instructors will be recorded on the permanent record card; the grade of F will be recorded for all other courses.

Summer Research

Qualified undergraduate students who are regular students at the Institute are permitted to engage in research during the summer, but in order to receive academic credit the student must have the approval of his or her division and must file a registration card for such summer work in the Office of the Registrar before June 1. Students who are registered for summer research will not be required to pay tuition for the research units.

SCHOLASTIC REQUIREMENTS

All undergraduates are required to meet certain scholastic standards as outlined below.

Ineligibility for Registration. Eligibility to register is determined by the student's record as of Registration Day of the term in which registration is sought. Undergraduates who register for programs that make it appear they are no longer candidates for a B.S. degree or who are not making satisfactory academic progress may be refused further registration by the Undergraduate Academic Standards and Honors Committee. Freshmen who have accumulated 27 or more units of E or F, exclusive of PE, are ineligible to register for subsequent terms and must petition the Committee for reinstatement if they wish to continue as students. The Dean of Students or the Associate Dean may act on the petition if the student has received fewer than 42 units of E or F, exclusive of PE. For other petitions action can be taken only by the Committee. Freshmen who have been reinstated will be ineligible to register if in any subsequent term of their freshman year they obtain 6 or more units of E or F, exclusive of PE. In this situation, action can be taken only by the Committee.

Undergraduate students, except freshmen, are ineligible to register for another term:

(a) If they fail during any one term to obtain a grade-point average of at least 1.4, or if they receive 27 or more units of E or F, exclusive of PE, during any one term.

(b) If they fail to obtain a grade-point average of at least 1.9 for the academic year, or if they accumulate 45 or more units of E or F, exclusive of PE, over the academic year. (Students who have completed at least three full terms of residence at the Institute and have been registered for their senior year shall no longer be subject to the requirement that they make a grade-point average of at least 1.9 for the academic year. Seniors must, however, receive a grade-point average of at least 1.4 or receive fewer than 27 units of E or F each term.)

(c) If once reinstated, they fail to complete a full load of at least 36 units in the following term with a grade-point average of at least 1.9.

If a late grade makes a student ineligible after the start of the next term, the permanent record card shall show the ineligibility and a reinstatement. If the late grade is reported to the Registrar before midterm deficiency notices are due for the subsequent term, the student shall be held to the condition in (c) above.

If a late grade received on or before the last day for adding classes makes a student who has been reinstated eligible, the ineligibility and the reinstatement will be removed from the student's record.

No student ineligible to register on Registration Day will be permitted to register unless a petition for reinstatement has been submitted and acted upon.

Students ineligible for registration because of failure to meet the requirements stated in the preceding paragraphs may submit a petition to the Undergraduate Academic Standards and Honors Committee for reinstatement, giving any reasons that may exist for their previous unsatisfactory work and stating any new conditions that may lead to better results. Each such petition will be considered on its merits. *For the first such ineligibility,* the petition will be acted upon by the Dean of Undergraduate Students, after consultation with the student and examination of the record. At the dean's discretion, such cases may be referred to the Undergraduate Academic Standards and Honors Committee for action. *All subsequent reinstatements must be acted upon by the Committee.* In any case being considered by the Committee, the students may, if they wish, appear before the Committee or, on request by the Committee, they may be required to appear. A second reinstatement will be granted only under exceptional conditions.

Departmental and Option Regulations

Continuing in an Option. Students whose grade-point averages are less than 1.9 at the end of an academic year in a specific group of subjects designated by their department or option may, at the discretion of their department, be refused permission to continue the work of that option. Such disbarment does not prevent the students from continuing in some other option or from repeating courses to raise their average in their original option. Students without an option will fall under the direct jurisdiction of the Dean of Students. Students may remain without an option for no more than one year.

Change of Option. An undergraduate in good standing at the Institute shall be permitted to transfer into any option of his or her choice provided he or she has (a) a 1.9 G.P.A. in subjects required for graduation in that option or in a specific group of subjects designated by that option or (b) permission of the option representative or committee. A change of option is effected by obtaining a Change of Option petition from the Registrar's Office. The completed petition must then be signed by the option representative for the new option (who will assign a new adviser), and filed with the Registrar's Office. Institute regulations require that a student who has made normal progress at the Institute be able to change options at any time up to the end of the sophomore year without penalty either as to time until graduation or as to excessive unit requirements in any term.

Term Examinations will be held in all subjects unless the instructor in charge of any subject shall arrange otherwise. No student will be exempt from these examinations. When conflicts exist in a student's schedule, it is the student's responsibility to report the conflict to the instructor in charge of one of the conflicting examinations and make arrangements for another time.

Satisfactory Academic Progress. A student who has earned, on the average, 36 units or more for each term in residence is considered to be making satisfactory progress toward a degree. Satisfactory progress is normally determined at the end of the third term of each academic year.

Graduation Requirement. To qualify for graduation a student must complete the prescribed work in one of the options with a passing grade in each required subject and with a grade-point average of 1.9. A grade of F in an elective course need not be made up, provided the student has received passing grades in enough other accepted units to satisfy the minimum total requirements of the option.

Graduation in the Normally Prescribed Time. Any undergraduate student who fails to complete the requirements for graduation at the end of the normally prescribed time must petition the

Undergraduate Academic Standards and Honors Committee for approval to register for further work.

Requirement for a Second Bachelor of Science Degree. Under exceptional circumstances a student may be permitted to return to study for a second Bachelor of Science degree. As a general rule this second degree must be in an option which is not in the same division as that of the original degree. To receive this permission the student must petition the Curriculum Committee. If the petition is approved the student must then register for three consecutive terms of additional study, completing in each term at least 36 units, and must meet all the requirements for graduation in the second option. If additional time is needed to complete the degree, the student must also petition the Undergraduate Academic Standards and Honors Committee for an extension. A student admitted for a second Bachelor of Science degree in a particular option may not change to another option without first submitting a new petition to the Curriculum Committee and receiving the explicit approval of that committee.

Honor Standing. At the close of each academic year the Committee on Undergraduate Academic Standards and Honors awards Honor Standing to students in the sophomore and junior classes, based on the scholastic records of the students.

Graduation with Honor. Students who have achieved a high scholastic standing or who have carried out creative research of high quality may be recommended to the Faculty for graduation with honor by the Committee on Undergraduate Academic Standards and Honors. The Committee shall consider for graduation with honor those students who have achieved an overall grade-point average of 3.5 and others who, on the basis of exceptional creativity, have been recommended to the Committee by a faculty member or by a Division of the Institute.

Excess of or Fewer than Normal Units (Overloads and Underloads). An overload is defined as registration for more than 58 units and an underload is registration for fewer than 36 units. A student who wishes to carry an overload in any term must obtain the approval of his or her adviser and the approval of the Undergraduate Academic Standards and Honors Committee. Petitions for overload will not be accepted later than the last day for adding classes in any term.

Underloads must also be approved by the Undergraduate Academic Standards and Honors Committee. An underload may be granted if the student's record is such that at the end of the term in question a minimum of 43 units per term in residence will have been completed. Approval of an underload under other conditions will not be granted to any student who is not a senior, except in extraordinary circumstances. The Undergraduate Academic Standards and Honors Committee has the latitude, however, to grant part-time status to a small number of exceptional, highly motivated students with at least junior standing for reasons deemed valid by the committee.

Miscellany

Transfer of Credit from Other Institutions. Regularly enrolled students who want to obtain credit for college courses taken elsewhere should have a copy of the transcript of their work sent to the Registrar's Office. The student should then obtain an "Allowance of Credit" form from the Registrar's Office; credit will be granted when this form, with the appropriate signatures, is returned to the Office.

Other Allowances of Credit. Except for transfer credit and advanced placement credit upon admission, credit will not be granted for Caltech courses not registered for, except in special circumstances by arrangement with the instructor. Such arrangements must be approved by the Curriculum Committee, and the student must petition the Committee before the work is undertaken.

Selection of Option. At the beginning of the third term, freshmen must notify the Registrar's Office of their selection of an option in engineering, humanities, social sciences, or science to be pursued in subsequent years. Upon the selection of an option, a freshman will be assigned an adviser in that option, whose approval must then be obtained for preregistration for the following year.

An undergraduate may be allowed to major in two options for the Bachelor of Science degree. As a general rule, the two options should not be in the same division. The student must obtain the approval of the Curriculum Committee prior to the beginning of the senior year. He or she will then be assigned an adviser in each option.

Candidacy for the Bachelor's Degree. A student must file with the Registrar a declaration of his or her candidacy for the degree of Bachelor of Science on or before the first Monday of November preceding the date on which he or she expects to receive the degree. All subjects required for graduation, with the exception of those for which the candidate is registered during the last term of his or her study, must be completed and the grade recorded, by the second Monday of May preceding commencement.

Transcripts of Records. A student, or former student, may request that official transcripts of his or her records be forwarded to designated institutions or individuals. Requests should be filed at the Registrar's Office at least five days before the date on which the transcripts are to be mailed.

ATHLETICS AND PHYSICAL EDUCATION

Before graduation each undergraduate is required to successfully complete three terms of physical education. This requirement may be satisfied entirely or in part by participation in intercollegiate athletics, successful completion of a physical education class, or successful completion of a student-designed program of physical fitness.

Participation as a bona fide member of an intercollegiate team for the period covered by a sport in a given term satisfies the requirement for that term. Students dropping from an intercollegiate team before the end of the term or the season must enroll in a physical education class immediately, if they wish to receive credit for physical education.

A broad program of instruction is provided each term. Enrollment in classes is conducted in the gymnasium and pool on the day of General Registration. Students planning to enroll in sailing must pass a swimming test. Standards for evaluation of student performance will be clearly defined at the beginning of each class. Participation in intramural sports will count toward the successful completion of an instructional activity.

Student-designed programs of physical fitness are submitted in writing to the Department of Physical Education during the first week of each term. These programs must provide for regular participation in vigorous physical activity at least three days per week. The programs may consist of individual or group participation and may include intramural sports participation. At the end of the term the student files a brief written report with the Department of Physical Education reviewing his or her accomplishment of prestated objectives. It is assumed that students proposing their own programs of physical fitness are competent in these activities.

UNDERGRADUATE EXPENSES

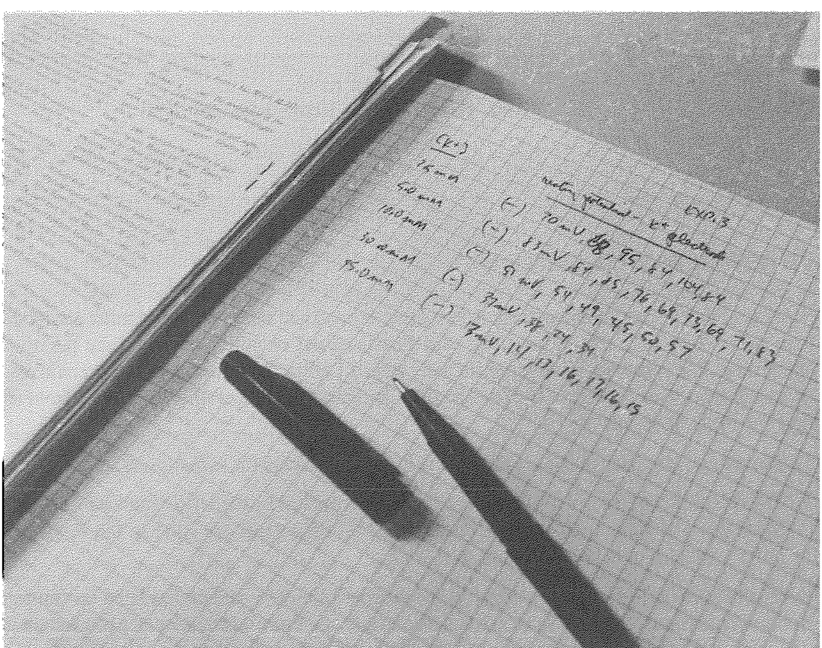
For freshmen applying for admission, there is a $25 application fee. This fee is not refundable, but it will be applied to tuition fees upon registration.

A registration fee, $100 for freshmen and $10 for transfer students, is payable upon notification of admission. This fee is not refundable, but it will be applied to tuition fees upon registration. Housing contracts must be submitted to the Master's Office by the date specified in the instructions accompanying the contract.

Expense Summary 1986-87

General:	
General Deposit	$ 25.00[1]
Tuition	10,440.00
Student Body Dues, including *The California Tech*	60.00[2]
Assessment for *Big T*	24.00[2]
	$10,549.00
Other:	
Student House Living Expenses, including 10 meals per week while Institute is in session (Room and Board rates are subject to change)	
Room	$1,675.00
Board	1,540.00
Dues	75.00
Meals not covered by board contract are available at Chandler Dining Hall (approx.)	1,012.00
Books and Supplies (approx.)	480.00
	$4,707.00

[1]This charge is made only once during residence at the Institute.
[2]Fees subject to change by action of the Board of Directors of the Associated Students of the California Institute of Technology.



The following is a list of undergraduate student fees at the California Institute of Technology for the academic year 1986–87 together with the dates on which these charges are due. Fees are subject to change at the discretion of the Institute.

Date	*First Term*	*Fee*
September 24, 1986	General Deposit	$ 25.00
(Freshmen)	Tuition	3,480.00
September 29, 1986	Associated Student Body Dues	20.00
(All Others)	Assessment for *Big T*	8.00
	Room and Board (for on-campus residence)	1,184.40
	Student House Dues	25.00
	Second Term	
January 5, 1987	Tuition	$3,480.00
	Associated Student Body Dues	20.00
	Assessment for *Big T*	8.00
	Room and Board (for on-campus residence)	1,037.40
	Student House Dues	25.00
	Third Term	
March 30, 1987	Tuition	$3,480.00
	Associated Student Body Dues	20.00
	Assessment for *Big T*	8.00
	Room and Board (for on-campus residence)	993.20
	Student House Dues	25.00

Tuition Fees for fewer than normal number of units:

	36 units or more	Full Tuition
	Per unit per term	$ 97.00
	Minimum tuition per term	970.00
	Audit Fee $97.00 per lecture hour, per term.	

Other Items of Interest

Refunds. Students withdrawing from the Institute or reducing their number of units during the first three weeks of a term are entitled to a partial refund of tuition based on the period of attendance. The schedule for the specific percentage of tuition to be refunded for specific days of attendance is shown below. The days in attendance are the number of days counted from the first day of the term to:

1. The date of approval of the request by the Dean of Students for *withdrawals;*
2. The date that registration for the reduced units is approved by the Undergraduate Academic Standards and Honors Committee or the date that drop cards are filed in the Registrar's Office, whichever is later, for *reduction in units.*

Board contracts are prorated according to the number of days a student has been on campus. Room contracts are charged on a term basis for all students. Early termination of a room contract will be granted only with the approval of the Master of Student Houses.

Tuition Refund Schedule. Tuition is refunded according to the following schedule:

Days	*Percent of tuition due the Institute*	*Days*	*Percent of tuition due the Institute*
1–7	20.00	15	40.00
8	30.67	16	41.33
9	32.00	17	42.67
10	33.33	18	44.00
11	34.67	19	45.33
12	36.00	20	46.67
13	37.33	21	48.00
14	38.67	22	100.00

ASCIT Dues. As a service to the Associated Students of the California Institute of Technology, Inc., or ASCIT, dues, of $60 per year and an assessment of $24 for the college annual, the *Big T,* are collected by the Institute and turned over to ASCIT. A subscription to the student newspaper, *The California Tech,* is included in these dues, and the balance is used in the support of student activities as deemed appropriate by the ASCIT Board of Directors. Students not wishing to join ASCIT or to purchase the *Big T* should so indicate at the time of registration.

General Deposit. Each new student is required at his or her first registration to make a general deposit of $25, to cover possible loss and/or damage of Institute property. Upon graduation or withdrawal from the Institute, any remaining balance of the deposit will be refunded.

Fees for Late Registration. Registration is not complete until the student has personally turned in the necessary forms for a program approved by his or her adviser and has paid tuition and other fees. A penalty fee of $10 is assessed for failure to register within five days of the scheduled dates.

Student Houses. Students in the houses must supply their own blankets. Bed linens and towels are furnished and laundered by the Institute.

Application for rooms in the student houses may be made by addressing the Master of Student Houses, 0-54, California Institute of Technology, Pasadena, CA 91125.

Special Fees. Students taking the Summer Field Geology course (Ge 123) should consult with the division about travel and subsistence arrangements and costs.

Unpaid Bills. All bills owed the Institute must be paid when due. Any student whose bills are past due may be refused registration for the term following that in which the past due charges were incurred. Transcripts will not be released until all bills have been paid or satisfactory arrangements for payment have been made with the Office of Student Accounts.

FINANCIAL AID

Caltech offers financial assistance to students from families whose resources are insufficient to meet the total cost of education. Family contributions are calculated using federally approved formulas, and are based on an analysis of information provided on the financial aid forms and supporting documents that are filed with the Financial Aid Office each year. Financial need is the difference between a standard budget and family financial resources. Components of the budget include actual tuition and fees, room and board, an allowance for meals not covered in the Institute board contract, books and supplies, personal expenses, other allowable expenses approved by the Director of Financial Aid, and a limited travel allowance (see page 71 for a breakdown of the basic budget for 1986–87). Note: a travel allowance is not included for students whose residence is outside the U.S., Canada, or Mexico.

Eligibility for each type of assistance varies, depending upon the source of funds. Most students who attend Caltech receive some kind of financial aid from Caltech, federal and state agencies, outside organizations such as foundations and businesses, and/or lending institutions. Assistance offered by Caltech includes federal and institutional grants, low-interest loans, and subsidized jobs. Students with complete financial aid applications on file will be considered for all types of need-based assistance. A renewal application must be submitted each year. In general, assistance is available to eligible students for the first 12 terms of registration (or the equivalent for transfers), providing they maintain satisfactory academic progress as defined on page 68.

Although Caltech expects students and families to finance the cost of education to the fullest extent possible, the Institute will make every effort to assist those who need help, including those whose financial circumstances change during the year. In addition to direct financial assistance, information is offered about education payment plans and financial planning resources. (For information on non-need-based scholarships, see page 78.)

All students who believe they will need assistance to attend Caltech are encouraged to submit financial aid applications to the Financial Aid Office. Application procedures are outlined below.

The financial aid staff is happy to talk with students and their families at any time to explain the application process and Caltech's computations. For further information on determination of financial need, application procedures, and financial aid awards and programs, contact the Director of Financial Aid, California Institute of Technology, 12-63, Pasadena, CA 91125, 818-356-6280.

How to Apply for Financial Aid

There are slightly different application procedures for each category of students who apply for financial aid. The categories are:

- Early Decision Admission Candidates
- Freshman Admission Candidates
- Transfer Admission Candidates
- All International Student Applicants (except Canadians and Mexicans)
- Returning Students
- Self-Supporting Students

Note: In addition to fulfilling categorical requirements, students must submit several additional documents to complete their application. These documents are discussed under the section *General Requirements*.

Early decision admission candidates must file an Early Version Financial Aid Form with the College Scholarship Service by December 1 of the year preceding the year in which they hope to enter Caltech (the regular FAF and Student Aid Application for California [SAAC] cannot be filed until January 1). Caltech should be designated as a recipient of the form (code 4034). Students accepted to Caltech will receive a preliminary offer of financial aid with their offer of admission. Between January 1 and February 11 they must also complete the application procedures for prospective freshmen (see below).

Freshman admission candidates (other than international students — see below) must submit a copy of the Financial Aid Form (FAF), completed on both sides, to the College Scholarship Service between January 1 and February 11 and designate Caltech as a recipient (code 4034). *California residents* must use the Student Aid Application for California (SAAC) instead of the FAF, and complete both sides. A preliminary award will accompany the admissions offer. After review of the supporting documents, the financial aid staff will make any appropriate adjustments and send a final award.

Transfer admission candidates must submit a Financial Aid Form (FAF) or Student Aid Application for California (SAAC), which is completed on both sides and lists Caltech as a recipient (code 4034), to the College Scholarship Service by April 1. (Students should note on the FAF or SAAC whether they are 3-2, special, or regular transfer candidates.) In addition, they must submit to Caltech a Financial Aid Transcript (FAT) from each college previously attended, whether or not they received financial aid from the college(s). FATs are available from the financial aid office of the school the student is currently attending.

International student applicants (with the exception of Canadians and Mexicans, who should follow the procedures for the appropriate group of domestic students listed above) must submit to the Financial Aid Office by February 1 the Foreign Students' Financial Aid Application and Declaration (in place of the Financial Aid Form or Student Aid Application for California). This must be done at the time they apply for admission to Caltech. (Those applying as transfer students should note on their application whether they are 3-2, special, or regular candidates.) Admitted students will be notified at that time of their financial aid award. Those offered assistance will be eligible to apply for aid in subsequent years. Returning international students must pick up financial aid packets in the Financial Aid Office in December and file them with the Financial Aid Office by April 15.

International students who *do not* apply for aid at the time of admission, or are denied aid, will be ineligible for aid for any other academic period while they are undergraduates at Caltech. (Canadian and Mexican students are exempt from this rule.)

Returning students (other than international students) must pick up a financial aid application packet along with necessary supporting forms (e.g., Business/Farm supplements) from the Financial Aid Office in December. The Student Aid Application for California (SAAC) is appropriate for most students attending Caltech; those having a grant from another state might have to file a Financial Aid Form (FAF) or other application form to satisfy that state's requirements. Both sides of the SAAC must be completed. The SAAC, listing Caltech as a recipient (code 4034), must be submitted to the College Scholarship Service in Berkeley by February 11.

Self-supporting students attending Caltech are few. Specific criteria are used in determining whether a student may be considered self-supporting. Generally, such a student must have been living and working on his or her own for three years prior to the year in which application is made for financial assistance. In special cases (wards of the court, veterans, students from extremely adverse family situations that can be verified to by people in his or her community), the three-year rule can be waived.

The basic application procedures are otherwise as outlined above for each category. Married students and students with dependent children generally must have an interview with a financial aid counselor to determine their appropriate budget.

General Requirements

All applicants must file some or all of the documents described below. All items followed by an asterisk (*) are provided to new students with the preliminary award letter, and to returning students in the application packet available each December.

Tax Returns

All financial aid applicants must submit *signed* copies of their own and their parents' federal tax returns for the year prior to the year for which they apply for financial aid (for 1987-88 it is the 1986 return). Students, or their parents, who did not file a federal return should submit a Personal Income Statement, which can be obtained from the Caltech Financial Aid Office.

Note: International students must submit returns from their country of nationality and/or from the country where their parents are employed. Many countries restrict the exchange of currency; however, a number of those countries will grant special permission for students pursuing particular courses of study abroad. Such a waiver must be requested and proof of the acceptance or denial of the waiver must be provided along with the tax forms.

Business/Farm Supplements must be filed with the College Scholarship Service by all students and parents who own businesses or farms, along with the Financial Aid Form (FAF) or Student Aid Application for California (SAAC). A separate form must be completed for each business or farm; if separate tax returns are filed for these enterprises (examples, IRS form 1120 or 1120S), copies of those returns must be submitted to the Financial Aid Office.

All California residents must apply for a Cal Grant between January 1 and February 11 if they have never had such a grant. Applications are available in high school guidance and financial aid offices. Students who have previously received Cal Grants must submit the Cal Grant renewal form to the College Scholarship Service by February 11.

All U.S. citizens and permanent residents must apply for a Pell Grant by checking the appropriate box on the Financial Aid Form (FAF) or Student Aid Application for California (SAAC). Students who apply for a Pell Grant will receive a Student Aid Report (SAR) from the Department of Education within six weeks of submitting the FAF/SAAC. This document may consist of one, two, or three parts, depending upon the student's eligibility and application status. SARs must be submitted to the Financial Aid Office.

All students who apply for federal aid (grants, loans and/or work) must file a "Draft Registration Compliance Statement"* with the Financial Aid Office.

CIT Supplements are required of all applicants.* Supplements are used for the awarding of restricted need-based scholarships and summer work-study. Students are encouraged to provide as much information as possible about their activities, interests, employment history, and research experience. CIT Supplements are submitted directly to the Financial Aid Office.

Financial Aid Funds

Applicants for admission who have a complete financial aid application on file will be considered for all financial aid administered by the Institute. Financial need can be met either by a single type of aid or by a combination of scholarships or grants, loans, and student employment.

Scholarships and Grants

There are various kinds of grants and scholarships awarded by Caltech. "Name" scholarships are derived from money given to the Institute as endowments or annual gifts by individuals or organizations for scholarship purposes and are named by or for the donor. Students who meet the specifications of the donor are considered for "name" scholarships. One-year Caltech and Institute Grants are funds derived from endowments specially set aside for the purpose of assisting undergraduates. Eligible students receive Pell Grants and can be awarded Supplemental Educational Opportunity Grants, both of which are federally funded. The amount of a scholarship or grant award depends on financial need and the restrictions of the donor or funding agency.

Student Aid Loan Funds

Loans are available to members of all undergraduate classes, including entering freshmen, who are eligible for such aid. Loans are awarded as part of the total financial aid package offered by the Financial Aid Office. The four sources of loan funds, which are described below, are awarded to the extent of available funds.

1. Caltech loan funds are available to undergraduate students. No interest is charged and no repayment of principal is required during undergraduate residence at the Institute, as long as residence is continuous (the term "residence" includes the usual vacation periods). For those who transfer or continue on to graduate school, interest is charged but repayment of principal is not required until termination of formal education. Repayment terms, including interest rates, may be obtained from the Office of Student Accounts.

Loan amounts for international students are limited. It is inadvisable for foreign students from countries with seriously adverse rates of exchange to borrow much more than they can repay from savings earned in the United States from employment during the "training period" following graduation. Students from countries that prohibit currency exchange are not eligible for loans.

2. Federal loans under the National Direct Student Loan (NDSL) Program are available to undergraduate students who are citizens or permanent residents of the United States. The program limits borrowing to $3,000 during the first two years, with a maximum of $6,000 while in undergraduate status. The borrower must demonstrate financial need. No interest is charged on these loans until six months after a student reduces his or her status to less than half-time. Repayment of principal and interest begins six months after termination of formal education. During repayment, interest is charged at the rate of 5 percent per annum on the unpaid balance.

3. The Guaranteed Student Loan Program (GSL) provides up to $2,500 per academic year with an aggregate maximum of $12,500 for undergraduate education. The interest rate for first-time borrowers is currently 8 percent. Further information on this program, including application forms, may be obtained from the Financial Aid Office.

4. PLUS loans are available to parents of dependent undergraduates, independent undergraduates, and graduate students. These federally subsidized loans enable the borrower to prorate payment of their contribution toward educational costs. Interest for parents begins to accrue immediately, and repayment must begin sixty (60) days after the loan is made. The current interest rate is 12 percent. (The average monthly payment on a $3,000 loan is $65.) Parents may borrow an annual maximum of $3,000 and an aggregate maximum of $15,000 per dependent child. Details about these loans and application forms can be obtained from the Financial Aid Office.

Student Employment

Students who desire part-time or summer employment may receive job location assistance from the Career Development Center. If an undergraduate student is a financial aid recipient, any term-time earnings must be considered part of the student's financial aid package regardless of whether the wages are subsidized through the work-study program. Because academic requirements are so demanding, undergraduate students must receive approval from the Dean of Students to work more than 16 hours per week. In addition, any freshman seeking employment must receive permission from the Dean before he or she may work. We do not recommend that freshmen commence employment until after the end of the first term.

College Work-Study Program. This federally funded program is designed to pay part of the salaries of undergraduate and graduate students who are citizens or permanent residents of the United States. In addition to the above general employment constraints, College Work-Study employment is limited to students who are employed by Caltech and JPL and who demonstrate financial need. Further information is available through the Financial Aid Office. Work-study job listings and general advice on job-seeking is available in the Career Development Center.

Foreign Student Employment Program. This is a program funded by Caltech that provides part-time employment for needy undergraduates from foreign countries to provide them with the same opportunity that U.S. citizens have to earn part of their aid. Students eligible to work under the FSEP program are limited to on-campus employment. Since this program was designed to accomplish the same results as College Work-Study, the same rules and guidelines apply to its administration.

No-Need Scholarships

A number of scholarships are available to students regardless of financial need. Merit scholarships include Caltech Merit Awards and several other private and corporate scholarships that are awarded to upperclassmen who have outstanding academic and/or research records.

In 1985-86, 36 Caltech undergraduates were awarded prizes of $3,000 and $4,000. The honor is recorded on transcripts and listed in the commencement program when prize scholars graduate.

Several corporations, including Kodak, General Motors, Hughes Aircraft, and Xerox offer partial or full tuition scholarships to students who have demonstrated particular facility in the options that represent the types of expertise the corporations need in their research and development groups. Students may generally apply for such scholarships in the spring of their sophomore year.

Other organizations announce competitions throughout the year; eligibility criteria and deadlines are periodically advertised by the Financial Aid Office in the student newspaper, *The California Tech.*

Financial Payment Plans

The following organizations offer financial payment plans to help cover the costs of education at Caltech:

1. Academic Management Services, 1110 Central Avenue, Pawtucket, RI 02862 (800-531-4300), offers a nine-month annual budget payment plan. Payment under this plan begins June 1. Cost of this program is a $45 annual fee. A Life Benefit Coverage is provided at no additional cost.

2. EFI Fund Management Corporation, 2700 Sanders Road, Prospect Heights, IL 60070 (800-323-8399). It offers a ten-month budget plan for annual cost of tuition, fees, room and board with option for a two-, three-, and four-year program offering 12 payments a year after the initial year. Payment under this plan begins in June. Cost of this program is a $30 annual fee. These programs offer optional insurance coverage to protect the budget plan selected.

3. Knight Tuition Plan, 53 Bacon St., Boston, MA 02108 (617-742-3911), makes available two plans of monthly repayment. The Insured Tuition Payment Plan allows payment of university expenses in a monthly payment plan while attending school. Payments to the university are made for the student from an individual money market account established in the student's name and insured by FDIC. No interest is charged. Life insurance is automatically scaled to cover future payments if applicable. The Extended Repayment Plan is a low-cost loan that allows the extension of monthly payments beyond the student's graduation. The Plan pays the university, and the student repays the loan in 48, 60, or 80 months. Interest is at an attractive variable rate and is charged on the actual amount paid to the university and not yet repaid.

4. The Tuition Plan, Inc., Concord, NH 03301 (800-258-3640), offers a Deferred Monthly Payment Plan (Loan Program) to cover tuition, fees, and any related educational expenses of schooling over a period of one to four years. Life insurance is available to all insurable parents. Monthly repayment starts one month after the first check is received from the Tuition Plan. Cost of this program is for interest expense of 17.5 percent and insurance premiums (if coverage is desired). The maximum number of months allowed for repayment is 120. A prepayment program is available that provides monthly budgeted expenses in advance of each school term. Cost of this plan is a $35 initial fee, and insurance is available to insurable parents (if coverage is desired).

PRIZES

Mabel Beckman Prize

The Mabel Beckman Prize was established in 1986 in honor of Mrs. Beckman's many years of commitment to Caltech's educational and research programs. The $3,000 prize is awarded to an undergraduate woman who, upon completion of her junior year at Caltech, has achieved academic excellence and demonstrated outstanding leadership skills, a commitment to personal excellence, good character, and a strong interest in the Caltech community.

Eric Temple Bell Undergraduate Mathematics Research Prize

In 1963 the department of mathematics established an Undergraduate Mathematics Research Prize honoring the memory of Professor Eric Temple Bell and his long and illustrious career as a research mathematician, teacher, author, and scholar. His writings on the lives and achievements of the great mathematicians continue to inspire many hundreds of students at Caltech and elsewhere. A prize of $500 is awarded annually to one or more juniors or seniors for outstanding original research in mathematics, the winners being selected by members of the mathematics faculty. The funds for this prize come from winnings accumulated over the years by Caltech undergraduate teams competing in the William Lowell Putnam Mathematics Contest, an annual nationwide competition.

Donald S. Clark Memorial Awards

From a fund contributed by the Caltech Alumni Association, annual awards of $500 are made to two juniors in engineering options in recognition of service to the campus community and grade point averages equal to or greater than those required for graduation with honor. The awards honor the work of Professor Clark, class of 1929, both in the field of engineering and in his service to the Alumni Association.

Haren Lee Fisher Memorial Award in Junior Physics

Mr. and Mrs. Colman Fisher have established the Haren Lee Fisher Memorial Award in Junior Physics in memory of their son. The General Electric Foundation also contributed to the fund under the matching plan of their Corporate Alumnus Program. A prize of $300 will be awarded annually to a junior physics major, who is selected by a physics faculty committee as demonstrating the greatest promise of future contributions to physics.

Henry Ford II Scholar Awards

Henry Ford II Scholar Awards are funded under an endowment provided by the Ford Motor Company Fund, a nonprofit organization supported primarily by contributions from the Ford Motor Company. Each award, up to $5,000, will be made annually either to the engineering student with the best academic record at the end of the third year of undergraduate study, or to the engineering student with the best first-year record in the graduate program. The chairman of the Division of Engineering and Applied Science names the student to receive the award.

Jack E. Froehlich Memorial Award

The family and friends of the late Jack E. Froehlich, who did his undergraduate and graduate work at Caltech and was later the project manager for Explorer I for the Jet Propulsion Laboratory, have established a prize fund that will provide an award of $500 to a junior in the upper five percent of his or her class who shows outstanding promise for a creative professional career. The student is selected by the division chairmen and the deans, together with the Undergraduate Academic Standards and Honors Committee.

George W. Green Memorial Prize

The George W. Green Memorial Prize was established in 1963 with contributions given in memory of George W. Green, who for fifteen years served on the staff of the Caltech business office and was Vice President for Business Affairs from 1956 to 1962. The prize of $750 is awarded annually to an undergraduate student in any class for original research, an original paper or essay, or other evidence of creative scholarship beyond the normal requirements of specific courses. The student is selected by the division chairmen and the deans, together with the Undergraduate Academic Standards and Honors Committee.

Arie J. Haagen-Smit Memorial Fund

The Arie J. Haagen-Smit Memorial Award was established in 1977 to honor the memory of the late pioneering bio-organic chemist who discovered the chemical constituents of smog. Dr. Haagen-Smit was a member of the Caltech faculty for 40 years, and his family and friends have arranged for a prize of $500 to be given at the end of the sophomore or junior year to a student in biology or chemistry who has shown academic promise and who has made recognized contributions to Caltech. The selection is made by a committee of representatives from the biology and chemistry divisions and the deans.

Frederic W. Hinrichs, Jr., Memorial Award

The Board of Trustees of the California Institute of Technology established the Frederic W. Hinrichs, Jr., Memorial Award in memory of the man who served for more than 20 years as dean and professor at the Institute. In remembrance of his honor, courage, and kindness, the award bearing his name is made annually to the senior who throughout his or her undergraduate years at the Institute has made the greatest contribution to the student body and whose qualities of character, leadership, and responsibility have been outstanding. At the discretion of the deans, more than one award or none may be made in any year. The award, presented at commencement without prior notification, consists of a cash award and a certificate.

David Joseph Macpherson Prize in Engineering

The David Joseph Macpherson Prize in Engineering was established in 1957 by Margaret V. Macpherson in memory of her father, a graduate of Cornell University in civil engineering, class of 1878. A prize of $400 is awarded annually to a graduating senior in engineering who exemplifies excellence in scholarship. The winning student is selected by a faculty committee of three, appointed annually by the chairman of the Division of Engineering and Applied Science. This prize is available only to U.S. citizens.

Artur Mager Prize in Engineering

The Aerospace Corporation established the Artur Mager prize to honor Dr. Artur Mager, an alumnus of the California Institute of Technology and formerly group vice president, engineering, of the Aerospace Corporation. Dr. Mager demonstrated outstanding qualities of technical creativity, leadership, and character throughout his career. The prize is awarded to a senior student in engineering selected by the chairman of the Division of Engineering and Applied Science based on excellence in scholarship and the promise of an outstanding professional career. The prize consists of a cash award of $2,000 and a certificate.

Mary A. Earl McKinney Prize in Literature

The Mary A. Earl McKinney Prize in Literature was established in 1946 by Samuel P. McKinney, M.D., of Los Angeles. Its purpose is to promote proficiency in writing. The terms under which it is given are decided each year by the literature faculty. It may be awarded for essays submitted in connection with regular literature classes, or awarded on the basis of a special essay contest. The prize consists of cash awards amounting to $750.

Robert L. Noland Leadership Scholarship

The Robert L. Noland Leadership Scholarship is a cash award of $1,500 for upperclass students who exhibit qualities of outstanding leadership. The kind of leadership to be recognized is most often expressed in personal actions that have helped other people and that have inspired others to fulfill their leadership capabilities. The scholarship was set up by Ametek in 1978 in honor of their president, Robert L. Noland, a Caltech alumnus. Two or more awards are generally made each year.

H. J. Ryser Scholarships

The H. J. Ryser Scholarships were established in 1986 in memory of H. J. Ryser, who was professor of mathmematics at Caltech from 1967 to 1985. Professor Ryser contributed greatly to combinatorial mathematics and inspired many students with his carefully planned courses. The scholarships are given on the basis of merit, preferably in pure mathematics. Recipients are selected by the executive officer for mathematics after consulting the faculty.

Richard P. Schuster Memorial Prize

This award is made from a fund established by family, friends, and colleagues of Richard P. Schuster, Jr., a graduate of Caltech and the Institute's Director of Development at the time of his death. The recipient is a junior or senior in chemistry or chemical engineering; selection is based on financial need and a demonstration of academic promise.

Don Shepard Award

Relatives and friends of Don Shepard, class of 1950, have provided this award in his memory. The award is presented to a student, the basic costs of whose education have already been met but who would find it difficult, without additional help, to engage in extracurricular activities and in the cultural opportunities afforded by the community. The recipients, upperclassmen, are selected on the basis of their capacity to take advantage of and to profit from these opportunities rather than on the basis of their scholastic standing.

Sigma Xi Award

In accordance with the aim of The Society of the Sigma Xi to encourage original investigation in pure and applied science, the Institute chapter of the Society annually awards a prize of $750, funded from membership dues, to a senior selected for an outstanding piece of original scientific research. The student is selected by the division chairmen and the deans, together with the Undergraduate Academic Standards and Honors Committee.

Morgan Ward Prize

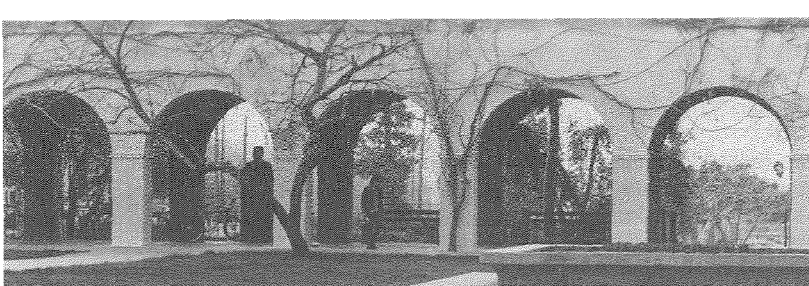
The Morgan Ward Prize was established by the department of mathematics in 1963 to honor the memory of Professor Morgan Ward in recognition of his long service to mathematics and to the Institute. The competition is open only to freshmen and sophomores. An entry consists of a mathematical problem together with a solution or a significant contribution toward a solution. One or more winners are selected by a faculty committee acting on the advice of student judges. Each prize of $75 is funded by the same source used to sponsor the Eric Temple Bell Prize.

GRADUATION REQUIREMENTS, ALL OPTIONS

To qualify for a Bachelor of Science degree at the Institute, a student must obtain passing grades in each of the required courses listed below, must satisfy the additional requirements listed under the undergraduate options, and must achieve a grade-point average of not less than 1.9. The student must also register for programs that make normal progress toward a B.S. degree.

Students must register for the Institute requirements below, in the year specified, unless they have previous credit. If for some reason they are not able to complete the requirements at the proper time, they must register at the earliest possible opportunity. (The Curriculum Committee may in unusual cases excuse undergraduate students from any of the following Institute or option requirements upon presentation of petitions.)

The Institute unit system is described in the opening paragraphs of Section 5.



Institute Requirements, All Options

Course	Units
1. Freshman Mathematics (Ma 1 abc)	27
2. Sophomore Mathematics (Ma 2 abc)	27
3. Freshman Physics (Ph 1 abc)	27
4. Sophomore Physics (Ph 2 abc or Ph 12 abc)	27
5. Freshman Chemistry (Ch 1 abc)[1]	18
6. Freshman Chemistry Laboratory (Ch 3 a)	6
7. Additional Freshman Laboratory	9
8. Computing	6
9. Humanities Courses (as defined below)	36
10. Social Sciences Courses (as defined below)	36
11. Additional Humanities and Social Sciences Courses	36
12. Physical Education	9

Freshman Laboratory Requirement. All freshmen are required to take at least 15 units of laboratory work in experimental science including Ch 3 a (6 units). The additional 9 units of laboratory work must be chosen from APh 9 (6 units), Bi 1 (3 units), Bi 10 (6 units), Ch 3 b (6 units), Ch 4 ab (6 units per term), ChE 10 (3 units), CS/EE 11 (6 units), E 5 (6 units), Ge 1 (3 units), Ph 3 (6 units), Ph 4 (6 units).

Computing Requirement. All students must satisfactorily complete 6 units of coursework in computing. The units must be chosen from CS 10 (9 units), E 1 a (3 units), E 1 b (3 units), AMa 98 c (3 units), Ma 4 a (6 units), Ma 4 b (6 units), CS 112 (9 units), Ph 20 (3 units), Ph 21 (3 units), Ph 22 (3 units), Ph 76 (6 units).

Humanities and Social Science Requirements. All students must complete satisfactorily 108 units in the Division of the Humanities and Social Sciences. Of these 108 units, 36 must be in the humanities (art, history, humanities, literature, music, philosophy, and, with certain restrictions, languages and linguistics) and 36 in the social sciences (anthropology, economics, law, political science, psychology, social science), in each case divided equally between introductory and advanced courses. The remaining 36 may be drawn from either. They may include work done under the HSS Tutorial Program. They may include (to the limit of 27 units) courses in business economics and management (BEM). They may *not* include reading courses unless granted credit by petition. No more than 27 units of Freshman Humanities may be taken, 9 units of which may be employed to fulfill the final 36-unit HSS requirement.

Entering freshmen are required to take two terms of "Freshman Humanities" (humanities courses numbered 20 or below in the catalog). These courses may be taken in any two terms of the freshman year. Freshmen who score below 1200 on the combined verbal SAT and English achievement test of the CEEB, or those not taking the second test who score below 600 on the verbal SAT, will be required to take a diagnostic English examination before the beginning of first term. Students who fail this examination will not be allowed to enter Freshman Humanities courses until they complete successfully a remedial English program to be offered during the first term. This program will not count toward the 108-unit requirement or toward the requirements for Freshman Humanities. The common denominator of freshman humanities courses is 4,000 words of essay writing a term. Successful completion of two terms is a prerequisite for advanced humanities (numbered above 20), but *not* for introductory social sciences.

[1]This requirement can also be met by completing Ch 2 ab or any two terms of Ch 41 abc.

A student must take 18 units of advanced humanities courses that require essay writing. Courses that count toward the advanced humanities requirement are marked in the catalog by an asterisk. Courses numbered from 21 through 199 without the asterisk can be taken to fulfill the final 36 units of the 108-unit HSS requirement unless otherwise noted. The first four terms of a foreign language do not count toward the 36-unit humanities requirement; however, every term receives credit towards the final 36 units of the 108-unit requirement in HSS. In addition, the fifth, but not the sixth, term of a language counts towards the 18-unit advanced humanities requirement.

Students are required to take 18 units of introductory social science courses, consisting of two courses of 9 units each, chosen from the following: Anthropology: An 22, Economics: Ec/SS 11, Ec 15, Law: SS 33, Political Science: PS/SS 12, Psychology: Psy 10, Ps 12, Social Science: SS 13.

Students must also take 18 units of courses numbered 100 or above, selected from the following categories: anthropology, economics, law, political science, psychology, and social science, but only from a field in which they have completed an introductory course.

Courses that are cross-listed between Humanities and Social Science disciplines (e.g., psychology and literature, or history and economics) will not count toward either upper-division requirement unless so listed in the catalog.

First Year Course Schedule, All Options

Differentiation into the various options begins in the second year.

		Units per term		
		1st	2nd	3rd
Ma 1 abc	Freshman Mathematics (4-0-5)	9	9	9
Ph 1 abc	Classical Mechanics and Electromagnetism (4-0-5)	9	9	9
Ch 1 abc	General and Quantitative Chemistry (3-0-3)	6	6	6
Ch 3 a	Experimental Chemical Science (0-6-0)[1]	6 or	6 or	6
	Introductory courses in the humanities and social sciences. A wide choice of alternatives will be available to students; the Registrar will announce the offerings for each term	9	9	9
	Freshman Laboratory Courses[2]	x	x	x
	Additional Electives[3]	x	x	x
PE	Physical Education[4]	3	3	3

x—Except for the minimum laboratory unit requirement, the number of units chosen here is optional. If the student chooses no electives except physical education and takes the minimum permissible laboratory courses, the total unit load will be 42 for two terms and 39 for one term. A total load—including electives—of more than 51 units per term is considered a heavy load. A load of more than 58 units requires formal approval of a petition for overload.

[1]This course is offered in each of the three terms.
[2]The additional 9 units of laboratory work must be chosen from APh 9 (6 units), Bi 1 (3 units), Bi 10 (6 units), Ch 3 b (6 units), Ch 4 ab (6 units per term), ChE 10 (3 units), CS/EE 11 (6 units), E 5 (6 units), Ge 1 (3 units), Ph 3 (6 units), Ph 4 (6 units).
[3]A partial list of electives particularly recommended for freshmen includes the following: APh 3, APh/MS 4, Ay 1, Bi 1, Bi 3, ChE 10, CS/EE 4, CS 10, E 1 a, E 1 b, EE 5, Env 1, Ge 1, Ph 20, Ph 21, Ph 22.
[4]Three terms (9 units) of PE are required for the B.S. degree. Students need not elect to take the required PE in the freshman year. It may be taken in any three terms before graduation.

Applied Mathematics Option

The undergraduate option in applied mathematics is for those students who want to combine their basic studies in mathematics with considerable involvement in applications. The program is similar in general outline to the mathematics option, with additional requirements to ensure a balance between courses that develop mathematical concepts and courses that show the interplay of these concepts with a variety of applications. Complete programs will be worked out with faculty advisers.

Option Requirements

1. Ma 5 abc, AMa 95 abc, and AMa 101 abc.
2. One of the following (or an approved combination): AMa 98 abc, AMa 151 abc, AMa 152 abc, AMa 153 abc, AMa 181 abc, or AMa 104 and AMa 105 ab.
3. One of the following (or an approved combination): Ma 108 abc, Ma 110 abc, Ma 118 abc, Ma 120 abc, Ma 121 abc, Ma 142 abc, or Ma 137 and Ma 143 ab, Ma 147 abc.
4. Passing grades must be obtained in a total of 483 units, including the courses listed above.

Typical Course Schedule

		Units per term		
Second Year		1st	2nd	3rd
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ph 2 abc	Waves, Quantum Mechanics, and Statistical Physics (4-0-5)	9	9	9
Ma 5 abc	Introduction to Abstract Algebra (3-0-6)	9	9	9
	Humanities Electives	9	9	9
	Electives	9	9	9
		45	45	45
Third Year				
AMa 95 abc	Introductory Methods of Applied Mathematics (4-0-8)	12	12	12
	Humanities Electives	9	9	9
	Electives	27	27	27
		48	48	48
Fourth Year				
AMa 101 abc	Methods of Applied Mathematics (3-0-6)	9	9	9
	Humanities Electives	9	9	9
	Electives[1]	27	27	27
		45	45	45

[1]See items 2 and 3 under option requirements.

Applied Physics Option

The applied physics option is designed to connect what is conventionally considered "engineering" and "pure physics." Research in applied physics is an effort to answer questions related to problems of technological concern. Since the interests of both engineering and pure physics cover fields that overlap, a definite dividing line cannot be drawn between them. Realizing this, the applied physics option draws its faculty from the Divisions of Physics, Mathematics and Astronomy; Engineering and Applied Science; Chemistry and Chemical Engineering; and Geological and Planetary Sciences. This interdivisional aspect of the option allows a flexibility and range in curriculum, appropriate to the student's particular research interests, that may end up being a mixture of courses and research in different divisions.

Specific subject areas of interest in the program cover a broad spectrum of physics related to different fields of technology. Solid state physics includes work in superconductivity, ferromagnetism, and semiconducting solid state. Work on electromagnetic waves extends from antenna problems into lasers and nonlinear optics. Fluid physics includes magnetohydrodynamics, high-temperature plasmas, and superfluids. Transport phenomena in gases, liquids, and solids form another active area related to nuclear and chemical engineering.

The undergraduate curriculum attempts to reflect and maintain a close relationship with the various disciplines. This facilitates a transition to or from any of these, if at any time in the student's course of study and research this would be considered beneficial.

Attention is called to the fact that any student who has a grade-point average less than 1.9 at the end of the academic year in the subjects listed below under option requirements may be refused permission to continue work in this option.

Option Requirements

1. Any three of the following: APh 24, Ph 3, Ph 5, Ph 6, Ph 7.
2. APh/ME 17 abc, APh 50 abc, and Ph 106 abc.
3. AMa 95 abc.
4. Either APh 78 abc or one term of APh 77 and one chosen from the following: APh 77, APh 154, Ph 77, EE 91, Ch 6, Ae/APh 104 bc, ChE 126, CS/EE 121, MS 130, MS 131, MS 132.
5. 27 additional units of APh courses numbered over 100, which must include one of the following: APh 101 abc, APh 105 abc, APh 114 abc, APh 156 abc, APh 181 abc, APh 190 abc. None of these courses may be taken on a pass/fail basis. Note that APh 100 and APh 200 do not satisfy this requirement.
6. Passing grades must be earned in a total of 516 units, including the courses listed above.

Typical Course Schedule

		Units per term		
Second Year		1st	2nd	3rd
Ph 2 abc	Waves, Quantum Mechanics, and Statistical Physics (4-0-5)	9	9	9
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
	Humanities Electives	9	9	9
	Laboratory Electives[1]	6	6	6
APh 17 abc	Thermodynamics (3-0-6)	9	9	9
	Other Electives	9	9	9
		51	51	51
Third Year				
APh 50 abc	Applied Physics (3-0-6)	9	9	9
APh 110 abc	Topics in Applied Physics	2	2	2
AMa 95 abc	Introductory Methods of Applied Mathematics (4-0-8)	12	12	12
	Humanities Electives	9	9	9
	Other Electives[2]	18	18	18
		50	50	50

[1]See item 1, option requirements.
[2]See item 5, option requirements.

Fourth Year				
APh 78 abc	Senior Thesis, Experimental[1]	6	6	6
or				
APh 77	Laboratory in Applied Physics[1]	9	9	.
APh 106 abc or Ph 106 abc	Topics in Classical Physics	9	9	9
	APh Electives[2]	9	9	9
	Humanities Electives	9	9	9
	Other Electives	18	18	18
		51–54	51–54	51

Suggested Electives

The student may elect any course that is offered in any term provided he or she has the necessary prerequisites for that course. The following subjects are especially suitable for a well-rounded course of study. They need not be taken in the year suggested.

Sophomore Year	*Junior Year*	*Senior Year*
Aph/ME 17 abc	APh 77	APh 77
APh 23	Ph 77 ab	APh 100
APh 24	EE 114 abc	Ae/APh 101 abc
Ge 1	Ch 6 ab	APh 105 abc
Ge 2	Ge 154 abc	APh 114 abc
Bi 1	APh 100	AMa 101 abc
Ay 1	ME 19 abc	AMa 104
ME 1 ab		AMa 105 ab
EE 14 abc		Ch 125 abc
EE 90 abc		Ph 125 abc
Ma 5 abc		Ph 129 abc
MS 15 abc		Ph 77 ab

More Specialized Courses		
APh/MS 126 abc	APh 181 abc	Ch 113 abc
APh 140 abc	APh 190 abc	EE 91 abc
APh 153 abc	APh 195 ab	EE 155 abc
APh 154	AM 135 abc	Ge 104 abc
APh 156 abc	ChE 103 abc	Ge 166
APh 161 abc	ChE 126 abc	

[1]See item 4, option requirements.
[2]See item 5, option requirements.

Astronomy Option

The astronomy option is designed to give the student an understanding of the basic facts and concepts of astronomy, to stimulate his or her interest in research, and to provide a basis for graduate work in astronomy. The sophomore-junior sequence (Ay 20, 21, 22, 101, 102) constitutes a solid introduction to modern astronomy. More advanced courses may be taken in the junior and senior years.

Attention is called to the fact that any student whose grade-point average is less than 1.9 at the end of an academic year in the subjects listed in the Division of Physics, Mathematics and Astronomy may, at the discretion of his or her department, be refused permission to continue the work in this option.

Option Requirements

1. Ay 20, Ay 21 or 102, Ay 101, 14 units of Ay electives (excluding Ay 1), Ph 3, Ph 5 or 6, Ph 7, Ph 98 abc or Ph 125 abc, and Ph 106 abc.
2. 54 additional units of Ay or Ph courses.
3. 27 additional units of science or engineering electives, of which 18 must be outside the Division of Physics, Mathematics and Astronomy.
4. Passing grades must be earned in a total of 516 units, including the courses listed above.

Typical Course Schedule

		Units per term		
Second Year		1st	2nd	3rd
Ph 2 abc	Waves, Quantum Mechanics and			
or	Statistical Physics (4-0-5)	9	9	9
Ph 12 abc[1]	Quantum and Statistical Mechanics (3-0-6)			
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ay 20	Basic Astronomy and the Galaxy (3-2-6)	11	.	.
Ay 21	Galaxies and Cosmology (3-0-6)	.	9	.
Ph 3, 5, 6, 7	Physics Laboratory[2]	0-6	0-6	6
	Humanities Electives	9	9	9
	Electives[3]	0-9	3-6	12-15
	Suggested total number of units	38-53	39-48	45-48
Third Year				
Ph 98 abc	Quantum Physics (3-0-6)	9	9	9
Ph 106 abc	Topics in Classical Physics (3-0-6)	9	9	9
Ay 101	The Physics of Stars (3-2-6)	.	11	.
Ay 102	Plasma Astrophysics and the			
	Interstellar Medium (3-0-6)	.	.	9
	Humanities Electives	9	9	9
	Electives	18-24	9-12	9-15
	Suggested total number of units	45-51	47-50	45-51
Fourth Year				
	Astronomy or Physics Electives	18	18	18
	Humanities Electives	9	9	9
	Electives	18-24	18-24	18-24
	Suggested total number of units	45-51	45-51	45-51

Students are encouraged (but not required) to undertake research leading to a senior thesis; credit for this work is provided through Ay 42.

Suggested Electives

The student may elect any course offered in any division in a given term, provided that he or she has the necessary prerequisites for that course. The following courses are useful to work in various fields of astronomy and astrophysics: AMa 95[4], Ay 22, Ay 110, Ay 151, Ay 152, Ay 153, Ay 154, Ay 155, Ay 156, Bi 1, EE 5, EE 14, EE 90, EE 157, Ge 1, Ge 4, Ge 101 a, Ge 131, Ge 153, Ge 154, Ge 167, Ma 5, Ma 112, Ph 77, Ph 125[4], Ph 129, Ph 136[4].

[1]Prerequisite for Ph 98.
[2]Students are required to take (a) Ph 3 if not already taken, (b) Ph 5 or Ph 6, and (c) Ph 7.
[3]Sophomore electives include at least 27 units of science and engineering courses, of which at least 18 units must be in subjects other than mathematics, physics, and astronomy. It is desirable for a student to acquire as broad a background as possible in other related fields of science and engineering.
[4]Students who plan to do graduate work in astronomy should elect some of these courses during their third and fourth years, in consultation with their advisers.

Biology Option

The undergraduate option in biology is designed to build on a solid foundation in mathematics and physical science by providing an introduction to the basic facts, concepts, problems, and methodologies of biological science. The option serves as a basis for graduate study in any field of biology or for admission to the study of medicine. Instruction is offered in the form of participation in the ongoing research programs of the division, as well as in formal course work. Course work emphasizes the more general and fundamental properties of living organisms, and areas of current research interest, rather than the traditional distinct fields within the life sciences.

The division encourages undergraduate participation in its research program and believes that research participation should be a part of each student's program of study at the Institute. Students may elect to prepare an undergraduate thesis (Bi 90). Research opportunities may be arranged with individual faculty members, or guidance may be obtained from a student's individual faculty adviser in the division or from the biology undergraduate student adviser.

The requirements listed below for the biology option are minimal requirements. An adequate preparation for graduate work in biology will normally include additional elective research or course work in biology and/or advanced course work in other sciences or mathematics. Flexibility to accommodate varied individual scientific interests, within the broad scope of biology, is achieved through the provision of elective courses, arrangements for individual research (Bi 22), and tutorial instruction (Bi 23). In addition, arrangements may be made to take courses at neighboring institutions in fields of biology that are not represented in our curriculum.

Premedical Program. The undergraduate course for premedical students is essentially the same as that for biology students and is intended as a basis for later careers in research as well as in the practice of medicine. It differs in some respects from premedical curricula of other schools; however, it has been quite generally accepted as satisfying admission requirements of medical schools.

It is recommended that all students contemplating application to medical school consult with the premedical adviser, Dr. Marlene Coleman.

Option Requirements

1. Specific courses: Bi 1, Bi 7, Bi 9, Bi/Ch 110 abc, Bi 122, Bi 123, Bi 150[1], and Ch 41 abc.
2. An additional 55 units of Bi courses. At least 10 of these units must be in Bi 22 or laboratory courses (Bi 10, Bi 161, Bi 162, Bi 180).
3. Passing grades must be earned in a total of 516 units, including the courses listed above.

Typical Course Schedule

		Units per term		
Second Year		1st	2nd	3rd
	Humanities Electives	9	9	9
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ph 2 abc	Waves, Quantum Mechanics, and Statistical Physics (4-0-5)	9	9	9
Ch 41 abc	Chemistry of Covalent Compounds (3-0-6)	9	9	9
Bi 1	Introduction to Molecular Biology (3-3-6)	.	12	.
Bi 9	Cell Biology (3-0-6)	.	.	9
	Electives	9-15	0-3	0-6
		45-51	48-51	45-51

[1]The sequence of courses Bi 150, Bi 152, Bi 156, and Bi 157 is designed to provide a comprehensive introduction to the field of neurobiology. Students with a strong interest in biophysics may substitute Bi/Ph 50 for the Bi 150 course requirement for the biology option.

Third Year

	Humanities Electives	9	9	9
Bi 7	Organismic Biology (3-3-3)	9	.	.
Bi/Ch 110 abc	Biochemistry (4-0-8)	12	12	12
Bi 122	Genetics (3-0-6)	.	9	.
Bi 123	Genetics Laboratory (0-3-0)	.	3	.
	Electives[1,2,3]	15-21	12-18	24-30
		45-51	45-51	45-51

Recommended Electives[2]

Ch 21 abc	The Physical Description of Chemical Systems	9	9	9
Ch 24 ab	Introduction to Biophysical Chemistry	.	9	9

Fourth Year

	Humanities Electives	9	9	9
Bi 150	Neurobiology (4-0-6)	10	.	.
	Electives[1,3]	26-32	36-42	36-42
		45-51	45-51	45-51

Suggested Electives

Second Year

Second Term: Bi/Ph 50, Ch 4 a   Third Term: Bi 10, Ch 4 b

Third Year

First Term: Bi 22, Bi 23, Bi 114, Bi 135, Ch 21 a, L 1 a, L 32 a, L 50 a

Second Term: Bi 22, Bi 23, Bi 106, Ch 21 b, Ch 24 a, Ch 90, L 1 b, L 32 b, L 50 b

Third Term: Bi 22, Bi 23, Bi 115, Bi 137, Bi/Ph 151, Bi 156, Bi 157, Bi 158, Ch 21 c, Ch 24 b, Env 144, L 1 c, L 32 c, L 50 c

Fourth Year

In addition to those listed for the third year:

First Term: Bi 90a, Bi 217, Ch 144 a, Ch 244 a

Second Term: Bi 90b, Bi 125, Bi/Ch 132 a, Bi 152, Bi 154, Bi 161, Bi 162, Bi 220, Bi 222, Bi 225, Ch 144 b, Ch 244 b, Env 145 a

Third Term: Bi 90c, Bi/Ch 132 b, Bi 218, Bi 219, Bi 241, Env 145 b, Ge 5

[1]Electives must include sufficient units of work in biology to complete the graduation requirement for 143 units of work in biology.
[2]Ch 21 or the combination of Ch 21 a, Ch 24 ab is strongly recommended for students interested in chemical biology, as many graduate programs expect entering students to have taken a course in physical chemistry.
[3]The sequence of courses Bi 150, Bi 152, Bi 156, and Bi 157 is designed to provide a comprehensive introduction to the field of neurobiology. Students with a strong interest in biophysics may substitute Bi/Ph 50 for the Bi 150 course requirement for the biology option.

Chemical Engineering Option

Chemical Engineering is one of the broader of the engineering disciplines, involving the application of mathematics, physics, chemistry, and economics to a variety of problems, characterized mainly by chemical change. Study in this option leads, especially when followed by graduate work, to research and development work in industry and government laboratories or to research and teaching in universities.

Freshman and sophomore students normally take the fundamental courses in chemistry, physics, and mathematics (Ch 1 abc, Ch 41 abc, Ph 1 abc, Ph 2 abc, Ma 1 abc, and Ma 2 abc). Students who show themselves to be qualified may, however, elect to take more advanced courses.

Students interested in an introduction to the breadth of chemical engineering are encouraged to take ChE 10. The open-ended projects in ChE 10 also offer an opportunity to become acquainted with some of the faculty in chemical engineering.

In the second year, students normally take a basic course in chemical engineering thermodynamics, ChE 63 abc. In addition, there are 27 units of elective courses.

Juniors take courses in the physical description of chemical systems, an introduction to the techniques of applied mathematics, and a unified course in transport phenomena involving the study of transfer of momentum, energy, and materials in situations of practical interest. They also take a course in applied chemical kinetics involving the basic study of chemical reactions combined with transport processes in systems of practical interest. Seniors take courses in separation processes and the fundamentals of the control of dynamic systems. The work in kinetics and control and other previous chemical engineering courses is used in senior courses in the optimal design and simulation of chemical systems. Seniors may also take the chemical engineering laboratory during the second and third terms.

Undergraduate research is emphasized, and students are encouraged even in the freshman year to participate in research in association with staff members. Over the past year such research has resulted in a number of publications in scientific journals.

Attention is called to the fact that any student whose grade-point average is less than 1.9 at the end of an academic year in the subjects listed under the Division of Chemistry and Chemical Engineering may at the discretion of the faculty in this division be refused permission to continue the work of this option.

Option Requirements

1. Ch 41 abc, ChE 63 abc, AMa 95 abc, Ch 21 abc, ChE 101, ChE 103 abc, ChE 104, ChE 105, ChE 110 ab, ChE 126 a or Ch 6 a and ChE 126 b, and either Ec/SS 11, Ec 15, or BEM 100a[1]
2. 18 units of chemistry electives[2]
3. 27 units of science and engineering electives[3]
4. Passing grades must be earned in a total of 516 units, including the courses listed below.

[1]These 9 units partially satisfy the Institute requirements in humanities and social sciences.
[2]In addition to chemistry courses taught within the Division of Chemistry and Chemical Engineering, other courses such as Bi 110 and Env 142 may be used to satisfy this requirement.
[3]If research units (ChE 80) are to be used to fulfill elective requirements in the chemical engineering option, a written research report approved by the research director must be submitted in duplicate before May 10 of the year of graduation.

Typical Course Schedule

		Units per term		
Second Year		1st	2nd	3rd
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ph 2 abc	Sophomore Physics (4-0-5)	9	9	9
Ch 41 abc	Sophomore Chemistry (3-0-6)	9	9	9
ChE 63 abc	Chemical Engineering Thermodynamics (3-0-6)	9	9	9
	Electives	9	9	9
		45	45	45
Third Year				
AMa 95 abc	Introductory Methods of Applied Mathematics (4-0-8)	12	12	12
Ch 21 abc	The Physical Description of Chemical Systems (3-0-6)	9	9	9
ChE 101	Chemical Kinetics and Reactor Design (3-0-6)	.	.	9
ChE 103 abc	Transport Phenomena (3-0-6)	9	9	9
	Electives	18	18	9
		48	48	48
Fourth Year				
ChE 104	Separation Processes (3-0-6)	9	.	.
ChE 105	Process Control (3-0-6)	.	9	.
ChE 110 ab	Optimal Design of Chemical Systems (3-0-9)	.	12	12
ChE 126 ab	Chemical Engineering Laboratory (1-6-2)	.	9	9
ChE 161	Advanced Chemical Kinetics and Reactor Design (3-0-6)	9	.	.
	Electives	18	9	18
		36	39	39

Chemistry Option

Study in the chemistry option leads, especially when followed by graduate work, to careers in teaching and research in colleges and universities, in research in government and industry, in operation and control of manufacturing processes, and in management and development positions in the chemical industry.

A first-year general chemistry course is taken by all freshman students. The emphasis is on fundamental principles and their use to systematize descriptive chemistry. Students who show themselves to be qualified and receive the instructor's consent may elect to take an Advanced Placement first-year chemistry course (at least two terms from Ch 2 ab, Ch 21 abc, or Ch 41 abc). The one-term required laboratory course (Ch 3 a) presents basic principles and techniques of synthesis and analysis and develops the laboratory skills and precision that are fundamental to experimental chemistry. The laboratory in the following two terms (Ch 4 ab), normally taken concurrently with Ch 41, introduces the student to methods of synthesis, separation, and instrumental analysis used routinely in research.

Beyond the freshman year, each student in the chemistry option, in consultation with his or her adviser, selects a suitable course of study under the supervision of the division. The requirements of the option are listed below. A student wishing to deviate from these requirements should submit with justification an alternate curriculum for consideration by his or her adviser and the Undergraduate Study Committee.

Undergraduates in the option must also take chemistry courses below the 100 level for a letter grade with the exception of the following courses, which are only offered on a pass/fail basis: Ch 1, Ch 2, Ch 3 a, Ch 90, and if taken during the freshman year, Ch 4 ab, Ch 21 abc, and Ch 41 abc. Within the total period of undergraduate study there are additional Institute requirements for Ma 1 abc, Ph 1 abc, Ma 2 abc, Ph 2 abc, and 108 units of humanities and/or social science as well as 9 units of PE.

The group of courses listed below would constitute a common core for many students in the option.

Any student of the chemistry option whose grade-point average is less than 1.9 will be admitted to the option for the following year only with the special permission of the Division of Chemistry and Chemical Engineering.

Option Requirements

1. Ch 14, Ch 21 abc (or Ch 21 a, Ch 24 ab), Ch 41 abc, Ch 90.
2. A minimum of five terms of laboratory work chosen from Ch 4 ab, Ch 5 ab, Ch 6 ab, Ch 15, and Bi 10.
3. A minimum of five terms of advanced chemistry electives from chemistry course offerings at the 100 and 200 level, including cross-listed offerings such as Bi/Ch 110 abc, Bi/Ch 132 ab, and ChE/Ch 164, but excluding Ch 180, Ch 280, and Bi/Ch 202.
4. Passing grades must be earned in the courses that constitute the approved program of study, including those listed above.
5. Passing grades must be earned in a total of 516 units, including courses listed above. This new requirement becomes effective for freshmen entering 1984-85 and after.

Typical Course Schedule

		Units per term		
Second Year		1st	2nd	3rd
Ch 41 abc	Chemistry of Covalent Compounds (3-0-6)	9	9	9
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ph 2 abc	Waves, Quantum Mechanics, and Statistical Physics (4-0-5)	9	9	9
Ch 5 a	Advanced Techniques of Synthesis and Analysis (1-6-2)	9	.	.
	Electives	6-9	15-18	15-18
PE	Physical Education (0-3-0)	3	3	3
		45-48	45-48	45-48
Third Year				
Ch 14	Chemical Equilibrium and Analysis (2-0-4)	6	.	.
Ch 15	Chemical Equilibrium and Analysis Laboratory (0-6-4)	10	.	.
Ch 21 abc	The Physical Description of Chemical Systems (3-0-6)	9	9	9
Ch 90	Oral Presentation (1-0-1)	.	2	.
	Electives	18-22	36-40	36-40
		43-47	47-51	45-49
Fourth Year				
Ch 6 a	Application of Physical Methods to Chemical Problems (0-6-4)	.	10	.
	Electives	47-51	37-41	47-51
		47-51	47-51	47-51

This core program is not specifically required for graduation in the option, nor is it in any sense a complete program. Students are expected to work out individual programs suitable for their interests and professional goals in consultation with their advisers. Several representative programs, including sets of possible electives, are shown below. These may well approximate choices by students who intend to do graduate work in conventional areas of chemistry.

Suggested Representative Courses of Study for Those Intending To Do Graduate Work in Particular Areas of Chemistry[1,2]

Inorganic Chemistry	*Chemical Physics*	*Organic Chemistry*	*Chemical Biology*
Sophomore Year	*Sophomore Year*	*Sophomore Year*	*Sophomore Year*
Ch 5 ab[3]	Ch 21 abc[7]	Ch 5 ab[3]	Ch 5 a[3]
Ch 41 abc	Ch 6 ab[7]	Ch 41 abc	Ch 41 abc
Ma 2 abc	Ch 14	Ma 2 abc	Bi 1
Ph 2 abc	Ma 2 abc	Ph 2 abc	Bi 9
HSS elective	Ph 2 abc	HSS elective	Ma 2 abc
other elective(s)	HSS elective	other elective(s)	Ph 2 abc
			HSS elective
Junior Year	*Junior Year*	*Junior Year*	*Junior Year*
Ch 14	Ch laboratory[8]	Ch 14	Ch laboratory[11]
Ch 21 abc	Ch 41 abc[7]	Ch 21 abc	Ch 14
Ch elective(s)[4]	Ch elective(s)[9]	Ch elective(s)[10]	Ch 21 a
Ch laboratory[5]	Ch 80[6]	Ch laboratory[5]	Ch 24 ab (or Ch 21 bc)
Ch 80[6]	Ch 90	Ch 80[6]	Ch 80[6] (or Bi 22)
Ch 90	HSS elective	Ch 90	Ch 90
HSS elective	AMa 95 ab	HSS elective	Bi/Ch 110 ab
			Bi 10
			HSS elective
Senior Year	*Senior Year*	*Senior Year*	*Senior Year*
Ch electives[4,5]	Ch 125 abc	Ch electives[5,10]	Ch (Bi) electives[11,12]
Ch 80[6]	Ch electives[8,9]	Ch 80[6]	Ch 80[6] (or Bi 22)
HSS elective	Ch 80[6]	HSS elective	HSS elective
	HSS elective		

[1]A significant fraction of the chemical literature, especially in organic chemistry, is in German. A reading knowledge of German is therefore useful in research at the doctoral level. Russian is another important language for chemistry; however, the leading Russian periodicals are translated and published in English.
[2]Experience in computer programming and use is now important to all areas of chemistry.
[3]Requires Ch 4 ab; if Ch 4 ab was not taken in the freshman year, it can be taken in the sophomore year, and Ch 5 ab deferred to the junior year.
[4]Ch 112, Ch 117, Ch 120 ab, Ch 122 abc, Ch 135 ab, Ch 144 ab, Ch 154, Ch 155, Ch 213 abc, Ch 241 ab, Ch 242 ab, Ch 247 ab.
[5]Ch 15, Ch 26 ab, Ch 118 ab, Bi 10.
[6]See "Research Opportunities for Undergraduates in Chemistry," which may be obtained from the Chairman of the Undergraduate Studies Committee.
[7]Students without sufficient math preparation may delay Ch 21 abc and Ch 6 ab until their junior year and take Ch 5 ab and Ch 41 abc during their sophomore year.
[8]Ch 5 ab[3], Ch 15, Ch 118 ab, Bi 10.
[9]Ch 120 ab, Ch 127 ab, Ch 130 ab, Ch 135 ab, Ch 144 ab, ChE/Ch 164, Ph 106 abc, AMa 105 ab.
[10]Ch 112, Ch 120 ab, Ch 122 ab, Ch 135 ab, Ch 144 ab, Ch 146, Ch 154, Ch 241 ab, Ch 242 ab, Ch 247 ab.
[11]Ch 5 b, Ch 15, Ch 6 ab, Ch 118 ab.
[12]Ch 122 abc, Ch 131, Bi/Ch 132 ab, Ch 144 ab, Ch 146, Ch 154, Ch 242 ab, Ch 244, Ch 247 ab.

Suggested Elective Courses for the Chemistry Option

1. *Chemical Engineering:* Chemical Engineering Systems (ChE 10), Chemical Engineering Thermodynamics (ChE 63), Undergraduate Research (ChE 80), Chemical Kinetics and Reactor Design (ChE 101), Transport Phenomena (ChE 103), Advanced Polymer Science (ChE 167), Polymer Science Laboratory (ChE 168), Introduction to Systems and Control (EE/ChE 170), Advanced Transport Phenomena (ChE 173).
2. *Biology:* Introduction to Molecular Biology (Bi 1), Cell Biology (Bi 9), Genetics (Bi 122).
3. *Engineering:* Introductory Methods of Applied Mathematics (AMa 95), Laboratory Research Methods in Engineering and Applied Science (E 5), Solid-State Electronics for Integrated Circuits (APh 3), Laboratory in Solid-State Electronics for Integrated Circuits (APh 9), Introduction to Linear Electronics (EE 5), Laboratory in Electronics (EE 90), Introduction to Computing (CS 10).
4. *Physics:* Physics Laboratory (Ph 3, Ph 4, Ph 5, Ph 6, Ph 7), Topics in Classical Physics (Ph 106), Quantum Mechanics (Ph 125), Mathematical Models of Physics (Ph 129), Statistical Physics (Ph 127).
5. *Humanities:* Introduction to Economics (Ec/SS 11), Introduction to Macroeconomics: Principles and Problems (Ec 15), Elementary French (L 102) or Elementary German (L 130) or Elementary Russian (L 141).
6. *Miscellaneous:* Introduction to Astronomy (Ay 1), Introductory Geology (Ge 1), Introduction to Geochemistry (Ge 130), Advanced Calculus (Ma 108).

Economics Option

The principal objectives of the economics option are to provide a useful, working knowledge of the economic system and its most important institutions and to present a rigorous curriculum in the conceptual basis and practical applications of modern economics. The upper division courses in microtheory, macrotheory, and econometrics build upon the methods of analysis provided in the Institute freshman and sophomore science and mathematics requirement, offering students comprehensive, scientific development of the fundamentals of modern economic theory. The remaining courses apply the tools of economic analysis to particular areas of public concern where economics is most relevant. The program provides students with an excellent preparation for graduate study in economics, and for an economics-oriented plan of study in a graduate professional school of business or law.

Option Requirements

1. Ec/SS 11, Ec 121 ab, Ec 122, and Ec 126 ab
2. Ma 100 a
3. 54 additional units of advanced economics and social science courses (not including Business Economics and Management). Students may take AMa 181 ab in partial fulfillment of this requirement.
4. 45 additional units of science, mathematics, and engineering courses. The requirement cannot be satisfied by courses listed as satisfying the freshman laboratory requirement or the Institute computing requirement or by APh 3, APh/MS 4, Ay 1, Bi 2, CS/EE 4, EE 5, Env 1, or GE 1.
5. Passing grades must be earned in a total of 516 units, including courses listed above.

Typical Course Schedule

		Units per term		
Second Year		1st	2nd	3rd
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ph 2 abc	Waves, Quantum Mechanics, and Statistical Physics (4-0-5)	9	9	9
Ec/SS 11	Introduction to Economics (3-0-6)	9	.	.
PS/SS 12	Introduction to Political Science (3-0-6)	.	9	.
	Electives[1]	18	18	27
		45	45	45
Third Year				
Ec 121 a	Intermediate Microeconomics (3-0-6)	9	.	.
Ec 122	Econometrics (3-0-6)	.	9	.
Ec 126 ab	Money, Income, and Growth (3-0-6)	9	9	.
Ma 100 a	Statistics (3-0-6)	9	.	.
	Electives[1]	18	27	45
		45	45	45
Fourth Year				
Electives[1]		45	45	45

[1]See requirements 4 and 5 above.

Electrical Engineering Option

The electrical engineering option is designed to provide a broad exposure to the fundamentals of the electrical sciences while allowing some degree of specialization in a particular aspect of modern electrical engineering. Study in this option leads, especially when followed by graduate work, to research and development work in industry and government laboratories or to research and teaching in universities.

Students electing this option normally begin their work in their sophomore year with the theory and laboratory practice of analog and digital electronics in EE 14 abc, EE 90 ab, and CS/EE 4, although many may have already been introduced to the field through freshman electives. The junior year program features basic courses in linear systems, EE 32 ab; communications, EE 160; energy processing, EE 40; and electromagnetics, EE 151 ab. In the senior year, the student will ordinarily demonstrate his or her ability to formulate and carry out a research or development project, through either the senior thesis, EE 78 abc, or the senior project laboratory, EE 91 abc. The senior student may elect advanced courses to continue special interests begun in the required courses or in the electives taken in the sophomore and junior years; alternatively, a senior may select a broader range of topics from EE or other engineering or science courses.

A student whose interests lie in the electrical sciences but who wishes to pursue a broader course of studies than that allowed by the requirements of the electrical engineering option may elect the engineering and applied science option.

Attention is called to the fact that any student who has a grade-point average less than 1.9 at the end of the academic year in the subjects listed under electrical engineering may be refused permission to continue work in this option.

Option Requirements

1. E 10
2. AMa 95 abc
3. EE 14 abc, EE 32 ab, EE 40, EE 151 ab, EE 90 ab, EE 160
4. CS/EE 4 or CS 112
5. EE 78 abc or two terms of EE 91 abc
6. In addition to the above courses, 27 units selected from EE, CS/EE, or EE/Ma courses numbered over 100.
7. Passing grades must be earned in a total of 516 units, including courses listed above.

Typical Course Schedule

		Units per term		
Second Year		1st	2nd	3rd
Ph 2 abc	Waves, Quantum Mechanics and Statistical Physics (4-0-5)	9	9	9
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
	Humanities Electives[1]	9	9	9
EE 14 abc	Introduction to Electronic Engineering (3-0-6)	9	9	9
EE 90 ab	Laboratory in Electronics (0-3-1)	.	4	4
	Electives	12	9	9
		48	49	49
Third Year				
AMa 95 abc	Introductory Methods of Applied Mathematics (4-0-8)	12	12	12
	Humanities Electives[1]	9	9	9
EE 32 ab	Introduction to Linear Systems (3-0-6)	9	9	.
EE 40	Fundamentals of Energy Processing Systems (3-0-6)	9	.	.
EE 151 ab	Engineering Electromagnetics (3-0-6)	.	9	9
EE 160	Communication System Fundamentals (3-0-6)	.	.	9
	Electives	9	9	9
		48	48	48
Fourth Year				
	Humanities Electives[1]	9	9	9
E 10	Technical Seminar Presentations (1-0-1)	.	2	.
EE 91 ab[2]	Experimental Projects in Electronic Circuits	6	6	.
	Electives	27	27	36
		42	44	45

Suggested Electives

First-year students interested in electrical engineering should consider selecting one or two courses per term from APh 3, APh 9, CS/EE 4, CS 10, CS/EE 11, E 5, EE 5, Ph 3.

Suggested elective course sequences for the second, third, and fourth year for various specializations within electrical engineering are given below. Students interested in other areas of specialization or interdisciplinary areas are encouraged to develop their own elective program in consultation with their faculty adviser.

[1]See Institute requirements for specific rules regarding humanities.
[2]See option requirement 5.

COMMUNICATIONS
Second Year
Selected from APh/ME 17 abc, APh 23, APh 24, CS 112, CS 114, CS/EE 121
Third Year
EE/Ma 126, EE/Ma 127 ab, Ma 112 a
Fourth Year
EE 112 abc, EE 162, EE 163 ab, EE 165, CS/EE 183 ab, EE 194

COMPUTER ENGINEERING
Second Year
CS 112, CS 114, CS/EE 121
Third Year
CS 137, CS 138 ab, CS 139 ab
Fourth Year
CS/EE 181 abc and selections from EE 114 abc, CS/EE/Ma 129 abc, CS 171 ab, CS/EE 183 ab

CONTROL
Second Year
APh/ME 17 abc, E 13, E 101
Third Year
EE 117 ab, EE/ChE 170 ab
Fourth Year
Selected from EE/ChE 171 ab, EE 112 abc, EE 114 abc, EE 162

ELECTRONIC CIRCUITS
Second Year
APh/ME 17 abc, E 13, E 101
Third Year
CS 112, CS 114, CS/EE 121
Fourth Year
EE 112 abc, EE 114 abc, EE 117 ab

QUANTUM ELECTRONICS
Second Year
APh/ME 17 abc, APh 23, APh 24
Third Year
APh 50 abc
Fourth Year
Selected from APh 105 abc, APh 114 abc, APh 153 abc, APh 190 abc, EE 155 abc, EE 194, Ph 125 abc

SOLID-STATE ELECTRONICS
Second Year
APh/ME 17 abc
Third Year
APh 50 abc
Fourth Year
APh 181 abc and selections from APh 105 abc, APh 114 abc

Engineering and Applied Science Option

The engineering and applied science option offers the opportunity for study in challenging areas of science and technology. In this option the student may undertake work in such diverse fields as environmental engineering science, solid state physics, energy engineering, the physics of fluids, applied mathematics, earthquake engineering, quantum electronics, aerodynamics, computer science, solid mechanics, the science of materials, soil mechanics, engineering science, elasticity and plasticity, plasma physics, and the theory of waves and vibrations. For those students who, in later life, hope to apply the science they learn to the useful and productive solution of the problems now confronting society, the option in engineering and applied science offers an unusually broad curriculum that permits students to tailor a course of study to their individual needs.

The first year of the four-year course of study leading to a Bachelor of Science degree is common for all students of the Institute, although freshman elective subjects are available as an introduction to various aspects of engineering and applied science. At the end of the first year, students who elect the engineering and applied science option are assigned advisers in their general fields of interest, and, together, they develop programs of study for the next three years. Beyond the Institute-wide requirements of physics, mathematics, and humanities, these programs require one year of applied mathematics and a certain number of units selected from a wide variety of engineering and applied science courses, from which the students and the advisers may build a solid foundation for the kinds of engineering and applied science activities that the students desire to learn. Engineering design (synthesis), as distinct from analysis, is considered an essential part of every engineer's capability. Advisers will expect students to select a sufficient number of courses that place emphasis on design.

Although a special electrical engineering option is available, students whose main interest is in electrical sciences may nevertheless choose the engineering and applied science option if they wish to pursue a broader course of studies.

Attention is called to the fact that any student whose grade-point average is less than 1.9 at the end of an academic year in subjects with the prefix Ae, AM, BIS, CE, ChE, CS, E, EE, ES, Env, Gr, Hy, JP, MS or ME may, at the discretion of the division faculty, be refused permission to continue the work of that option.

Option Requirements

1. E 10
2. AMa 95 abc or Ma 108 abc. Neither course may be taken pass/fail.
3. 126 additional units in courses in the following: Ae, AM, BIS, CE, ChE, CS, E, EE, ES, Env, Gr, Hy, JP, MS, or ME. Note that the student cannot exercise the pass/fail option on any courses offered to meet this requirement.
4. 9 units[1] of courses taken from the following list: APh 24, APh 77, APh 91 abc, Ae/APh 104 bc, AM 155, CE 105, CE 180, CS/EE 121, CS 140, CS/EE 181 abc, EE 90 abc, EE 91 abc, EE 194, Env 116, Env 143, Hy 111, Hy 121, JP 170, MS 90, MS 130, MS 131, MS 132, ME 126.
5. 9 units[1] of additional laboratory[2], excluding those for which freshman laboratory credit is allowed.
6. Passing grades must be earned in a total of 516 units, including courses listed above.

[1]These units will partially satisfy requirement 3 when in appropriate subjects.
[2]These electives must either be from the list in item 4 or they must be from courses with the word "laboratory" in the title.

Typical Course Schedule

	Units per term		
Second Year	1st	2nd	3rd
Ma 2 abc	9	9	9
Ph 2 abc	9	9	9
Humanities Electives	9	9	9
Electives	18	18	18
	45	45	45
Third Year			
AMa 95 abc or Ma 108 abc	12	12	12
Humanities Electives	9	9	9
Electives	24	24	24
	45	45	45
Fourth Year			
E 10	.	2	.
Humanities Electives	9	9	9
Electives	33	33	33
	42	44	42

NOTES:
1. Suggested electives suitable for particular fields of interest are given below.
2. The programs formed with these suggested electives are only samples of typical programs and are *not* meant to represent special option requirements.
3. These electives must be chosen so as to satisfy the laboratory requirements given above.

Suggested Electives

AERONAUTICS

First Year
One course per term selected from: APh/MS 4, ChE 10, E 5, CS/EE 4, CS 10

Second Year
APh/ME 17 abc; one course per term selected from: E 13, ME 1 ab, MS 15 abc, APh 23, APh 24, Ay 1, EE 5

Third Year
AM 97 abc, ME 19 abc; one course per term selected from: APh 50 abc, AM 96 abc, EE 90 abc, ME 5 abc, ME 22 abc, MS 5 abc, E 101

Fourth Year
Ae/APh 101 abc, or Hy 101 abc, or Ae/AM 102 abc, and three courses per term selected from: Ae 103 abc, Ae/APh 104 abc, Ae/AM 108 abc, AMa 101 abc, AM 151 abc, E 102 abc, Hy 111, ME 102 abc, ME 126, JP 121 abc, APh 105 abc, APh 153 abc, MS 105, MS 126 abc

APPLIED MECHANICS

First Year
One course per term selected from: E 5, Ge 1, CS/EE 4, CS 10, CS/EE 11

Second Year
One course per term selected from: APh/ME 17 abc, MS 15 abc, Ge 1, Bi 1, AM 96 abc, Ma 31, E 13

Third Year
AM 97 abc or AM 151 abc, ME 19 abc; one course per term selected from: Ge 2, Ma 112 ab, EE 90 abc, APh 50 abc, MS 5 abc

Fourth Year
AM 151 abc or AM 97 abc, AM 125 abc or AMa 101 abc; one or two courses per term selected from: ME 126, AM 96 abc, AM 135 abc, AM 141 abc, Hy 101 abc, Ph 106 abc, AMa 104, AMa 105, AMa 106

COMPUTER SCIENCE

First Year
CS/EE 4, CS 10, CS/EE 11, Ma 5

Second Year
CS 51, CS 52, CS/EE 53, CS/EE 54, CS/Ma 6 abc

Third and Fourth Years
CS 136 or CS 137, AMa/CS 138 ab, CS 139 ab, CS/EE 181 abc, Ma 116 abc, CS/Ma 117 abc; one or two courses per term selected from: CS/EE/Ma 129 abc, CS 140 ab, CS 142 abc, CS 144 abc, CS 171 ab, Lin 101 ab, Lin/SS 105

ENERGY ENGINEERING

First Year
One course per term selected from: APh 3, APh/MS 4, APh 9, ChE 10, E 5, CS/EE 4, CS/EE 11, Env 1, Gr 1, CS 10

Second Year
APh/ME 17 abc or ChE 63 abc; one course per term selected from: Env 20, EE 5, E 13, EE 14 abc, Ec/SS 11 ab, Ge 1, Ge 5, ME 1 ab, MS 15 abc

Third Year
ME 19 abc; one course per term selected from: APh 50 abc, AM 96 abc, Ch 21 abc, EE 90, ME 5 abc, ME 126, Ph 106 abc

Fourth Year
ME 102 abc, JP 131, ChE 101 ab; one or two courses selected from: Ae/APh 101 abc, Ae 103 abc, Ae 107 abc, AM 97 abc, APh 105 abc, ChE/Env 157, Hy 101 abc, ME 22 abc, ME 118 abc, ME 126, MS 15 abc, Env/Ge 103 abc, ChE 103 abc

NOTE: Electives in humanities and social sciences particularly appropriate to energy studies are Ec 115, Ec 116, Ec 118, SS 130 abc, SS 150 abc.

ENVIRONMENTAL ENGINEERING SCIENCE

First Year

Env 1; one course per term selected from: ChE 10, Bi 1, Bi 9, Ch 3 ab, E 5, Ge 1, CS 10, Gr 1

Second Year

APh/ME 17 abc or ChE 63 abc; one course per term selected from: Env 144, Env 145 ab, Ch 14, Ch 15, Ch 41 abc, CS/EE 4, CS/EE 11, E 13, Ge 5, MS 15 abc

Third Year

ME 19 abc or ChE 103 abc, Env 142 ab and Env 143; choose one course per term from: Ch 21 abc, Ch 24 ab, Bi/Ch 110 abc

Fourth Year

ChE/Env 157 abc plus Env 116 or Env 112 abc plus Hy 111; choose one course per term from: Ge 103 abc, Hy 101 abc, Hy 113 abc, Env 146, Env 147, AMa 101 abc, AMa 104, AMa 105

Note: Electives in humanities and social sciences that are especially appropriate to this field are Ec/SS 11, Ec 115, Ec 118.

FLUIDS AND THERMAL ENGINEERING

First Year

One course per term selected from: Gr 1, E 5, CS 10

Second Year

One course per term, selected from APh/ME 17 abc, APh 3, Env 20, CS/EE 4, APh/MS 4, EE 5, ME 1 ab, ChE 63 abc

Third Year

ME 19 abc, AM 96 abc; one course per term selected from: MS 15 abc, E 13, EE 14 abc

Fourth Year

ME 118 abc, JP 121 abc; one course per term selected from: Hy 101 abc, AM 97 abc, ME 22 abc, ME 102 abc, Hy 111, ME 126, JP 170, E 101, ME 5 abc

HYDRAULICS AND WATER RESOURCES

First Year

One course per term selected from: Gr 1, CS 10, E 5, Ge 1, Ge 2, Env 1

Second Year

One course per term selected from: APh/ME 17 abc, Ph 3, Ph 4, CS/EE 4, CS/EE 11, MS 15 abc, Gr 1, E 13, AM 96 abc

Third Year

AM 97 abc, ME 19 abc, Ec/SS 11

Fourth Year

CE 10 abc, CE 115 ab and CE 150, Hy 111 or ME 126, Hy 113 ab, Env 112 abc or Env 146 abc

MATERIALS SCIENCE

First Year

One course per term selected from: E 5, CS/EE 4, CS 10, ChE 10, APh 3, APh 9, APh/MS 4

Second Year

APh/ME 17 abc; one course per term selected from: ME 1 ab, EE 5, Gr 1

Third Year

Three courses per term, selected from AM 97 abc, MS 5 abc, APh 50 abc, MS 15 abc, MS 90

Fourth Year

MS 105, MS 120

MECHANICAL SYSTEMS AND ENGINEERING DESIGN

First Year

EI or CS 10, APh/MS 4, E 5, APh 23, Env 1, Bi 1 (One per term)

Second Year

APh/ME 17 abc, AM 35 abc, CS 112, EE 5, MS 5 abc, GR 1, ME 1 ab

Third Year

EE 32 ab, E 101, EE 14 abc or (APh 3, CS/EE 4, CS/EE 11) ME 19 abc, AM 97 abc, ME 72 abc (Design)

Fourth Year

AM 125 abc or AMa 101 abc or (AMa 104 and AMa 105 ab), AM 151 abc, AM 155, AE/AM 102 abc or AE/AM 108 abc, ME 130 ab (Robotics), ME 141 ab (Bond Graphs), ME 171 ab (CAD)

STRUCTURAL AND SOIL MECHANICS

First Year

One course per term selected from: Gr 1, CS 10, E 5, Ge 1, Ge 2

Second Year

One course per term selected from: APh/ME 17 abc, Ph 3, Ph 4, CS/EE 4, CS/EE 11, MS 15 abc, Gr 1, AM 96 abc

Third Year

AM 97 abc, ME 19 abc

Fourth Year

CE 10 abc, CE 115 ab and CE 105, AM 151 abc, CE 180, CE 181, and CE 182 or Hy 113 ab and Hy 111, Env 112 abc or Env 146

STRUCTURE AND PROPERTIES OF ALLOYS

First Year

One course per term selected from: E 5, CS 10, Gr 1, ChE 10, CS/EE 4, APh 3, APh 9, APh/MS 4

Second Year

APh/ME 17 abc; one course per term selected from: ME 1 ab, MS 15 abc, EE 5

Third Year

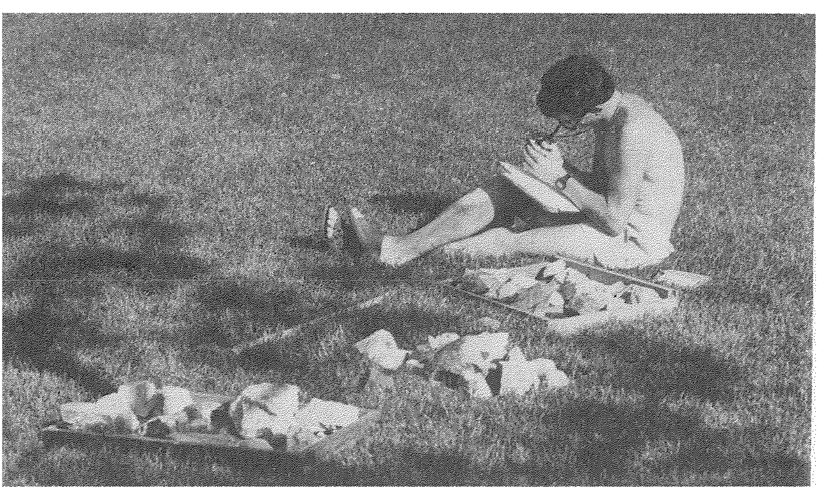
Three courses per term, selected from AM 97 abc, MS 5 abc, APh 105 abc, Ch 21 abc, APh 50 abc

Fourth Year

Three courses per term, selected from APh 114 abc, MS 90, MS 120, Ph 125 abc, MS 130, MS 131, MS 132

Geology, Geochemistry, Geophysics, and Planetary Science Options

The aim of the undergraduate program in the geological sciences is to provide thorough training in basic geological disciplines and, wherever possible, to integrate the geological studies with and build upon the courses in mathematics, physics, chemistry, and biology taken during the earlier years at the Institute. Field work is emphasized because it provides firsthand experience with geological phenomena that can never be satisfactorily grasped or understood solely from classroom or laboratory treatment. Options are offered in geology (including geobiology), geophysics, planetary science, and geochemistry. Electives permit students to follow lines of special interest in related scientific and engineering fields. Those who do well in the basic sciences and at the same time have a compelling curiosity about the earth and its natural features are likely to find their niche in the geological sciences, especially if they possess flexible minds that enable them to grapple with complex problems involving many variables. Most students majoring in the earth sciences now find further training at the graduate level necessary.



Undergraduate Research and Bachelor's Thesis. The division encourages undergraduate research, particularly of such scope and caliber as to merit the preparation of a bachelor's thesis. Guidance in seeking research opportunities and in drawing up a research plan leading to the bachelor's thesis is available from the divisional undergraduate research counselor.

Attention is called to the fact that any student whose grade-point average in science and mathematics courses is less than 1.9 at the end of an academic year may be refused permission to register in the geological sciences options.

Option Requirements and Typical Course Schedules

		YEAR 1	2	3	S	4
Institute Requirements						
Ma 1 abc	Freshman Mathematics	27				
Ph 1 abc	Freshman Physics	27				
Ch 1 abc	General and Quantitative Chemistry	18				
Ch 3 a	Experimental Chemical Science	6				
	Freshman Laboratory	9				
HSS	Humanities and Social Science Electives	27	27	27		27
PE 1 abc	Physical Education	9				
	Freshman Electives	3				
Ma 2 abc	Sophomore Mathematics		27			
Ph 2 abc	Sophomore Physics		27			
	Sophomore Science and Engineering Electives[1]		27			
	Total required courses	126	108	27		27

[1]These 27 units of sophomore electives should be used to broaden the students' backgrounds in science and engineering and to help them select an option. None of the introductory courses in the division, including Ge 1, Ge 4, and Ge 5, is specifically required of majors, but the election of one or more of these is highly recommended in the second year. The division recommends that an additional 9 units of physics, chemistry, and/or engineering laboratory courses be completed in the second year. The units may be selected from the first-year physics, chemistry, and engineering courses, e.g., Ph 5, Ph 6, Ph 7, and Ch 15.

		YEAR 1	2	3	S	4
Division Requirements–All Options						
Ge 100	Geology Club recommended			1		1
Ge 102	Oral Presentation					2
Ge 104 ab	Introduction to Mineralogy and Petrology			18		
Ge 105	The Geologic Record			9		
Ge 107	Geologic Field Mapping			9		
	Language Elective[1]					30
	Total required courses[2]	126	108	64		60

[1]The division requires 30 units of French, German, or Russian for graduation. Students with a good knowledge of one of these languages may petition the Academic Officer for waiver of this requirement. These units may be used as part of the 108 units of humanities and social sciences. Two years of language are highly recommended for students planning to do graduate work.

[2]The division requires that passing grades be earned in a total of 516 units, including the courses listed above under Institute requirements and below under option requirements.

Geochemistry Option Requirements

		YEAR 1	2	3	S	4
Ge 114	Optical and X-Ray Mineralogy					12
Ge 115 ab	Petrology and Petrography					24
Ge 123	Summer Field Geology				15	
Ch 21 abc	The Physical Description of Chemical Systems[1]			27		
Ch 14	Chemical Equilibrium and Analysis					6
Ch 15	Chemical Equilibrium and Analysis Laboratory					10
	Total required courses	126	108	91	15	112

[1]Ch 41 abc or other chemistry courses may be substituted with prior consent of adviser and option representative.

Geology Option Requirements

		YEAR 1	2	3	S	4
Ge 106	Structural Geology			9		
Ge 110	Sedimentary Geology			9		
Ge 114	Optical and X-Ray Mineralogy					12
Ge 115 ab	Petrology and Petrography					24
Ge 123a	Summer Field Geology				15	
Ge 121 abc	Advanced Field and Structural Geology					36
	Advanced Chemistry or Physics[1]			27		
	Geology Electives[2]			27		
	Total required courses	126	108	136	15	132

[1]Ch 21, Ch 41, or Ph 106 recommended.
[2]These 27 units may include Ge electives taken in other years and are taken in the fourth year if French, German, or Russian is taken in the third year. The student should particularly note the opportunity for undergraduate research provided by Ge 40 and Ge 41.

Geophysics and Planetary Science Option Requirements

		YEAR 1	2	3	S	4
Ph 106 abc	Topics in Classical Physics			27		
AMa 95abc	Introductory Methods of Applied Mathematics			36		
	Option Electives[1]					54
	Total required courses	126	108	127		114

[1]Recommended geophysics/geology courses: GE 101 c, Ge 106, Ge 166, Ge 176, Ge 177.

History Option

History majors must take not less than 99 units of history courses during their four years as undergraduates. Of these, not less than 45 *must* be in junior and senior tutorial (H 97 ab and H 99 abc), and another 18 *may* be in H 98 ab if students wish and their instructors agree.

The courses and tutorials in the history option cover four areas: medieval Europe to 1500, modern Europe, the United States, and Asia. Each history major will concentrate in one of these areas and write a research paper in it; each student must also take at least 36 units of history in other areas as approved by the adviser or the history option.

A student considering the history option when he or she comes to Caltech will be well advised to take H 1, 2, 6 or 8. In the sophomore year the student should take middle- or upper-level history courses, but this is also a good time to pursue the study of literature or philosophy, to begin or continue a foreign language (particularly desirable if the area of concentration is to be Europe or Asia), and to do introductory work in the social sciences. A student will normally make a commitment to an area of concentration early in the junior year, exploring this area through regular course work supplemented during the second and third terms by tutorial study in H 97 ab. At the beginning of the senior year a history major will enroll in H 99 abc and be assigned to a faculty member in his or her chosen area. After a period of preparation that may consume part or all of the first term, a student will embark on serious research, the end result of which will be a substantial research paper.

Since statistics can be a useful tool in historical analysis, the option recommends that two of the science and math courses that a history major takes beyond the sophomore year (to satisfy the 54-unit Institute requirement) be Ma 100 a and 100 b. Students who wish to write their senior research papers in the history of science are encouraged to use the rest of the 54 units to advance their understanding of one or two particular scientific disciplines.

Option Requirements

1. H 97 ab, H 99 abc
2. 54 additional units of history courses (including, if appropriate, H 98 ab), of which 36 must be in an area or areas other than the area of concentration.
3. 54 additional units of science, mathematics, and engineering courses. This requirement cannot be satisfied by courses listed as satisfying the freshman laboratory requirement or the Institute computing requirement or by APh 3, APh/MS 4, Ay 1, Bi 2, CS/EE 4, EE 5, Env 1, or GE 1.
4. Passing grades must be earned in a total of 516 units, including the courses listed above.

Typical Course Schedule

A suggested program follows. Requirements are underlined; courses in parentheses are recommended.

	Units per term		
Second Year	1st	2nd	3rd
Ma 2 abc (4-0-5)	9	9	9
Ph 2 abc (4-0-5)	9	9	9
Middle- or Upper-Level History, Literature, Philosophy, or Language	9	9	9
Introductory Social Science	9 (Ec/SS 11)	9 (PS/SS 12)	9
Electives	9	9	9
	45	45	45

Third Year			
H 97 ab (2-0-7)		9	9
Science or Math	9	9	9 (Ma 110 a)
History electives	9	9	9
Other electives	27	18	18
	45	45	45
Fourth Year			
H 99 abc (1-0-8)	9	9	9
Science or Math	9	9	9
History electives	9 (H 98 a)	9 (H 98 b)	9
Other electives	18	18	18
	45	45	45

Typical Course Schedule

		Units per term		
Second Year		1st	2nd	3rd
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ph 2 abc	Waves, Quantum Mechanics, and Statistical Physics (4-0-5)	9	9	9
	Electives[1]	24	24	24
		42	42	42
Third Year				
Electives		45	45	45
Fourth Year				
Electives		45	45	45

[1]81 of these units partially fulfill the Institute requirement in humanities and social science.

Independent Studies Program

The Independent Studies Program (ISP) is an undergraduate option that allows the student to create his or her own scholastic requirements, under faculty supervision, and to pursue positive educational goals that cannot be achieved with a normal option. A student's program may consist of normal Caltech courses, research courses, courses at other schools, and independent study courses (item 5 below). In scope and depth the program must be comparable to a normal undergraduate program, but it need not include the specific courses or groups of courses listed in the formulated Institute requirements for undergraduates.

The ISP Committee, a standing committee of the faculty, has overall responsibility for the program. In addition, each student has his or her own committee of three advisers, two of whom must be professorial faculty. The Registrar keeps records and transcripts of all ISP students, and has application materials for admission into ISP.

Administrative Procedures and Guidelines

1. The student submits a written proposal describing his or her goals, reasons for applying and plan of study for at least the next year. The student must also recruit three faculty members, representing at least two divisions of the Institute, who approve of his or her plans and agree to act as an advisory "committee of three."

2. The committee of three forms the heart of the program and bears the chief responsibility for overseeing the student's progress. The chairman and one other member must be on the professorial staff. The third member may be any qualified individual such as a postdoctoral fellow, graduate student or faculty member of another institution.

3. The ISP committee considers each proposed program in consultation with the prospective members of the committee of three. If the program seems suitable, a three-party written contract is drawn up among the ISP committee, the committee of three, and the student. This contract includes the agreed-upon content of the student's program and the methods for ascertaining satisfactory progress for those parts of the student's program that are not standard Institute courses. Copies of the student's contract, along with all ISP records for each student and his or her transcript, are kept in permanent files in the Registrar's Office.

4. The progress of each student in the ISP is monitored at least every quarter by consultation between the ISP committee and each committee of three. Standards for acceptable progress and satisfactory completion of the terms of the three-party contract are the responsibility of the ISP committee. When the ISP committee is satisfied that the terms of the contract have been fulfilled by the student, it recommends the student to the faculty for graduation.

5. A plan of study may include special ISP courses to accommodate individual programs of study or special research that falls outside ordinary course offerings. The student and the instructor first prepare a written course contract specifying the work to be accomplished and the time schedule for progress reports and for work completed. The units of credit and form of grading are decided by mutual agreement between the instructor, the student, and his or her committee of three. ISP courses are recorded on the student's transcript in the same manner as are other Caltech courses.

Literature Option

Students majoring in literature are offered a wide range of courses that enable them to concentrate on either English or American literature. In addition a number of courses in literature in translation enrich the curriculum. All majors are assigned an adviser who will help them select the courses best suited to their needs. Majors preparing for graduate work will be well advised to go beyond the minimum requirements listed below. All literature courses must be taken for grades. It is recommended that literature majors take electives in such related fields as the arts, languages, history, philosophy, and psychology.

Option Requirements

1. 108 units in the Lit 100-180 group of courses. Within these 108 units, the following are required:
   a. 18 units (two terms) of Shakespeare, Lit 114 a and b.
   b. 27 units (three terms) selected from the following group of courses in pre-twentieth-century English literature: Lit 106 a, Lit 112 a or b, Lit 116, Lit 120, Lit 122 a or b, Lit 125 a and b
   c. 27 units (three terms) selected from the following courses in American Literature: Lit 132, Lit 136, Lit 138, Lit 146 a, Lit 147
2. L 102 abc or L 130 abc or L 141 abc or the equivalent
3. 54 additional units of science, mathematics, and engineering courses. This requirement cannot be satisfied by courses listed as satisfying the freshman laboratory requirement or the Institute computing requirement or by APh 3, APh/MS 4, Ay 1, Bi 2, CS/EE 4, EE 5, Env 1, or GE 1.
4. Passing grades must be earned in a total of 516 units, including the courses listed above.

Mathematics Option

The four-year undergraduate program in mathematics leads to the degree of Bachelor of Science. The purpose of the undergraduate option is to give students an understanding of the broad outlines of modern mathematics, to stimulate their interest in research, and to prepare them for later work, either in pure mathematics or allied sciences. Unless students have done exceptionally well in their freshman and sophomore years, they should not contemplate specializing in mathematics. An average of at least "B" in mathematics courses is expected of students in order to major in mathematics.

Since the more interesting academic and industrial positions open to mathematicians require training beyond a bachelor's degree, students who intend to make mathematics their profession must normally plan to continue with graduate study. Some students use their background in mathematics as an entry to other fields such as physics, economics, computer science, business, or law. Students expecting to pursue a Ph.D. degree in mathematics should realize that many mathematics departments require a reading knowledge of one or two foreign languages.

The schedule of courses in the undergraduate mathematics option is flexible. It enables students to adapt their programs to their needs and mathematical interests and gives them the opportunity of becoming familiar with creative mathematics early in their careers. Each term during the junior and senior years students normally take 18 units of courses in mathematics or applied mathematics, including the required course Ma 108. Any course listed under applied mathematics is regarded as an elective in mathematics and not as an elective in science, engineering, or humanities. Sophomores who have not taken Ma 5 must take this course as juniors. Overloads in course work are strongly discouraged; students are advised instead to deepen and supplement their course work by independent reading.

Attention is called to the fact that students whose grade-point averages are less than 1.9 at the end of the academic year in the subjects under mathematics and applied mathematics may, at the discretion of the department, be refused permission to continue the work of the mathematics option.

Option Requirements

1. Ma 5 abc, Ma 108 abc
2. One of the following one-year courses: Ma 110 abc, Ma 116 abc, Ma/CS 117 abc, Ma 120 abc, Ma 121 abc, Ma 122 abc, Ma/EE 126 a followed by Ma/EE 127 ab, CS/EE/Ma 129 abc, Ma 142 abc, Ma 147 abc, Ma 151 abc, Ma 160 abc
3. 27 additional units in Ma or AMa
4. Passing grades must be earned in a total of 483 units, including the courses listed above.

Typical Course Schedule

		Units per term		
Second Year		1st	2nd	3rd
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ph 2 abc	Waves, Quantum Mechanics, and Statistical Physics (4-0-5)	9	9	9
Ma 5 abc	Introduction to Abstract Algebra (3-0-6)	9	9	9
	Electives in Science, Engineering or Humanities	9	9	9
	Humanities Electives	9	9	9
		45	45	45

Third Year

Ma 108 abc	Advanced Calculus (4-0-8)	12	12	12
	Selected courses in Mathematics, minimum	9	9	9
	Humanities Electives	18	18	18
	Electives in Science, Engineering, or Humanities	9	9	9
		48	48	48

Fourth Year

Selected course in Mathematics	9	9	9
Humanities Electives	18	18	18
Electives in Mathematics, Science, Engineering or Humanities	18	18	18
	45	45	45

Physics Option

The physics option offers instruction in the fundamentals of modern physics and provides a foundation for graduate study, which is generally necessary for a career in basic research. Many individuals have also found that the physics program forms an excellent basis for future work in a wide variety of allied fields.

While all Caltech students must take the two years of introductory courses, an intensive version of the sophomore course (waves, quantum mechanics, and statistical mechanics) is offered for those planning further study in physics. The required junior level courses give a thorough treatment of fundamental principles. Elective courses taken during the junior and senior years allow students to explore their particular interests. Some electives offer broad surveys, while others concentrate on particular fields of current research. A choice of laboratory courses is offered at several levels. Students are encouraged to become active participants in research on campus. Academic credit for physics work done outside of the classroom can be awarded in a variety of ways.

Students must maintain a grade-point average of 1.9 or better each year in the subjects listed under this division to remain in the physics option.

Option Requirements

Laboratory Courses:

1. Ph 3
2. One of the following:[1] Ph 5, Ph 6, APh 24, or EE 90
3. Ph 7

The above three requirements must be completed by the end of the second year. In planning a program, note that Ph 5, 6, and 7 are each offered only once per year, in the first, second, and third terms, respectively.

4. 18 units of Ph 77, APh 77 or Ph 78 in any combination.

Fundamental Physics:

5. Ph 106 or APh 106
6. Ph 98 or Ph 125

[1]Some laboratory courses from other options have considerable physics content, and students wishing to satisfy this requirement with such a course may petition the Physics Undergraduate Committee for approval.

Electives:

7. 54 units, in addition to the above, of any of the following: Bi/Ph 50, Ph 76, Ph 78, Ph 79, any Ph or APh course numbered 100 or above, or AMa 101. Students wishing to apply more than 9 units of Ph 171, Ph 172 or Ph 173 toward this 54-unit requirement must petition the Physics Undergraduate Committee for approval. Other courses in other departments with substantial physics content may be approved by the Physics Undergraduate Committee in individual cases. The student cannot exercise a pass/fail option for any courses offered to meet this requirement.
8. 27 units of science or engineering electives outside of Ph, APh, Ma and AMa.
9. Passing grades must be earned in a total of 516 units, including the courses listed above.

Typical Course Schedule

	Units per term		
	1st	2nd	3rd
Second Year			
Ph 2 or Ph 12	9	9	9
Ma 2	9	9	9
Humanities	9	9	9
Physics Laboratory	0	9	9
Electives	12	9	9
	39	45	45
Third Year			
Ph 106	9	9	9
Ph 98[1]	9	9	9
AMa 95 or Ma 108	12	12	12
Humanities	9	9	9
Electives	9	9	9
	48	48	48
Fourth Year			
Ph 77	9	9	0
Advanced Physics Electives	18	18	18
Electives	9	9	18
Humanities	9	9	9
	45	45	45

[1]Students who took Ph 2 should consult their adviser as to whether Ph 125 in the senior year might be more appropriate.

Social Science Option

The social science program is designed to provide undergraduates with multidisciplinary training in social science. The program focuses on the processes of social, political, and economic change and the analytical methods used by social scientists to describe and predict them. The program is designed to be sufficiently flexible to provide an excellent preparation for students intending to attend graduate school in any social science discipline, law, or business.

Option Requirements

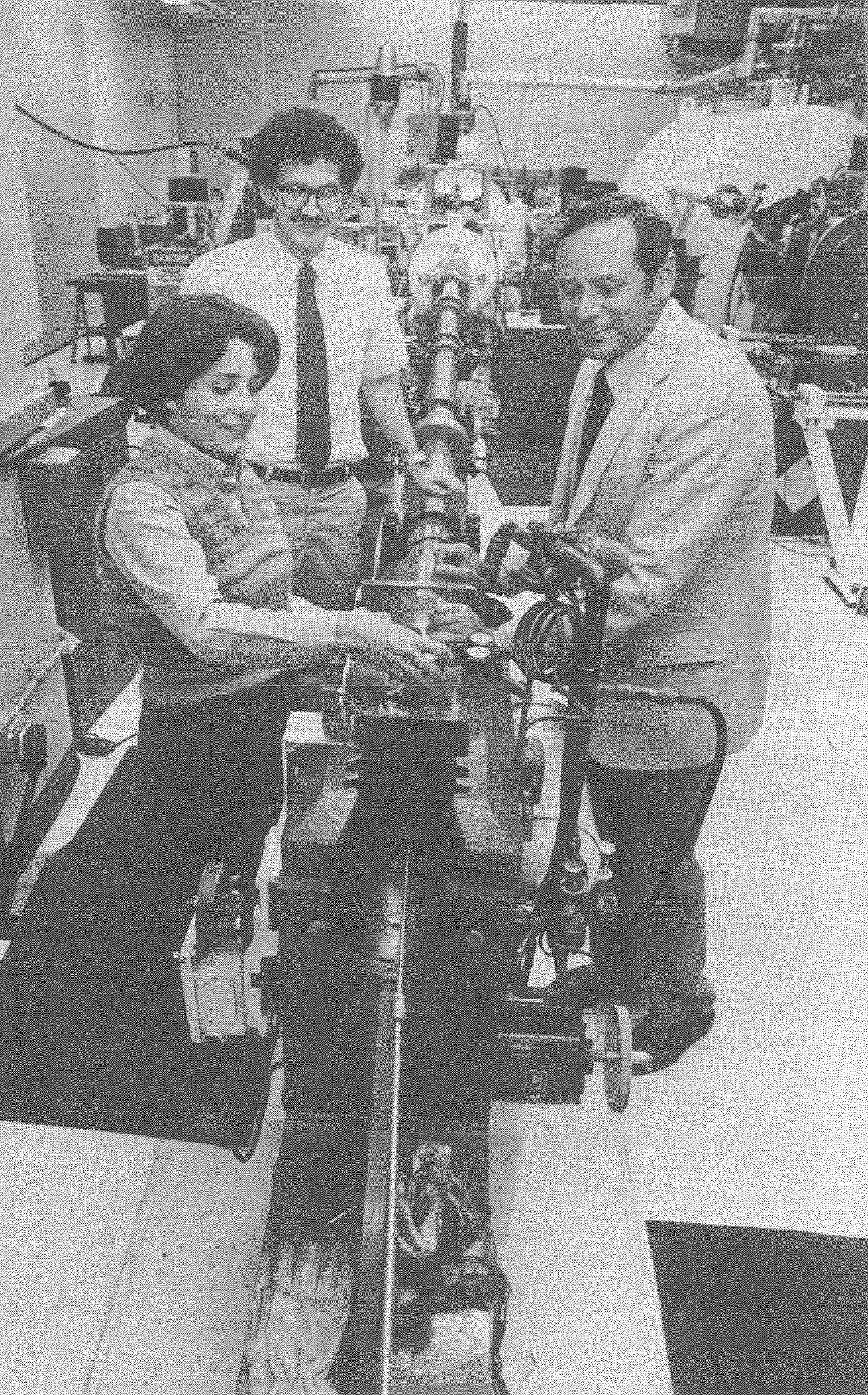
1. Ec/SS 11, PS/SS 12, Ec 121 a, Ma 100 a, Ec 122, PS/SS 122.
2. One of the following: An 22, An 101 a, Psy 10, or Psy 12.

3. 45 additional units of science, mathematics, and engineering courses. The requirement cannot be satisfied by courses listed as satisfying the freshman laboratory requirement or the Institute computing requirement or by APh 3, APh/MS 4, Ay 1, Bi 2, CS/EE 4, EE 5, Env 1, or GE 1.
4. 54 additional units of social science courses, which include any course listed under the following headings: anthropology, economics, political science, psychology, and social science.
5. Passing grades must be earned in a total of 516 units, including courses listed above.

Typical Course Schedule

		Units per term		
Second Year		1st	2nd	3rd
EC/SS 11	Introduction to Economics	9	.	.
PS/SS 12	Introduction to Political Science (3-0-6)	.	9	.
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ph 2 abc	Waves, Quantum Mechanics, and Statistical Physics (4-0-5)	9	9	9
	Electives	18	18	27
		45	45	45
Third Year				
Ma 100 a	Statistics (3-0-6)	9	.	.
Ec 121 a	Intermediate Microeconomics (3-0-6)	9	.	.
Ec 122	Econometrics (3-0-6)	.	9	.
PS/SS 122	Noncooperative Games in Social Science (3-0-6)	.	.	9
An 101 a or	Selected Topics in Anthropology (3-0-6)	9	.	.
An 22 or	Introduction to the Anthropology of Development (3-0-6)	.	9	.
Psy 10 or	Introduction to Psychological Development	.	.	9
Psy 12	Introduction to Abnormal Psychology	.	.	.
	Electives	18	27	27
		45	45	45
Fourth Year				
Electives[1]		45	45	45
		45	45	45

[1]Students may concentrate on research by taking 54 units of supervised research in their senior year.


DANGER

INFORMATION FOR GRADUATE STUDENTS

4

The Institute offers graduate work leading to the degrees of Master of Science and Doctor of Philosophy. In addition, it offers the following intermediate degrees: Aeronautical Engineer, Civil Engineer, Electrical Engineer, and Mechanical Engineer.

The academic work of the Institute is organized into six divisions: Biology; Chemistry and Chemical Engineering; Engineering and Applied Science; Geological and Planetary Sciences; the Humanities and Social Sciences; and Physics, Mathematics and Astronomy.

Graduate work at the Institute is further organized into graduate options, which are supervised by those professors whose interests and research are closely related to the area of the option, within the administrative jurisdiction of one or more of the divisions. The graduate student working for an advanced degree in one of the graduate options is associated with an informal group of those professors who govern the option, other faculty including research associates and fellows, and other graduate students working for similar degrees.

A faculty member serves as the representative for an option. The option representative provides consultation on academic programs, degree requirements, financial aid, etc., and provides general supervision to graduate students in the option. The Committee on Graduate Studies, which includes the option representatives, elected members of the faculty at large, and graduate students appointed by the Graduate Student Council, exercises supervision over the scholastic requirements established by the faculty for all advanced degrees, provides policy guidance to the Dean of Graduate Studies, and certifies all candidates for graduate degrees to the faculty for their approval. The representatives for 1986–87 are as follows:

Aeronautics	Prof. W. G. Knauss
Applied Mathematics	Prof. H. O. Kreiss
Applied Mechanics	Prof. F. S. Buffington
Applied Physics	Prof. P. M. Bellan
Astronomy	Prof. G. Mould
Biology	Prof. C. J. Brokaw
Chemical Engineering	Prof. G. Gavalas
Chemistry	Prof. P. J. Dervan
Civil Engineering	Prof. F. S. Buffington
Computer Science	Prof. A. J. Martin
Electrical Engineering	Prof. H. C. Martel
Engineering Science	Prof. F. S. Buffington
Environmental Engineering Science	Prof. F. S. Buffington
Geological and Planetary Sciences	Prof. D. S. Burnett

Materials Science	Prof. F. S. Buffington
Mathematics	Prof. C. De Prima
Mechanical Engineering	Prof. F. S. Buffington
Physics	Prof. S. C. Frautschi
Social Sciences	Prof. L. E. Davis

GENERAL REGULATIONS

Admission to Graduate Standing

Apply to the Dean of Graduate Studies, California Institute of Technology, 02-31, Pasadena, CA 91125, for an application form for admission to graduate studies. Admission will be granted *only to a limited number of students of superior ability,* and application should be made as early as possible. No application fee is required. In general, admission to graduate standing is effective for enrollment only at the beginning of the next academic year. The California Institute of Technology encourages applications from both men and women, including members of minority groups. Students wishing to apply for assistantships or fellowships may do so in the appropriate section of the application for admission. Completed applications are due in the Graduate Office no later than January 15. Some options will review an application received after the deadline, but that applicant may be at a disadvantage in the allocation of financial assistance or in the priority for admission. Although the application form asks the applicant to state his or her intended major field of study and special interests, the application may actually be considered by two or more divisions or interdisciplinary programs.

To be admitted to graduate standing an applicant must in general have received a bachelor's degree representing the completion of an undergraduate course in science or engineering equivalent to one of the options offered by the Institute. He or she must, moreover, have attained such a scholastic record and present such recommendations as to indicate that he or she is fitted to pursue, with distinction, advanced study and research. In some cases examinations may be required. Admission sometimes may have to be refused solely on the basis of limited facilities in the option concerned.

The Graduate Record Examination is strongly recommended for all applicants.

Students from non-English-speaking countries are expected to read, write, and speak English and comprehend the spoken language. Applicants whose first or native language is not English are required to take the Test of English as a Foreign Language (TOEFL) as part of their application procedure. This test is given at centers throughout the world on several dates each year. The testing schedule and registration information may be obtained by writing to TOEFL, Educational Testing Service, Princeton, NJ 08540. Results of the test should be sent to the Graduate Office. Special no-credit classes in English are sometimes offered at Pasadena City College for those students who need to improve their command of the language or who wish to perfect it. Information regarding these classes can be obtained from the chairman of the Faculty Committee on Foreign Students and Scholars or from the International Desk. It is strongly recommended that students who achieve a low TOEFL score make arrangements for remedial work during the summer preceding their registration.

Admission to graduate standing does not of itself admit the student to candidacy for a degree. Application for admission to candidacy for the degree desired must be made as provided in the regulations governing work for the degree. The student is responsible for seeing that admission is secured at the proper time.

Students may be admitted in exceptional cases as special graduate students to carry out full-time studies at the Institute without being candidates for a degree from Caltech. This status is ordinarily restricted to students who are registered in, or are on leave of absence from, an advanced degree program at another institution and who need to make use of resources available at Caltech. Admission to such status requires application through an appropriate option or directly to the Dean of Graduate Studies, following the same procedures as for regular graduate students.

Graduate Residence

One term of residence shall consist of one term's work of not fewer than 36 units of advanced work in which a passing grade is recorded. Advanced work is defined as study or research in courses whose designated course number is 100 or above. If fewer than 36 units are successfully carried, the residence will be regarded as shortened in the same ratio; but the completion of a greater number of units in any one term will not be regarded as increasing the residence. The residency requirement for each degree will be found under the degree regulation. In general, the residency requirements are as follows: for Master of Science, a minimum of three terms (one academic year) of graduate work; for Aeronautical Engineer, Civil Engineer, Electrical Engineer, and Mechanical Engineer, a minimum of six terms (two academic years) of graduate work; and for Doctor of Philosophy, a minimum of nine terms (three academic years) of graduate work.

Registration

Students are required to register and file a program card in the Registrar's Office at the beginning of each term of residence, whether they are attending a regular course of study, carrying on research, doing independent reading, writing a thesis, or utilizing any other academic service or campus facility. This program card must be signed by the student's adviser. An adviser is assigned to each entering graduate student by the option representative. In most options a new adviser is assigned when the student begins research. Only members of the professorial faculty may serve as advisers.

Students will not receive credit for courses unless they are properly registered. The students themselves are charged with the responsibility of making certain that all grades to which they are entitled have been recorded.

Before registering, students should consult with members of the option in which they are taking their major work to determine the studies that they can pursue to the best advantage. With the approval of the Committee on Graduate Study, any graduate student whose work is not satisfactory may be refused registration at the beginning of any term by the division in which the student is doing his or her major work.

All changes in registration must be reported, on drop or add cards, to the Registrar's Office by the student. Such changes are governed by the last dates for adding or dropping courses as shown on the academic calendar on pages 4 and 5. A student may not withdraw from or add a course after the last date for dropping or adding courses without his or her option's consent and the approval of the Dean of Graduate Studies.

A graduate student who undertakes activities related to the Institute (studies, research, an assistantship, or other employment) aggregating more than 62 hours per week must receive approval from the Dean of Graduate Studies. The number of units allowed for a course is so chosen that one unit corresponds roughly to one hour a week of work throughout the term for a student of superior ability. Petition forms for this purpose may be obtained from the Graduate Office and must carry the recommendation of the option representative of the student's major option before submission to the Graduate Office.

In registering for research, students should indicate on their program card the name of the instructor in charge, and should consult with him or her to determine the number of units to which the proposed work corresponds. At the end of the term, the instructor in charge may decrease the number of units for which credit is given in case he or she feels that the progress of research does not justify the full number originally registered for.

Graduate students are encouraged to continue their research during the whole or a part of the summer. The student must file a registration card for such summer work in the Registrar's Office in May. A minimum of ten units must be taken. There is no tuition charge for summer research units.

Graduate students will be required to maintain their admission status until all requirements for a degree are fulfilled, whether by continuity of registration or on the basis of approved leave of absence. In case of lapse in graduate standing, readmission must be sought before academic work may be resumed or requirements for the degree completed.

Graduate students who cannot devote full time to their studies are allowed to register only under special circumstances. Except by specific action of the Dean of Graduate Studies, graduate students will be required to register for at least 36 units during each of their first three terms of attendance at the Institute. Exceptions for part-time students are subject to regulations detailed in the following section on *Part-Time Programs*. A graduate student who is registered for 36 or more units is classified as a full-time student.

Part-Time Programs

Part-time graduate study programs at the Institute are subject to the following rules:

Degree Programs

a. Applicants for the part-time program must submit a regular application form.
b. Any research work done for academic credit shall be supervised by a Caltech faculty member.
c. Students admitted to the part-time program are required to take at least 27 units of graduate course work or research work each term during the first academic year. They may not commit themselves to work for more than 20 hours per week for the sponsoring organization.
d. Part-time studies in the program will be limited to the first two years of academic residence for each student. Beyond the initial period, students continuing their graduate work must do so on a full-time basis.
e. The program will, in each option, be restricted each year to less than 20 percent of the planned number of new graduate students, with the understanding that adjustments to this limit are permissible for small options.
f. Any option at the Institute retains the right not to participate in the program or to accept it under more stringent conditions.

Non-Degree Programs

Caltech employees, both campus and JPL, are eligible to apply to take one or more graduate courses for credit. Participants in this program will not be considered to be working toward a Caltech degree, in contrast to the part-time program for graduate degrees described above, and courses taken under this program cannot be used to fulfill the requirements for a Caltech degree.

At least one month prior to the start of the term, the employee should have initial discussion with the option representative of the option in which the course is to be taken. Application should be made to the Graduate Office by completing the special form provided for this purpose, and providing a transcript of academic work and one letter of recommendation. The employee must meet the prerequisites for the course, and must obtain the written permission of the instructor. Individual options may require further information such as GRE scores. The decision on admission to take each course will be made by the Option Admissions Committee, with final approval by the Dean of Graduate Studies. Taking an additional course at a later time will require full reapplication. It is the employee's responsibility to arrange a revised work schedule with the appropriate supervisor. Approval of the employee's division is required.

Part-time non-degree students are subject to the Honor System (see page 22) and are under the purview of the Dean of Graduate Studies. They may take only courses numbered 100 or higher. Research courses are excluded from the program. For courses in which a letter grade is offered, these students may not register to receive a pass/fail grade in the course, nor can credit for the course be obtained by examination. The option may limit the number of non-degree students admitted to any one course.

Working at Special Laboratories

a. Any student who desires to take advantage of the unique opportunities available at the special laboratories, e.g., JPL or EQL, for Ph.D. thesis work, should be allowed to do so, provided he or she maintains good contact with academic life on campus, and the laboratories commit support for the duration of the thesis research, and provided that all Caltech graduate thesis research carried out at the special laboratories be under the supervision of Caltech faculty members.
b. A student's request to carry out thesis work at a special laboratory should be formally endorsed by the appropriate committee of his or her option and by the special laboratory on a petition submitted through the option representative to the Dean of Graduate Studies. The special laboratory would recognize its commitment of special equipment or any other resources required for the thesis work. Approval of the special laboratory should also indicate that the thesis topic is a sensible one, and it is not likely to be preempted by the laboratory.
c. Special laboratories' support of Caltech students doing thesis research at the special laboratories should be provided, if possible, through a campus graduate research assistantship (GRA) under a suitable work order. In this way a student would be eligible for a tuition award on the same basis as a campus thesis student.
d. Employment by the special laboratories of a graduate student for work not connected with his or her thesis should be regarded as equivalent to other outside employment.

Exchange Program with Scripps Institution of Oceanography

An exchange program has been established with the Scripps Institution of Oceanography (SIO), University of California, San Diego, permitting Caltech graduate students to enroll in and receive credit for graduate courses offered by SIO. Arrangements should be made through the student's major option and the Office of the Dean of Graduate Studies. The student must obtain the advance approval of the instructors of courses to be taken at SIO. In some cases, when it is in the best interests of the student, arrangements may be made for the student to be temporarily in full-time residence at SIO.

Thesis research done partly at SIO may be arranged directly by the student's option and the staff of appropriate research laboratories at SIO, without the necessity of enrolling for SIO courses designated for research; in this case the student will continue to be under the supervision of his or her Caltech thesis adviser and will enroll for Caltech research units.

DEGREE REGULATIONS

Degree of Master of Science

The Master of Science degree is a professional degree designed to prepare a student for teaching, for further graduate studies, or for more advanced work in industry. Detailed requirements are based primarily on professional studies, and the program should be planned in consultation with the faculty in the appropriate discipline. Under normal circumstances, the requirements for the M.S. degree can be completed in one academic year.

A student who enters the Institute holding a master's degree from another institution will not normally be awarded a master's degree in the same field from the Institute unless the initial admission to Caltech graduate standing indicated that the student was to be a master's candidate. A student may not normally be awarded two master's degrees from the Institute.

Special regulations for the master's degree are listed under each graduate option.

Residence and Units of Graduate Work Required. At least one academic year of residence at the Institute and 135 units of graduate work subsequent to the baccalaureate degree are required for the master's degree. Included in these units are at least 27 units of free electives or of required studies in the humanities. Courses used to fulfill requirements for the bachelor's degree may not be counted as graduate residence.

To qualify for a master's degree, a student must complete the work indicated in the section on special regulations for his or her option with a grade-point average for the approved M.S. candidacy courses of at least 1.9.

In special cases, with the approval of the instructor and the Dean of Graduate Studies, courses taken elsewhere before enrollment at the Institute may be offered for credit. An examination may be required to determine the acceptability of such courses. Course credit, if granted, shall not be construed as residence credit.

Registration. Continuity of registration must be maintained until all requirements for the master's degree have been completed, with the exception of summer terms and authorized leaves of absence.

Admission to Candidacy. Before mid-term of the first term of the academic year in which the student expects to receive the degree, he or she should file in the Office of the Dean of Graduate Studies an application for admission to candidacy for the degree desired. On the candidacy form, the student must submit a proposed plan of study, which must have the approval of his or her option. This approved plan of study will constitute the requirements for the degree. Any modifications must be approved by the option representative and the initialed plan of study resubmitted to the Graduate Office at least two weeks before Commencement.

Engineer's Degree

Engineer's degrees are awarded in aeronautical engineering, civil engineering, electrical engineering, and mechanical engineering. The work for an engineer's degree must consist of advanced studies and research in the field appropriate to the degree desired. It must conform to the special requirements established for that degree and should be planned in consultation with the members of the faculty concerned. Students who have received the master's degree and wish to pursue further studies leading toward either the engineer's or the doctor's degree must file a new petition to continue graduate work toward the desired degree. Students who have received an engineer's degree will not in general be admitted for the doctor's degree.

Residence. At least six terms of graduate residence subsequent to a baccalaureate degree equivalent to that given by the Institute are required for an engineer's degree. Of these, at least the last three terms must be at Caltech. It must be understood that these are minimum requirements, and students must often count on spending a somewhat longer time on graduate work.

To qualify for an engineer's degree, a student must complete the work prescribed by his or her supervising committee with a grade-point average of at least 1.9. Research work and the preparation of a thesis must constitute no fewer than 55 units. More than 55 units may be required by certain options, and the student should determine the particular requirements of his or her option when establishing his or her program.

Registration. Continuity of registration must be maintained until all requirements for the engineer's degree have been completed, with the exception of summer terms and authorized leaves of absence.

Admission to Candidacy. Before mid-term of the first term of the academic year in which the student expects to receive the degree, he or she must file in the Office of the Dean of Graduate Studies an application for admission to candidacy for the degree desired. Upon receipt of this application, the Dean of Graduate Studies, in consultation with the chairman of the appropriate division, will appoint a committee of three members of the faculty to supervise the student's work and to certify to its satisfactory completion. One of the members of the committee must be in a field outside the student's major field of study. The student should then consult with this committee in planning the details of this work. The schedule of his or her work as approved by the committee shall be entered on the application form and shall then constitute a requirement for the degree. Changes in the schedule will not be recognized unless initialed by the proper authority. No course that appears on the approved schedule and for which the applicant is registered may be removed after the last date for dropping courses as listed in the catalog.

The student will be admitted to candidacy for the degree when the supervising committee certifies: (a) that all the special requirements for the desired degree have been met, with the exception that certain courses of not more than two terms in length may be taken after admission to candidacy; (b) that the thesis research has been satisfactorily started and probably can be finished at the expected time.

Such admission to candidacy must be obtained by mid-term of the term in which the degree is to be granted.

Thesis. At least two weeks before the degree is to be conferred, each student is required to submit to the Dean of Graduate Studies two copies of his or her thesis in accordance with the regulations that govern the preparation of doctoral dissertations, which may be obtained from the Graduate Office. The candidate must obtain written approval of the thesis by the chairman of the division and the members of the supervising committee, on a form obtained from the Office of the Dean of Graduate Studies.

The use of "classified" research as thesis material for any degree will not be permitted. Exceptions to this rule can be made only under special circumstances, and then only when approval is given by the Dean of Graduate Studies before the research is undertaken.

Examination. At the discretion of the option in which the degree is desired, a final examination may be required. This examination would be conducted by a committee appointed by the candidate's supervising committee.

Degree of Doctor of Philosophy

The degree of Doctor of Philosophy is conferred by the Institute primarily in recognition of breadth of scholarship, depth of research, and of power to investigate problems independently and efficiently, rather than for the completion of definite courses of study through a stated period of residence. The work for the degree must consist of research and the preparation of a thesis describing it, and of systematic studies of an advanced character, primarily in science or engineering. In addition, the candidate must have acquired the power of clear and forceful self-expression in both oral and written language.

Subject to the general supervision of the Committee on Graduate Study, the student's work for the degree of Doctor of Philosophy is specifically directed by the division in which he or she has chosen the major subject. Each student should consult his or her division concerning special divisional and option requirements.

Admission. With the approval of the Dean of Graduate Studies, students are admitted to graduate standing by the option in which they choose their major work toward the doctor's degree. In some cases, applicants for the doctor's degree may be required to register for the master's or engineer's degree first; however, these degrees are not general prerequisites for the doctor's degree. Students who have received the master's degree and wish to pursue further studies leading toward either the engineer's or the doctor's degree must file a request to continue graduate work toward the desired degree. Students who have received an engineer's degree will not, in general, be admitted for the doctor's degree.

A student who holds a Ph.D. degree from another institution will not normally be admitted to graduate standing at Caltech to pursue a second Ph.D. degree. A student will not normally be awarded two Ph.D. degrees from the Institute.

Minor Programs of Study. The Institute does not require a minor for the Ph.D. degree, but the individual options may have minor requirements as part of their requirements for the major.

A student may undertake a minor program of study in any option. Completion of a minor program of study is recognized on the Ph.D. diploma by the statement, " . . . and by additional studies in (minor option)."

A minor program of study should be at a level of study in the minor substantially beyond that typically acquired by students as part of their major requirements. Most options require 45 units or more, including at least one 200-level course and a coherent program of the supporting 100-level courses. The faculty of the minor option may approve a proposed minor program on the basis of overall class performance and/or by an oral examination. Detailed requirements for minor options are listed under the individual options.

Residence. At least nine terms (three academic years) of residence subsequent to a baccalaureate degree equivalent to that given by the Institute are required for the doctor's degree. Of this at least one year must be in residence at the Institute. It should be understood that these are minimum requirements, and students must usually count on spending a somewhat longer time in residence. A student whose undergraduate work has been insufficient in amount or too narrowly specialized, or whose preparation in his or her special field is inadequate, must count upon spending increased time in work for the degree. This petition must include a plan and schedule for completion, agreed upon and signed by the student, the research adviser, and the option representative.

However, no student will be allowed to continue work toward the doctor's degree for more than five academic years (15 terms) of graduate residence, nor more than 18 terms for full- or part-time academic work without approval of a petition by the Dean of Graduate Studies. This petition must include a plan and schedule for completion, agreed upon and signed by the student, the research adviser and the option representative.

Registration. Continuity of registration must be maintained until all requirements for the doctor's degree have been completed, with the exception of summer terms and authorized leaves of absence.

Admission to Candidacy. On recommendation of the chairman of the division concerned, the Dean of Graduate Studies will admit a student to candidacy for the degree of Doctor of Philosophy after the student has been admitted to work toward the doctor's degree and has been in residence at least one term thereafter; has initiated a program of study approved by the major option and, if needed, by the minor option; has satisfied the several options concerned by written or oral examination or otherwise shown that he or she has a comprehensive grasp of the major and minor subjects and of subjects fundamental to them; has fulfilled any necessary language requirements; and has shown ability in carrying on research in a subject approved by the chairman of the division concerned. Option regulations concerning admission to candidacy are given in a later section. Members of the Institute staff of rank higher than that of assistant professor are not admitted to candidacy for a higher degree.

A standard form, obtained from the Dean of Graduate Studies, is provided for making application for admission to candidacy. Such admission to candidacy must be obtained before the close of the second term of the year in which the degree is to be conferred. *The student is responsible for seeing that admission is secured at the proper time.* A student not admitted to candidacy before the beginning of the fourth academic year of graduate work at the Institute must petition through his or her division to the Dean of Graduate Studies for permission to register for further work.

Candidacy (and permission to register) may be withdrawn by formal action of the option from a student whose research is not satisfactory, or for other compelling reasons. However, the option must petition through its Division Chairman to the Dean of Graduate Studies before taking such action.

Foreign Languages. The Institute believes in the importance of the knowledge of foreign languages and encourages their study as early as possible, preferably before admission to graduate standing. Although there is no Institute-wide foreign language requirement for the degree of Doctor of Philosophy, graduate students should check for possible specific requirements set by their division or option. Previous work is recognized, and further study as a graduate student is possible.

Final Examination. Each doctoral candidate shall undergo broad oral examination on the major subject, the scope of the thesis, and its significance in relation to the major subject. The examination, subject to the approval of the Dean of Graduate Studies, may be taken after admission to candidacy whenever the candidate is prepared; however, it must take place at least two weeks before the degree is to be conferred.

The examination may be written in part, and may be subdivided into parts or given all at one time at the discretion of the options concerned. The student must petition for this examination, on a form obtained from the Graduate Office, not less than two weeks before the date of the examination. Ordinarily, more than two weeks are needed for the necessary arrangements. The date of the examination and the composition of the examining committee will not be approved by the Dean of Graduate Studies until the thesis is submitted in final form—i.e., ready for review by the Dean, the members of the examining committee, and the Graduate Office proofreader. (See *Thesis,* below.)

Thesis. The candidate is to provide a copy of his or her completed thesis to the members of the examining committee at least two weeks before the final oral examination. The date of the examination and the composition of the examining committee will not be approved by the Dean of Graduate Studies until the thesis is submitted in completed form, i.e., ready for review by the Dean, the members of the examining committee, and the Graduate Office proofreader. A student may petition the Dean of Graduate Studies for registration for 10 units and for minimum tuition charges if the student supplies a copy of the thesis, schedules the examination, and submits the necessary petitions for the Ph.D. examination and for the 10 units registration prior to 5:00 p.m. on the third Friday of the term in which the examination will be taken. A student need not register and will not be charged tuition for the term in which the thesis examination is taken, provided the examination is taken and passed before 5:00 p.m. on the first Friday of that term. In addition, all necessary procedures must be followed, including adherence to the deadline dates mentioned above and maintaining continuity of registration or being on an authorized leave of absence.

The last date for submission of the final, corrected thesis to the Dean of Graduate Studies is two weeks before the degree is to be conferred. Two copies of the thesis are to be submitted in accordance with the regulations governing the preparation of doctoral dissertations, obtainable from the Graduate Office. For special option regulations concerning theses, see specific graduate options.

Before submitting the final, corrected thesis to the Dean of Graduate Studies, the candidate must obtain approval of the thesis by the chairman of his or her division and the members of the examining committee, on a form that can be obtained at the Graduate Office.

With the approval of the option concerned, a portion of the thesis may consist of one or more articles published jointly by the candidate and members of the Institute staff or other co-authors. In any case, however, a substantial portion of the thesis must be the candidate's own exposition of his or her own work.

The use of "classified" research as thesis material for any degree is not permitted. Exceptions to this rule can be made only under special circumstances, and then only when approval is given by the Dean of Graduate Studies before the research is undertaken.

Regulations and directions for the preparation of theses may be obtained from the Office of the Dean of Graduate Studies, and should be followed carefully by the candidate.

GRADUATE EXPENSES

The tuition charge for all students registering for graduate work is currently $10,440 per academic year, payable in three installments at the beginning of each term. Graduate students who cannot devote full time to their studies are allowed to register only under special circumstances. Students desiring permission to register for fewer than 36 units should therefore petition on a form obtained from the Graduate Office. If reduced registration is permitted, the tuition for each term is at the rate of $97 a unit for fewer than 36 units, with a minimum of $970 a term. Adjustments of tuition charges may be arranged for changes in units if reported during the first three weeks of a term. Additional tuition will be charged to students registering for special courses that are not part of the normal educational facilities of the Institute.

The payment of tuition by graduate students is required (a) without reference to the character of the work by the student, which may consist of research, independent reading, or writing a thesis or other dissertation, as well as attendance at regular classes; (b) without reference to the number of terms in which the student has already been in residence; and (c) without reference to the status of the student as an appointee of the Institute, except that members of the academic staff of rank of Instructor or higher are not required to pay tuition.

Each graduate student is required to make a general deposit of $25 to cover loss of, or damage to, Institute property used in connection with work in regular courses of study. Upon completion of graduate work, or upon withdrawal from the Institute, any remaining balance of the deposit will be refunded.

Unpaid Bills. All bills owed the Institute must be paid when due. Any student whose bills are past due may be refused registration for the term following that in which the past due charges were incurred. Transcripts are not released until all bills due have been paid or satisfactory arrangements for payment have been made with the Office of Student Accounts.

Information regarding fellowships, scholarships, and assistantships is discussed on the following pages. Students of high scholastic attainment may be offered special tuition awards covering all or a part of the tuition fee. Loans also may be arranged by making an application to the Graduate Office.

Expense Summary 1986–87

General:	
General Deposit	$ 25.00[1]
Tuition	10,440.00
Graduate Student Council Dues	9.00[2]
	$10,474.00

[1]This charge is made only once during residence at the Institute.

[2]Graduate students registered during the summer term are required to pay an additional $3.00 Graduate Student Council dues.

Other:

Books and Supplies (approx.)	$625.00
Graduate House Living Expenses	
Room—$1,890.00 to $2,475.00 per academic year[3]	
(Room rates are subject to change.)	
Meals—Available at Chandler Dining Hall or the Athenaeum (members only)	

[3]Room rent is billed at the end of each month and is payable upon receipt of the monthly statement.

The following is a list of graduate fees at the California Institute of Technology for the Academic Year 1986–87, together with the dates on which these charges are due. Fees are subject to change at the discretion of the Institute.

	First Term	*Fee*
September 29, 1986	General Deposit	$ 25.00
	Tuition	3,480.00
	Graduate Student Council Dues	3.00
	Second Term	
January 5, 1987	Tuition	3,480.00
	Graduate Student Council Dues	3.00
	Third Term	
March 30, 1987	Tuition	3,480.00
	Graduate Student Council Dues	3.00

Tuition fees for fewer than normal number of units:

36 units	Full Tuition
Per unit per term	97.00
Minimum per term	970.00
Audit Fee, $97.00 per lecture hour, per term	

Fees for Late Registration. Registration is not complete until the student has personally turned in the necessary registration forms for a program approved by his or her adviser and has paid tuition and other fees. A penalty fee of $10 is assessed for failure to register within five days of the scheduled dates.

ASCIT Dues. Graduate students are eligible for membership in the Associated Students of the California Institute of Technology, Inc., or ASCIT, pursuant to by-laws thereof. Dues are $60 annually.

Graduate Student Council Dues. Dues of $9 are currently charged to each graduate student for the academic year. In addition, $3 is collected for each graduate student registered during the summer. The council uses the dues to support a program of social and athletic activities and other activities it deems beneficial to graduate student life.

Refunds. Students withdrawing from the Institute or reducing their number of units during the first three weeks of a term are entitled to a partial refund of tuition based on the period of attendance. The schedule for the specific percentage of tuition to be refunded for specific days of attendance appears on page 73. The days in attendance are the number of days counted from the first day of the term to the date that the petition for *withdrawal, leave of absence,* or *reduction of units* (to fewer than 36) is approved by the Dean of Graduate Studies.

Housing Facilities. The Institute has three residence houses on campus providing single rooms for 134 graduate students. In September 1984, the Institute completed construction of an apartment complex, Catalina I, that provides an additional 156 single rooms in four-bedroom units. Catalina II, due for completion in September 1986, will have 154 single rooms in two-bedroom units. These apartments are also available to married students with families.

Rates for housing vary, depending upon the accommodations and services provided. A contract is required to live in these houses for the academic year. During the summer only, rooms may be rented on a month-to-month basis. A $50 deposit must accompany each housing application. The deposit will be refunded if there is no delinquent rent or damages. Complete information and reservations can be obtained by writing to the Housing Office, Mail Code 1-56, California Institute of Technology, Pasadena, CA 91125.

The Institute also owns a limited number of apartments and single family houses that are available for rental, on a lease basis, to married graduate students. Because of the limited availability relative to demand, there is a waiting list for these properties, and priorities are assigned to various categories of students and dependents. For additional information, and sign-up forms, contact the Housing Office, Mail Code 1-56, California Institute of Technology, Pasadena, CA 91125.

The Off-Campus Housing Office maintains a current file of available rooms, apartments, and houses in the Pasadena area. The listings are available for use upon arrival at Caltech. Please note that the Institute cannot make negotiations for individual housing off campus.

Dining Facilities. Graduate students are granted the privilege of joining the Athenaeum (faculty club), which affords the possibility of contact with fellow graduate students and with others using the Athenaeum, including The Associates of the Institute, distinguished visitors, and members of the professional staffs of the Huntington Library and the California Institute of Technology.

The Chandler Dining Hall, located on the campus, is open Monday through Friday and most weekends when the Institute is in session. Breakfast, lunch, and snacks are served cafeteria style.

Health Services. Health services available to graduate students are explained in Section 2.

The International Desk. The International Desk is maintained to help foreign students and visiting scholars with non-academic problems. They will find the services of the desk very helpful, particularly when they first arrive on campus. The International Desk operates under the advice of the Faculty Committee on Foreign Students and Scholars.

FINANCIAL ASSISTANCE

The Institute offers in each of its divisions a number of fellowships, tuition scholarships, and graduate assistantships. In general, tuition scholarships may be for full or partial tuition charges; assistantships provide stipends; and fellowships often provide both tuition scholarship awards and stipends. Graduate assistants are eligible to be considered for special tuition awards.

A request for financial assistance is included on the application for admission to graduate standing. These applications should reach the Graduate Office by January 15. Some options will review applications received after the deadline date, but that applicant may be at a disadvantage in the allocation of financial assistance. Appointments to fellowships, scholarships, and assistantships are for one year only; and a new application must be filed with option representatives each year by all who desire appointments for the following year, whether or not they already hold such appointments.

Graduate students receiving any form of financial aid from the Institute are required to report any financial aid from other sources to the Dean of Graduate Studies. Students may accept outside employment if the time commitment does not interfere with their graduate studies. However, the number of hours per week spent on outside employment must be reported to the Dean of Graduate Studies.

Loans are available to graduate students who need such aid to continue their education. Application should be made to the Graduate Office.

Graduate Assistantships

Graduate assistants help with teaching, laboratory work, or research that affords them useful experience. Teaching assistantships are for 12 or 15 hours per week during the academic year and are devoted to preparation, grading, and consulting with students. Laboratory assistantships and research assistantships usually are for 15 hours per week, sometimes up to 20 hours per week during the academic year and 30 hours per week during the summer. Combined teaching and research assistantships are possible. Assistantships ordinarily permit carrying a full graduate residence schedule also.

Graduate Scholarships, Fellowships, and Research Funds

The Institute offers a number of endowed fellowships and scholarships for tuition and/or stipend to graduate students of exceptional ability who wish to pursue advanced study and research.

In addition to the National Science Foundation, the Department of Health and Human Services, the Department of Energy, and the California State Graduate Fellowship program, gifts are received from other donors to support graduate study.

A number of governmental units, industrial organizations, educational foundations, and private individuals have contributed funds for the support of fundamental research related to their interests and activities. These funds offer financial assistance to selected graduate students in the form of graduate research assistantships.

Work-Study Programs

Limited opportunities are available for work-study programs in certain areas of interest. At the present time the sponsors of such programs are the Hughes Aircraft Company, Scientific Education Office, World Way, P.O. Box 90515, Los Angeles, CA 90009, and the Jet Propulsion Laboratory of the California Institute of Technology. Potential students considering participation in the Hughes program may make inquiry to the address above when applying for graduate study at the Institute. Those wishing to be considered for the JPL program should consult JPL and their option representative after their admission. In general, such programs require some part-time employment during the academic year, as well as full-time work during the summer.

Loans

There are three sources of loans available to graduate students: federal loans under the National Direct Student Loan (NDSL) program, loans under the Guaranteed Student Loan (GSL) program, and loans from special funds of the California Institute of Technology. The amount of loans available from the programs of the federal government is limited by the appropriate government regulations. NDSL borrowers are subject to the same repayment terms and qualification requirements as those outlined for undergraduate students on page 77. Caltech loan funds are also listed on page 77. Repayment terms, including interest rates, may be obtained from the Office of Student Accounts.

PRIZES

William F. Ballhaus Prize

A prize of $500 will be awarded, for an outstanding doctoral dissertation in aeronautics, to be selected by the aeronautics faculty. This award is made possible by a gift from Dr. William F. Ballhaus, a California Institute of Technology alumnus, who received his Ph.D. degree in aeronautics in 1947.

Bohnenblust Travel Grants in Mathematics

Special grants may be awarded to outstanding graduate students in mathematics to enable them to travel here or abroad to further their mathematical education. The mathematics faculty established these awards in 1978 to honor H. F. Bohnenblust, who served Caltech as Professor of Mathematics, Executive Officer for Mathematics, and Dean of Graduate Studies.

W. P. Carey & Co., Inc. Prizes in Applied Mathematics

Prizes of up to $500 will be awarded by a faculty committee in applied mathematics for outstanding doctoral dissertations. These awards have been made possible by gifts from William Polk Carey and from W. P. Carey & Co., Inc.

Richard Bruce Chapman Memorial Award

A prize of $200 will be awarded annually to a graduate student who has distinguished himself or herself in research in the field of hydrodynamics.

Bruce Chapman was awarded an M.S. from Caltech in 1966 and a Ph.D. in 1970, both in engineering science. This award has been established in his memory by his family and friends.

Milton and Francis Clauser Doctoral Prize

An annual prize of $1,500 is awarded to the Ph.D. candidate whose research is judged to exhibit the greatest degree of originality as evidenced by its potential for opening up new avenues of human thought and endeavor as well as by the ingenuity with which it has been carried out.

The Milton and Francis Clauser Doctoral Prize is made possible by gifts from the family and friends of these twin alumni, who received bachelor's degrees in physics in 1934, master's degrees in 1935, and doctor's degrees in aeronautics in 1937.

Henry Ford II Scholar Awards

The Henry Ford II Scholar Awards are funded under an endowment provided by the Ford Motor Company Fund. Each award, up to $5,000, will be made annually either to the engineering student with the best academic record at the end of the third year of undergraduate study, or to the engineering student with the best first-year record in the graduate program. The chairman of the Division of Engineering and Applied Science names the student to receive the award.

Ernest E. Sechler Memorial Award in Aeronautics

An award of $500 is made annually to an aeronautics student who has made the most significant contribution to the teaching and research efforts of the Graduate Aeronautical Laboratories of the California Institute of Technology (GALCIT), with preference given to students working in structural mechanics.

The Ernest E. Sechler Memorial Award in Aeronautics was established in 1980 in memory of Ernest E. Sechler, who was one of the first graduates of GALCIT and who then served as a GALCIT faculty member for 46 years. Throughout his career Sechler was the faculty adviser for aeronautics students. In addition, he made many contributions to structural mechanics in areas ranging from aeronautics to the utilization of energy resources.

John Stager Stemple Memorial Prize in Physics

A prize of $250 is awarded annually to a graduate student in physics for outstanding progress in research as demonstrated by an excellent performance on the oral Ph.D. candidacy exam. John S. Stemple was a Caltech physics graduate student when he died; a memorial fund was established from contributions made by the community of Falls Church, Virginia, John's hometown.

SPECIAL REGULATIONS OF GRADUATE OPTIONS

Aeronautics

Aims and Scope of Graduate Study in Aeronautics
The Institute offers graduate programs in aeronautics leading to the degrees of Master of Science, Aeronautical Engineer, and Doctor of Philosophy. The programs are designed to provide intense training in the foundations of the aeronautical sciences, with emphasis on research and the experimental method. Entering graduate students should have a thorough background in undergraduate mathematics, physics, and engineering science. Applicants for graduate study are asked to submit Graduate Record Examination scores with their applications.

In working for a degree in aeronautics, a student may do major study in, for example, one of the following areas: physics of fluids, technical fluid mechanics, structural mechanics, mechanics of fracture, aeronautical engineering and propulsion, and aero-acoustics.

While research and course work in aeronautics at the Institute cover a very broad range of subjects, a choice of one of the above fields allows students to focus their activities while taking advantage of the flexibility offered by the breadth of interests of the aeronautics group. A student with an interest in energy-related subjects will find many suitable courses and research projects of particular use. Subjects of major importance in the efficient use of energy, such as turbulent mixing, drag reduction, and lightweight structures, have historically been the focus of research activity in the aeronautics option.

In consultation with his or her adviser, a student may design a program of study in one of the above fields, consisting of the fundamental courses prescribed in the regulations for the separate degrees listed below and of electives selected from the list of aeronautics courses. Special attention is called to the list of courses numbered Ae 210 or higher.

Degree of Master of Science in Aeronautics
Admission. Students with a baccalaureate degree equivalent to that given by the Institute are eligible for admission to work toward the Master's Degree in Aeronautics.

Course Requirements. Of the 135 units of graduate work required by Institute regulations, at least 108 units must be in the following subject areas:

Fluid mechanics .... 27 units
Solid mechanics .... 27 units

Experimental technique and laboratory work .... 27 units
Mathematics or applied mathematics... 27 units

In addition, three units of Ae 150 are required. Each student must have a proposed program approved by his or her adviser prior to registration for the first term of work toward the degree.

Degree of Aeronautical Engineer
The degree of Aeronautical Engineer is considered to be a terminal degree for the student who desires advanced training more highly specialized and with less emphasis on research than is appropriate for the Ph.D. degree.

Admission. Students with a baccalaureate degree or with a Master of Science degree equivalent to those given by the Institute are eligible for admission to work for the Engineer's degree.

Program Requirements. The degree of Aeronautical Engineer is awarded after satisfactory completion of at least 135 units of graduate work equivalent to the Master of Science program described above, plus at least 135 additional units of advanced graduate work. This latter program of study and research must consist of:

a. not less than 60 units of research in aeronautics or jet propulsion (Ae 200 or JP 280);
b. three units of an advanced seminar such as Ae 208, Ae/AM 209, or JP 290; and
c. satisfactory completion (with a grade of C or better, or Pass) of at least 27 units of aeronautics courses numbered Ae 200 or higher, excluding research and seminars.

A proposed program conforming to the above regulations must be approved by the student's adviser prior to registration for the first term of work toward the degree.

A thesis is required based on the research program and may consist of the results of a theoretical and/or experimental investigation or may be a comprehensive literature survey combined with a critical analysis of the state of the art in a particular field.

No student will be allowed to continue to work toward the degree of Aeronautical Engineer for more than six terms of graduate residence beyond the baccalaureate degree (not counting summer registrations) except by permission after petition to the aeronautics faculty.

Degree of Doctor of Philosophy in Aeronautics
Admission. Students with a baccalaureate degree or with a Master of Science degree equivalent to those given by the Institute are eligible for admission to work for the Ph.D. degree.

Qualifying Examination. Because of the broad spectrum in the backgrounds of graduate students entering the Ph.D. program in aeronautics, the student must pass a qualifying examination to determine whether he or she is qualified to pursue problems typical of Ph.D. work. This examination should be taken before the student has completed six terms of graduate residence after the baccalaureate degree (not counting summer registration), and after having made a satisfactory beginning on research in his or her chosen field. Emphasis in the qualifying examination is directed at any or all of the following: a) establishing the student's ability to formulate research plans, b) determining the extent of the student's knowledge in his or her field of interest, and c) determining the student's ability to use mathematical and physical principles for original work.

Candidacy. To be recommended for candidacy for the Ph.D. in aeronautics, the applicant must have satisfactorily completed at least 135 units of graduate work equivalent to the above Master of Science program and, in addition, must pass one of the following, or its equivalent, with a grade of C or better:

AMa 101 abc	Methods of Applied Mathematics
AM 125 abc	Engineering Mathematical Principles
Ma 108 abc	Advanced Calculus
Ph 129 abc	Mathematical Methods of Physics

and complete (with a grade of C or better, or Pass):

a. at least 45 units of aeronautics courses numbered Ae 200 or higher, excluding research and seminars

b. at least 54 units of courses outside of the applicant's chosen discipline, approved by the aeronautics faculty.

If any of the above subjects were taken elsewhere than at the Institute, the student may be required to pass special examinations indicating an equivalent knowledge of the subject.

In addition to fulfilling these course requirements, the applicant must pass a candidacy examination at least one year before the degree is expected to be conferred. This examination aims at determining whether the student is successful in integrating formal course work into a mature understanding of fundamental engineering concepts, and at demonstrating his or her professional competence in applying these concepts to problems in advanced research.

Foreign Languages. The student is encouraged to discuss with his or her adviser the desirability of studying foreign languages.

Thesis and Final Examination. By the beginning of the third term of the year in which the degree is to be conferred, a candidate for the degree of Doctor of Philosophy must deliver rough drafts of the thesis to the supervising committee. Not less than two weeks after the submission of the thesis rough drafts, the candidate is expected to give a seminar covering the results of his or her research, and this seminar will be followed by a thesis examination by the supervising committee. The seminar should be given as early as possible, but not later than two months before the degree is to be conferred.

Subject Minor in Aeronautics

A student majoring in a field other than aeronautics may, with the approval of the aeronautics faculty, elect aeronautics as a subject minor. A minimum of 54 units in subjects acceptable to the aeronautics faculty is required.

Applied Mathematics

Aims and Scope of Graduate Study in Applied Mathematics

A program for graduate study in applied mathematics leads to the Ph.D. degree and requires four or five years. This program is aimed at those students with a background in mathematics, physics, or engineering who wish to obtain a thorough training and to develop their research ability in applied mathematics.

Reflecting the interdisciplinary nature of the program, several different groups in addition to the applied mathematics faculty contribute to the teaching and supervision of research. Students in applied mathematics are expected to combine their basic mathematical studies with deep involvement in some field of application. In accordance with this, basic general courses are listed specifically under applied mathematics; these are to be supplemented according to the student's interest from the whole range of Institute courses in specific areas of physics, engineering, etc.

There is an applied mathematics colloquium in which visitors, faculty, and students discuss current research.

Admission

Each new graduate student admitted to work for the Ph.D. in applied mathematics is given an informal interview on Thursday or Friday of the week preceding the beginning of instruction for the fall term. The purpose of this interview is to ascertain the preparation of the student and assist him or her in mapping out a course of study. The work of the student during the first year will usually include some independent reading and/or research.

Categories of Courses

Courses that are expected to form a large part of the student's program are divided by the applied mathematics faculty into three categories as follows:

Group A. Courses in mathematics and mathematical methods. Examples of these would include AMa 101, AMa 104, AMa 105, AMa 156, AMa 157, AMa 201, AMa 204, Ma 109, Ma 137, Ma 143, Ma 144, Ma 147.

Group B. Courses of a general nature in which common mathematical concepts and techniques are applied to problems occurring in various scientific disciplines. Examples of these include: AMa 110, AMa 151, AMa 152, AMa 153, AMa/CS 138, AMa 181, AMa 220, AMa 251, AMa 260.

Group C. Courses dealing with special topics in the sciences. A complete list cannot be given here, but examples are courses in elasticity, fluid mechanics, dynamics, quantum mechanics, electromagnetism, communication theory, and computer science.

Master's Degree in Applied Mathematics
Entering graduate students are normally admitted for the Ph.D. program. The master's degree may be awarded in exceptional cases. Of the 135 units of graduate work required by Institute regulations, at least 81 units of advanced graduate work should be in applied mathematics.

Degree of Doctor of Philosophy in Applied Mathematics
The Oral Candidacy Examination. In order to be recommended for candidacy the student must, in addition to satisfying the general Institute requirements, pass an oral candidacy examination administered by a faculty committee. This examination is normally given during the first term of the second graduate year. It is based upon one year's work in courses of the type described in group A above, and upon one year's work in courses of the type described in groups B and C. The examination will also cover any independent study carried out by the student during his or her first graduate year.

Further Requirements. In order to be recommended for the Ph.D. in applied mathematics, the student must do satisfactory work in a program containing at least 45 units of work in courses of the type indicated in group A, and at least 45 units of courses chosen from groups B and C. This is intended to prevent undue specialization in either the more mathematical or the more engineering type of courses.

Submission of Thesis. On or before the first Monday in April of the year in which the degree is to be conferred, a candidate for the degree of Ph.D. in applied mathematics must deliver a typewritten or printed copy of the completed thesis to his or her research supervisor.

Final Examination. The final oral examination is held within four weeks after the submission of the thesis. The examination covers the thesis and related areas.

Subject Minor in Applied Mathematics
Students majoring in other fields may take a subject minor in applied mathematics, provided the program consists of 45 units sufficiently far removed from their major program of study and is approved by the applied mathematics faculty.

Applied Mechanics

Master's Degree in Applied Mechanics
Study for the degree of Master of Science in Applied Mechanics ordinarily will consist of three terms of course work totaling at least 135 units. AM 125 abc: Engineering Mathematical Principles, and E 150 abc: Engineering Seminar, are required. However, with faculty approval, AM 125 abc may be replaced by Ma 108 abc: Advanced Calculus, AMa 101 abc: Methods of Applied Mathematics, or other satisfactory substitute. A minimum of 54 units of graduate-level courses (numbers 100 and above) must be selected from courses in AM, AMa, Ae, Hy, JP, CE and ME with the approval of the student's adviser and the faculty in applied mechanics. Students are encouraged to consider a humanities elective as part of their free electives.

Students admitted for study toward a master's degree but interested in pursuing subsequent study toward a Ph.D. degree in Applied Mechanics should also read the following section concerning the Ph.D. degree.

Degree of Doctor of Philosophy in Applied Mechanics

The degree of Doctor of Philosophy in Applied Mechanics ordinarily involves a second year of graduate work in advanced courses and research, plus at least one additional year on a comprehensive thesis research project. Such study and research programs are individually planned to fit the interests and background of the student.

Counseling. A counseling committee of three faculty members is appointed for each student upon his or her admission to work toward a Ph.D. degree in Applied Mechanics in order to advise the student on a suitable course program. The committee member closest to the student's current interests acts as committee chairman and interim adviser until this responsibility is assumed by the dissertation supervisor.

In addition, a special joint faculty committee is appointed annually by the faculties in applied mechanics, civil engineering, materials science, and mechanical engineering, which meets both collectively and individually with first-year graduate students aiming toward the doctoral degree in order to provide further perspective on graduate study and research, as well as to discuss the student's evolving interests.

Admission to or Continuation in Ph.D. Status. All new students admitted for study toward the Ph.D. degree in Applied Mechanics, and all other graduate students wishing to become eligible for study toward this degree, are required to take a short oral examination early in the third term of their first year of graduate study at the Institute. This examination, which is conducted by the special joint faculty committee referred to above, is confined to elementary but basic topics in the general areas represented by the committee. One purpose of this examination is to identify possible deficiencies in the student's background and recommend appropriate remedial measures; in addition, the examination contributes to the information used in assessing the student's promise for successful doctoral studies.

Admission to Candidacy for the Ph.D. in Applied Mechanics. To be recommended for candidacy for the Ph.D. degree in applied mechanics, the student must, in addition to meeting the general Institute requirements:

a. complete 12 units of research;
b. complete at least 108 units of advanced courses arranged by the student in conference with his or her adviser and approved by the faculty in applied mechanics. If the student chooses to take a subject minor, the units thereof may be included in the total of 108, subject to the approval of the faculty in applied mechanics;
c. pass with a grade of at least C an advanced course in mathematics or applied mathematics such as AM 125 abc, Ph 129 abc or AMa 101 abc, acceptable to the faculty in applied mechanics. The requirement in mathematics shall be in addition to requirement (b) above and shall not be counted toward a minor;
d. pass an oral examination on the major subject, and, if the student has a minor, examination on the subject of that program may be included at the request of the discipline offering the minor.

Language Requirements. The student is encouraged to discuss with his or her adviser the desirability of taking foreign languages, which may be included in a minor with proper approvals. Foreign languages are not required.

Thesis and Final Examination. A final oral examination will be given after the thesis has been formally completed. This thesis examination will be a defense of the doctoral thesis and a test of the candidate's knowledge in his or her specialized field of research.

Subject Minor in Applied Mechanics

A student majoring in another branch of engineering, or another division of the Institute, may elect applied mechanics as a subject minor, with the approval of the faculty in applied mechanics and the faculty in his or her major field. The group of courses shall differ markedly from the major subject of study or research, and shall consist of at least 54 units of advanced work. The student shall pass an oral examination that is separate from the examination in the student's major.

Applied Physics

Aims and Scope of the Graduate Program in Applied Physics

A graduate student in applied physics may be admitted to work toward a master's degree or toward the Ph.D. degree.

A professional in the field should be able to cope with any physics problem that confronts him or her in a technological context. Graduate study in applied physics should therefore cover considerable ground with the least possible loss of depth. Independent and original research is essential, but not for the purpose of acquiring advanced knowledge in a narrow specialty. In today's rapidly changing technology, an applied physicist should not expect to remain precisely within the field of thesis research; the training received should enable him or her to contribute easily to related fields of physics.

Master's Degree in Applied Physics

Of the 135 units required for this degree, at least 54 units must be selected from APh 114, Ch 125 or Ph 125, APh 105, Ae/APh 101, and APh 156. Topics in Applied Physics, APh 110 abc, is required. The remaining portion of the 135 units is to be made up from electives approved by the option representative. No more than 27 units may be earned in APh 200.

Suggested electives include APh 105, APh 114, Ae/APh 101, APh/MS 126, APh 140, APh 153, APh 156, APh 181, APh 190, APh 200, Ph 125, Ph 129, AMa 101, AMa 104, AMa 105, AM 135, ChE 103, ChE 165, Ch 120, Ch 125, Ge 104, Ge 154, Ge 166. As a result of consultation with his or her adviser, a student may be required to take AM 113 abc, depending on his or her previous experience.

Degree of Doctor of Philosophy in Applied Physics

Candidacy. To be recommended for candidacy for the doctor's degree the applicant must satisfy the requirements listed below:

a. Competence must be demonstrated in the following subjects, at the levels indicated.

1. Classical Physics: Mechanics and Electromagnetism
   course level: Ph 106 or APh 106
2. Quantum Mechanics
   course level: Ph 125 or Ch 125
3. Mathematical Methods
   course level: AMa 101, AM 125, or Ph 129
4. Statistical Physics and Thermodynamics
   course level: APh 105
5. Solid-State Physics or Fluid Dynamics or Plasma Physics
   course level: APh 114, Ae/APh 101, or APh 156

Competence will be demonstrated in either of two ways. The applicant may complete an appropriate Caltech course with a grade no lower than C. Alternatively, should he or she supply evidence of having done equivalent course work elsewhere, the student will be permitted to demonstrate competence through an oral examination. Separate examinations will be required for each area.

b. Oral candidacy examination. The student will prepare a brief presentation on a topic agreed upon by the student and the student's proposed thesis research adviser, normally the projected research topic. The candidacy examination will be based upon the student's background in applied physics and its relation to this presentation.

The oral examination will be given only after the student has demonstrated competence in the five areas and must be completed before the close of the student's second year of residence.

c. Competence in research must be demonstrated as follows: The student must have a doctoral thesis adviser and must have completed 18 units of research with this adviser no later than the beginning of the student's third year of residence.

The Minor. By its nature, applied physics spans a variety of disciplines, and the major requirements reflect this. A minor is *not* required of students majoring in applied physics. Students are, however, encouraged to take advanced courses appropriate to their particular interests.

Thesis and Final Examination. The candidate is required to take a final oral examination covering his or her doctoral thesis, its significance and relation to his or her major field. This final examination will be given not less than two weeks after the doctoral thesis has been presented in final form, and prior to its approval. This examination must be taken at least four weeks before the commencement at which the degree is to be granted.

Subject Minor in Applied Physics

Graduate students electing a subject minor in applied physics must complete 54 units of graduate courses in applied physics. The courses may be selected from any of the applied physics courses with numbers *greater than* 100, excluding APh 110 and APh 200.

The student's proposed program must be approved by the Applied Physics Graduate Studies Committee. The committee will examine the course program to determine which of the following areas of interest in applied physics it includes:

Group A: Ae/APh 101, APh 156

Group B: APh 105, APh 114, APh 140, APh 181, APh 214

Group C: APh 153, APh 190, APh 154

It is recommended that the program include courses from more than one of the above areas.

The Applied Physics Graduate Studies Committee may recommend an oral examination based upon its evaluation of the course program. When the program includes more than one of the above areas of interest, then an oral examination may not be required.

Astronomy

Admission

All applicants for admission to graduate study in astronomy, including those from foreign countries, are required to submit Graduate Record Examination scores for verbal and quantitative aptitude tests and the advanced test in physics.

Placement Examination

Each student admitted to work for an advanced degree in astronomy is required to take the Placement Examination in physics (see Placement Examinations, page 161) covering material equivalent to Ph 106, Ph 125, and Ph 129. This examination will test whether the student's background is sufficiently strong to permit advanced study in astronomy. If it is not, students will be required to pass the appropriate courses.

Master's Degree in Astronomy

The choice of astronomy and other science elective courses must be approved by the department. At least 36 units of the 135 units must be selected from Ay 151, Ay 152, Ay 153, Ay 154, Ay 155, Ay 156. The courses Ph 106, Ph 125, and Ph 129 may be required of those students whose previous training in some of these subjects proves to be insufficient. At least 27 units of advanced courses in fields other than astronomy are required.

Degree of Doctor of Philosophy in Astronomy

Astronomy Program: The student's proposed overall program of study must be planned and approved by the department during the first year. Required courses for candidacy are Ay 151, Ay 152, Ay 153, Ay 154, Ay 155, and Ay 156. The student should take these courses as soon as they are offered. Also required are research and reading projects, starting in the second term of the first academic year. Credit for this work will be given under courses Ay 142 and Ay 143.

Written term papers dealing with the research or reading done will be required at the end of each term.

Physics Program: The student's program during the first two years of graduate study should include at least 36 units of physics courses, exclusive of Ph 106, Ph 125, and Ph 129. This requirement may be reduced on written approval of the department for students who take substantial numbers of units in Ph 106, Ph 125, and Ph 129. Students in radio astronomy may substitute an advanced course in electrical engineering or applied mechanics for up to 9 units of the required 36 units of physics. Theoretical astrophysics students should include at least 54 units of physics courses in their programs. Students in planetary physics may substitute appropriate advanced courses in geophysics and geochemistry. All the above courses must be passed with a grade of C or better.

The Minor: It is recommended that students take a subject minor in physics. Other fields in which subject minors are taken include geology or engineering, depending on the student's field of specialization.

Language Requirement: To be admitted to candidacy for the Ph.D. degree in astronomy, the student must demonstrate a knowledge of Russian, German, Spanish, or French sufficient for the reading of technical material in his or her field. Students will be required to take a special examination administered by the staff in fulfillment of this requirement.

Admission to Candidacy: To be recommended for candidacy for the Ph.D. degree in astronomy, a student must, in addition to meeting the general Institute requirements:

a. complete satisfactorily 36 units of research, Ay 142, or reading, Ay 143;
b. pass with a grade of C or better, or by special examination, Ay 151, Ay 152, Ay 153, Ay 154, Ay 155, Ay 156;
c. pass a written examination (see below);
d. pass an oral examination (see below);
e. fulfill the language requirement (see above); and
f. be accepted for thesis research by a member of the faculty, or by special arrangement, a staff member of the Mt. Wilson and Las Campanas Observatories.

The written examination will be given in October of the second year. It will cover the material from the required astronomy courses and will consist of two three-hour papers. The oral examination must be taken before the end of the first term of the third year. It will cover matters related to the subject of the candidate's proposed thesis. Special permission will be required for further registration if the candidacy course requirements and the written and oral examinations are not satisfactorily completed by the end of the third year of graduate work.

Final Examination: A final draft of the thesis must be submitted at least six weeks before the commencement at which the degree is to be conferred. At least two weeks after submission of the thesis, the student will be examined orally on the scope of his or her thesis and its relation to current research in astronomy.

Subject Minor in Astronomy

The program for a subject minor in astronomy must be approved by the department before admission to candidacy. In addition to general Institute requirements, the student must complete satisfactorily, with a grade of C or better, 45 units in advanced courses in astronomy.

Biology

Aims and Scope of Graduate Study in Biology

Graduate students in biology come with very diverse undergraduate preparation—majors in physics, chemistry, mathematics, or psychology, as well as in biology and its various branches. The aims of the graduate program are to provide, for each student, individual depth of experience and competence in a particular chosen major specialty; perception of the nature and logic of biology as a whole; sufficient strength in basic science to allow continued self-education after formal training has been completed and thus to keep in the forefront of changing fields; and the motivation to serve his or her field productively through a long career. In accordance with these aims, the graduate study program in biology includes the following parts: (a) the major program, which is to provide the student with early and intense original research experience in a self-selected subject of biology, supplemented with advanced course work and independent study in this subject; (b) an optional minor program, usually designed to provide the student with professional insight into a subject outside the major one and consisting of specialized course work, or course work and a special research program; and as a rule, (c) a program of course work designed to provide well-rounded and integrated training in biology and the appropriate basic sciences, which is adjusted to special interests and needs. An individual program will be recommended to each student in a meeting with the student's advisory committee (see below). The Division of Biology does not encourage applications from students who have pursued undergraduate study in biology at the Institute, because the broader perspective to be gained from graduate study in a different setting is considered to be essential for the full development of each student's potential. Exceptions to this policy may be considered by the faculty of the division if there are circumstances, such as completion of an advanced degree at another institution, which indicate that it would be in the best interests of a student to pursue graduate study at the Institute.

Admission

Applicants are expected to meet the following minimal requirements: mathematics through calculus, general physics, organic chemistry, physical chemistry (or the equivalent), and elementary biology. Students with deficient preparation in one or more of these categories may be admitted but required to remedy their deficiencies in the first years of graduate training, no graduate credit being granted for such remedial study. This will usually involve taking courses in the categories in which the student has deficiencies. In certain instances, however, deficiencies may be corrected by examinations following independent or supervised study apart from formal courses. Furthermore, the program in biology is diverse, and in particular fields such as psychobiology and experimental psychology, or in interdisciplinary programs, other kinds of undergraduate preparation may be substituted for the general requirements listed above.

When feasible, visits to the campus for personal interviews will be arranged before a final decision for admission is made. Graduate Record Examinations (verbal, quantitative, and an advanced test in *any* science) are required of applicants for graduate admission intending to major in biology. Applicants are encouraged to take these examinations and request that the scores be transmitted to Caltech, in November or earlier, to ensure unhurried consideration of their applications.

Advisory Committees

An advisory committee will be constituted for each student, to provide consultation and advice throughout the period of study until admission to candidacy. Each advisory committee will consist of three or four faculty members, including a student's current research supervisor and at least one member of the Graduate Admissions Committee who will serve as chairman of the advisory committee. The composition of the committee will be adjusted as necessary if the student changes research supervisors or areas of interest. Each student meets with his or her advisory committee at the time of beginning work in the division to formulate a plan of study, again in the third term of the first year of study to discuss progress and subsequent plans, and at other times when problems arise or advice is needed.

Teaching Requirements for Graduate Students

All students must acquire teaching experience.

Master's Degree in Biology

The Biology Division does not admit students for work toward the M.S. degree. In special circumstances the M.S. degree may be awarded, provided Institute requirements are met. In general the degree is not conferred until the end of the second year of residence. The degree does not designate any of the disciplines of the division, but is an M.S. in Biology.

Degree of Doctor of Philosophy in Biology

Major Subjects of Specialization. A student may pursue major work leading to the doctoral degree in any of the following subjects:

- Biophysics
- Cell Biology
- Developmental Biology
- Genetics
- Immunology
- Molecular Biology
- Neurobiology

At graduation, a student may choose whether the degree is to be awarded in biology or in the selected subject. If the award is to be in biology, a minor will be designated only if it is from another division of the Institute.

Minor Subjects. The Division of Biology does not have a requirement for a minor, but encourages students to undertake work outside their major subject. Recognition of such work on a student's diploma requires completion of a formal minor program, which usually consists of 45 units of advanced course work or research, either in another division of the Institute in accordance with the regulations of that division, or in one of the major subjects of specialization in biology that is not closely related to a student's major field. Students should consult with their advisory committee in planning such a program.

Admission to Candidacy. To be recommended by the Division of Biology for admission to candidacy for the doctor's degree, the student must have demonstrated an ability to carry out original research and have passed, with a grade of B or better, the candidacy examination in the major.

Thesis Committee. At the time of admission to candidacy, a thesis advisory committee is appointed for each student by the chairman of the division upon consultation with the student and the major professor. This committee will consist of the student's major professor as chairman and four other appropriate members of the faculty, including a member of the faculty of the minor (if any). The thesis committee will meet with the student soon after admission to candidacy and at intervals thereafter to review the progress of the thesis program. This committee will, with the approval of the Dean of Graduate Studies, also serve as the thesis examination committee (see below).

Thesis and Final Examination. Two weeks after copies of the thesis are provided to the examination committee, the candidate collects the copies and comments for correction. At this time, the date for the final examination is set at the discretion of the major professor and the division chairman, to allow as much time as necessary for such matters as publication of the examination in the Institute calendar, thesis correction, preparation of publications, and checking out and ordering of the student's laboratory space. The final oral examination covers principally the work of the thesis, and according to Institute regulation must be held at least two weeks before the degree is conferred. Two copies of the thesis are required of the graduate for the Institute library. A third copy is required for the division library.

Minor in Biology

A student majoring in another division of the Institute may, with the approval of the Biology Division, elect a subject minor in any of the subjects listed above under major subjects of specialization. Requirements for such a minor are determined by the faculty committee designated for each subject. A minor program in biology is also available to students of other divisions. Such a program shall consist of 45 units of upper division course work in the Biology Division, each course passed with a grade of C or better. Approval of each program must be obtained from the biology graduate option representative. A student majoring in another division who elects a subject minor in biology may, if desired, arrange to have the minor designated as biology, rather than with the name of the specific minor subject.

Chemical Engineering

Aims and Scope of Graduate Study in Chemical Engineering
The Institute was one of the earliest schools to emphasize instruction on basic subjects rather than on specialized material relating primarily to particular industries or processes. The general objective of the graduate work in chemical engineering is to produce individuals who are exceptionally well-trained to apply the principles of mathematics, the physical sciences, and engineering to the fundamental understanding of systems involving chemical reactions and transport phenomena and to the development of new processes and materials.

Admission
It is expected that each applicant for graduate study in the Division of Chemistry and Chemical Engineering will have studied mathematics, physics, and chemistry to the extent that these subjects are covered in the required undergraduate courses at Caltech. In case the applicant's training is not equivalent, the division may prescribe additional work in these subjects before recommending him or her as a candidate.

Master's Degree in Chemical Engineering
The master's degree is intended for students who plan to pursue careers in design, process engineering, development, or management. The degree is normally obtained in one calendar year.

Course Requirements. The requirements include engineering mathematics, AM 113 abc, if an equivalent course has not been taken previously. The M.S. requirements also include 36 units of advanced courses in chemical engineering, which should ordinarily constitute a coherent program of study, for example including ChE 173 ab, or ChE 164, 165, or ChE 161, 162. Other courses may be substituted upon approval by the chemical engineering faculty. In addition to the required courses, there are 45 units of electives, 18 units of which must be in science and engineering subjects and 27 units of which may include science and engineering subjects, humanities and social science subjects, or research. Finally, the M.S. requirements include at least 18 units of research, ChE 280, which represent two terms of research under the supervision of a chemical engineering faculty member or a two-term industrial research or development project performed with a member of the faculty in cooperation with professional staff at a local industrial laboratory. A research report must be submitted on the work performed under ChE 280 at least three weeks before the end of the final term of residence to a designated member of the faculty, who will ask that it be read and approved by three members of the faculty. A copy of each approved M.S. report will be kept in the chemical engineering library.

Degree of Doctor of Philosophy in Chemical Engineering
The work leading to the Ph.D. degree prepares students for careers in universities and in the research laboratories of industry and government, although Ph.D. graduates are also well qualified for the areas listed for the master's degree. Usually the first year of graduate work is principally devoted to course work in chemical engineering and related subjects. Time is also devoted during this period to the choice of a research project and to its initiation. During the second year the student is expected to spend at least half time on research, and to complete the course work and candidacy requirements. Some time is available for elective courses. It is expected that the student will work full time on the research project during the third and subsequent years.

Admission. During the Friday preceding general registration for the first term of graduate study, students admitted to work for the Ph.D. degree are required to consult with the professor in charge of the courses in chemical thermodynamics, transport phenomena, and applied chemical kinetics. This informal consultation is aimed at planning course work for each student.

Course Requirements. Although there are no formal chemical engineering course requirements, all Ph.D. students must take a selected number of courses outside of chemical engineering to provide both a broadening experience and an opportunity for obtaining further depth in the general thesis area. This requirement may be satisfied by completion of a subject minor in another option, or by completion of an integrated program of study, which normally consists of a total of 54 units (the equivalent of two one-year courses), and must be approved in advance by the Graduate Study Committee in chemical engineering. Generally, AM 113 will not be allowed, nor will research units from other options. A grade of C or better is required in any course that is to be included in the program.

Candidacy Requirements. To be recommended for candidacy the student must demonstrate proficiency at the graduate level in chemical engineering. This is done by way of chemical engineering courses, an oral subject examination, which is to be taken at the end of the third term of the student's first year of graduate residence at the Institute, and a written progress report on his or her research, to be submitted before the end of the second term of the student's second year of graduate residence. The oral examination will cover thermodynamics, applied chemical kinetics and transport phenomena, with emphasis at the discretion of the committee. Approval of the research report constitutes the final step for admission to candidacy. A student who fails to satisfy the division's candidacy requirements by the end of the third term of his or her second year of graduate residence at the Institute will not be allowed to register in a subsequent academic year except by special permission of the Division of Chemistry and Chemical Engineering.

Thesis and Final Examination. See page 121 for regulations concerning theses and final examinations. A copy of the corrected thesis is to be submitted to the chemical engineering graduate secretary for the chemical engineering library.

The final examination will be concerned with the candidate's oral presentation and defense of a brief resume of his or her research.

Subject Minor in Chemical Engineering

Graduate students electing a subject minor in chemical engineering must complete 54 units of graduate courses in chemical engineering that are approved by the chemical engineering faculty. The 54 units will consist of no more than 18 units from ChE 101, 103abc, 104, 105, and 110ab, and at least 36 units from ChE 173/174, ChE 161/162/163, ChE 164/165, or ChE 170/171. A 3.0 GPA is required for the courses taken.

Chemistry

Aims and Scope of Graduate Study in Chemistry

The graduate program in chemistry emphasizes research. This emphasis reflects the Institute's traditional leadership in chemical research and the conviction that has permeated the Division of Chemistry and Chemical Engineering from its founding, that participation in original research is the best way to awaken, develop, and give direction to creativity.

Soon after a new graduate student arrives in the laboratories, he or she will attend a series of orientation seminars that introduce students to the active research interests of the staff. Students then talk in detail with each of several staff members whose fields attract them, eventually settle upon the outlines of a research problem that interests them, and begin research upon it early in the first year. Students can elect to do research that crosses the boundaries of traditionally separate areas of chemistry, for in this relatively compact division, they are encouraged to go where their scientific curiosity drives them; they are not confined to a biochemical or physical or organic laboratory. A thesis that involves more than one adviser is not uncommon, and interdisciplinary programs with biology, physics, and geology are open and encouraged.

An extensive program of seminars will enable students to hear of and discuss notable work in chemical physics, organic chemistry, inorganic and electrochemistry, organometallic chemistry, and chemical biology. Graduate students are also encouraged to attend seminars in other divisions.

Placement Examination

During the week preceding registration for the first term of graduate study, students admitted to work for advanced degrees will be required to take written placement examinations in the fields of inorganic, organic, and physical chemistry and chemical equilibrium. In general, they are designed to test whether students possess an understanding of general principles and a power to apply these to specific problems. Students are expected to demonstrate a proficiency in the above subjects not less than that acquired by advanced undergraduates.

If a student fails to show satisfactory performance in any area of the placement examination, he or she will be required to complete satisfactorily a prescribed course, or courses, in order to correct the deficiency.

Course Program

For an advanced degree, no graduate courses in the principal area of research are required. Course work is involved in satisfying the minor requirement, as described below. Students should plan a program of advanced courses in consultation, at first with a representative of the divisional Committee on Graduate Study, and later with their research adviser.

Master's Degree in Chemistry

Students are not ordinarily admitted to graduate work leading to an M.S. degree, but the master's program is available. All master's programs for the degree in chemistry must include at least 40 units of chemical research and at least 30 units of advanced courses in science. The remaining electives may be satisfied by advanced work in any area of mathematics, science, engineering, or humanities, or by chemical research. Two copies of a satisfactory thesis describing this research, including a one-page digest or summary of the main results obtained, must be submitted to the divisional graduate secretary at least ten days before the degree is to be conferred. The copies of the thesis should be prepared according to the directions formulated by the Dean of Graduate Studies and should be accompanied by a statement approving the thesis, signed by the staff member directing the research, and by the chairman of the division Committee on Graduate Study.

Degree of Doctor of Philosophy in Chemistry

Candidacy. There is no formal course work required in the *major* field of interest (for minor requirements, see below). However, to be recommended for candidacy for the doctor's degree in chemistry, in addition to demonstrating an understanding and knowledge of the fundamentals of chemistry, a student must give satisfactory evidence of proficiency at a high level in the primary field of interest, as approved by the division. This is accomplished by an oral candidacy examination, which must be held during or before the fifth term of graduate residence (excluding summer terms). At this examination the student will be asked to demonstrate scientific and professional competence and promise by discussing a research report and propositions as described below.

The research report should describe progress and accomplishments to date and plans for future research. Two propositions, or brief scientific theses, must accompany the report, and at least one must be well removed from the student's field of research. These propositions should reflect his or her breadth of familiarity with the literature, originality, and ability to pose and analyze suitable scientific research problems. Students enrolled in the Caltech chemistry graduate program before January 1, 1983, may choose to satisfy the proposition requirement under the above policy or under the former policy in effect at their matriculation whereby *three* propositions are required. The propositions should *not* all be in the student's own field of research. Whichever proposition policy is chosen for the candidacy examination must also be followed for the Ph.D. examination. The research report and propositions must be in the hands of the examining committee one week before the examination regardless of which candidacy proposition policy is selected.

The result of the candidacy examination may be either (a) pass, (b) fail, or (c) conditional. Conditional status is granted when the committee decides that deficiencies in a student's research report, propositions, or overall progress can be remedied in a specific and relatively brief period of time. In order to change conditional to pass status, the student must correct the indicated deficiencies or in some cases schedule a new examination the following term. He or she must be admitted to candidacy at least three terms before the final oral examination. A student cannot continue in graduate work in chemistry (nor can financial assistance be continued) past the end of the sixth term of residence without being admitted to candidacy, except by petitioning the division for special permission. This permission, to be requested by a petition submitted to the graduate studies committee stating a proposed timetable for correction of deficiencies, must be submitted before registration for each subsequent term (including the summer following the sixth term of residence) until admission to candidacy is achieved.

Language Requirements and Candidacy. Satisfactory completion of the language requirement and removal of placement examination requirements are also necessary before a student can be admitted to candidacy. Ph.D. chemists must demonstrate proficiency in *one* foreign language: French, German, or Russian. This demonstration can be by test, by good performance in a course at Caltech, or by sufficient undergraduate course work in the language. A grade of B or better is required in all courses.

The Minor. In order to provide breadth in a student's graduate experience, he or she is required either to (a) complete a subject minor in another option (the requirements being set by that option) or (b) complete an approved program of course work outside the principal area of research. This program consists of at least 36 units of course work (the equivalent of approximately four standard one-term courses) outside the scientific area in which the dissertation research is performed (exclusive of courses taken in fulfillment of the chemistry language requirement). These courses may be either inside or outside the chemistry option. Courses for the minor shall be taken on a letter grade basis unless the course is offered with only a pass/fail option. A grade of C or better is required for credit toward the minor. The adviser has the responsibility of determining which courses fulfill the requirement in each particular case, subject to final approval by the chemistry graduate studies committee.

Length of Graduate Residence. Any graduate student who anticipates a need to register for a sixteenth academic term must request a meeting of his or her candidacy committee and present a petition for permission to register that includes a plan of action for the period of the requested registration and specific date for the completion of the degree requirements. This meeting must be held before the end of the third quarter of the fifth academic year of the student's studies. A recommendation from the candidacy committee must be submitted for approval to the chairman of the Chemistry Graduate Study Committee and, in cases where financial support is an issue, by the executive officer or division chairman before it is forwarded to the Dean of Graduate Studies. Financial support of graduate students who are required to petition to register will not normally be provided through teaching assistantships. Failure to complete the degree requirements by the date specified in the petition would require the entire approval process to be repeated.

Thesis and Final Examination. The final examination will consist in part of oral presentation and defense of a brief resume of the student's research and in part of the defense of a set of propositions he or she prepares. Three propositions are required. No more than *one* of these may be a carry-over from the candidacy examination, and *at least one* must be *well removed* from the field of research. Each proposition shall be stated explicitly and the argument presented in writing with adequate documentation. The propositions should display originality, breadth of interest, and soundness of training; a student will be judged on the selection and formulation of the propositions as well as on the defense of them. Formulating a set of propositions should begin early in the course of graduate study.

To emphasize the importance of these propositions, there will be a separate examination on the three propositions by the Ph.D. examining committee. This examination on the propositions must be held not less than ten weeks in advance of the Ph.D. examination. A copy of the propositions, along with suitable abstracts, must be submitted to the examining committee and to the division graduate secretary not less than two weeks before the propositions examination. These propositions must be acceptable to the committee before the final Ph.D. examination can be scheduled.

A copy of the thesis must be submitted to each member of the examining committee not less than two weeks before the final examination. A copy of the thesis should be submitted to the Institute Graduate Office for proofreading three weeks prior to the final examination. One reproduced copy of the thesis, corrected after proofreading, is to be submitted to the division graduate secretary for the divisional library. Two final copies (one on ®Permalife paper) are to be submitted to the Institute Graduate Office.

Students enrolled in the Caltech chemistry graduate program before January 1, 1983, may choose to satisfy the propositions requirement for the final examination under the above policy or, unless the new proposition policy was selected for the candidacy examination, under the former policy in effect at their matriculation whereby five propositions are required. Not more than two of the five propositions shall be related to the immediate area of the thesis research. Propositions of exceptional quality presented at the time of the candidacy examination may be included among the five submitted at the time of the final examination. Under the five-proposition policy, a copy of the thesis and propositions must be submitted in final form to the chairman and to each member of the examining committee, and a copy of the propositions, along with an abstract of the propositions to the division graduate secretary, not less than two weeks prior to the final examination.

Subject Minor in Chemistry

Graduate students in other options taking chemistry as a subject minor will be assigned a faculty adviser in chemistry by the chemistry graduate studies committee. In consultation with this adviser, the student will work out an integrated program of courses, including at least 45 units of formal course work at the 100 level or above. This program must be approved by the chemistry graduate studies committee, and a grade of C or better in each course in the approved program will be required.

Civil Engineering

Aims and Scope of Graduate Study in Civil Engineering

Students who have not specialized in civil engineering as undergraduates, as well as those who have, may be admitted for graduate study. As preparation for advanced study and research, a good four-year undergraduate program in mathematics and the sciences may be substituted for a four-year undergraduate engineering course, with the approval of the faculty. The qualifications of each applicant will be considered individually, and, after being enrolled, the student will arrange his or her program in consultation with a member of the faculty. In some cases the student may be required to make up deficiencies in engineering science courses at the undergraduate level. However, in every case the student will be urged to take some courses that will broaden an understanding of the overall field of civil engineering, as well as courses in his or her specialty. Most graduate students are also required to take further work in applied mathematics.

Master's Degree in Civil Engineering

Although the first year of graduate study involves specialized engineering subjects, the student working for the Master of Science degree is encouraged not to overspecialize in one particular field of civil engineering. For the M.S. degree a minimum of 138 units of academic credit is required. The program must include three units of CE 130 abc and 108 units (minimum) of graduate level courses (numbers 100 and above) from at least three of the five general subject areas of structures and solid mechanics, soil mechanics, hydraulics and water resources, environmental engineering science, and mathematics. Students who have not had AMa 95 abc or its equivalent will be required to include AM 113 abc in their program. The faculty encourages students to take 27 units in the humanities and social sciences.

Degree of Civil Engineer
Greater specialization is provided by work for the engineer's degree than for the master's. The candidate for this degree is allowed wide latitude in selecting his or her program of study, and is encouraged to elect related course work of advanced nature in the basic sciences. The degree of Civil Engineer is considered to be a terminal degree for the student who desires advanced training more highly specialized and with less emphasis on research than is appropriate to the degree of Doctor of Philosophy. However, research leading to a thesis is required for both degrees. The student should refer to Institute requirements for the engineer's degree.

Degree of Doctor of Philosophy in Civil Engineering
Upon admission to work toward the Ph.D. degree in civil engineering, a counseling committee of three members of the faculty is appointed to advise the student on his or her program. One member of the committee who is most closely related to the student's field of interest serves as interim chairman and adviser. The student's thesis adviser is chosen by the student and the advisory committee at a later time, when the student's research interests are more clearly defined.

In addition, a special joint faculty committee, appointed annually by the faculties in applied mechanics, civil engineering, materials science, and mechanical engineering, meets both collectively and individually with first-year graduate students aiming at the doctoral degree in order to provide further perspective on graduate study and research, as well as to discuss the student's evolving interests.

Admission to or Continuation in Ph.D. Status. All new students admitted for study toward the Ph.D. degree in civil engineering, and other graduate students wishing to become eligible for study toward this degree, are required to take a short oral examination early in the third term of their first year of graduate study at the Institute. This examination, which is conducted by the special joint faculty committee referred to above, is confined to basic topics in the general areas of mechanics and mathematics. One purpose of this examination is to identify possible deficiencies in the student's background with a view toward appropriate remedial measures; in addition, the examination contributes to the information used in assessing the student's promise for successful doctoral studies.

Major Subjects of Specialization. A student may pursue major work leading to the doctor's degree in civil engineering in any of the following disciplines: structural engineering and applied mechanics, earthquake engineering, soil mechanics, hydraulics, coastal engineering, and environmental engineering. Other disciplines may be selected with approval of the civil engineering faculty.

Course Requirements. A student must complete at least 108 units of advanced courses, arranged in conference with his or her adviser and approved by the faculty in civil engineering. Students are expected to take not less than 45 units of work in subjects, other than the required mathematics, not closely related to their thesis research. If a student elects to take a subject minor, the units so taken may be included in the total 108, and shall be subject to the approval of the faculty in civil engineering.

Admission to Candidacy. To be recommended to candidacy for the Ph.D. degree in civil engineering the student must, in addition to meeting the general Institute requirements:

a. complete a program of advanced courses as arranged in consultation with his or her advisory committee, and approved by the faculty in civil engineering;
b. pass at least 27 units of course work in advanced mathematics, such as AM 125, AMa 101, Ph 129, or a satisfactory substitute. For a student whose program is more closely related to the sciences of biology or chemistry than physics, AMa 104 and AMa 105 (or AMa 104 and AMa 181 ab) will be an acceptable substitute for the mathematics requirement;
c. pass an oral candidacy examination on the major subject; if the student has a subject minor,

examination on the minor subject may be included at the request of the discipline offering the minor.

The oral candidacy examination must be taken before registration day of the fifth term of residence as a post-M.S. student or equivalent and will comprise:

a. a section where the student will be questioned on the content of courses taken during graduate residence in which he or she will be expected to demonstrate an understanding of the major field of interest;
b. a discussion of a brief research report describing accomplishments to date, including reading, study, and plans for future research. The student must present the report to the examining committee at least ten days before the examination.

Thesis and Final Examination. Copies of the completed thesis must be provided to the examining committee two weeks prior to the examination. The date for the final oral examination is decided at the discretion of the major professor and the division chairman to allow, as necessary, for such matters as publication of the examination in the Institute calendar. The oral examination covers principally the work of the thesis; the examining committee will consist of such individuals as may be recommended by the chairman of the division and approved by the Dean of Graduate Studies.

Subject Minor in Civil Engineering

A student majoring in another branch of engineering, or in another division of the Institute, may, with the approval of the faculty in civil engineering, elect civil engineering as a subject minor. At least 54 units of approved courses must be taken, and an oral examination must be passed.

Computation and Neural Systems

Aims and Scope of Graduate Study in Computation and Neural Systems

An integrated approach to graduate study combining computation and neural systems is organized jointly by the Division of Biology, the Division of Engineering and Applied Science, and the Division of Physics, Mathematics and Astronomy. This curriculum is designed to promote a broad knowledge of relevant and related aspects of neurobiology, computational devices, information theory, emergent or collective systems, parallel computation, modeling, and complex systems, in conjunction with an appropriate depth of knowledge in the particular field of the thesis research.

Admission

Applicants for admission should have an undergraduate major in electrical engineering, biology, physics, mathematics, or computer science and a general background that will permit enrolling in advance courses in the other relevant disciplines. Graduate students apply to the option. Admitted students will become affiliated with one of the three participating divisions as appropriate to their background and interests. All applicants for admission, including those from foreign countries, are strongly urged to submit Graduate Record Examination test scores for verbal and quantitative aptitude tests and for an advanced test in physics, biology, engineering, or mathematics.

Advisory Committees

Upon admission each student will be assigned an adviser in the option and a committee of three members, chaired by the adviser, which will approve the initial course of study by the student. The committee will be the judge of the completion of the breadth requirement, necessary before the candidacy examination. The adviser will be replaced by a research adviser when the direction of specialization is determined, not later than the beginning of the second year.

Categories of Courses
The four categories of courses relevant to the option are:

Computer Science and Collective Computation: EE/Ma 126, EE/Ma 127, CS/EE/Ma 129, EE 162, EE 163, CS/EE 181, CS/Bi/Ph 185, CS/Bi/Ph 186, CS/Ph 187

Neurobiology: Bi 150, Bi 151, Bi 152, Bi 154, Bi 157, Bi 161, Bi 162, Bi 212, Bi 217, Bi 218

Physical Computational Devices: CS/EE 182, APh 181, APh 153

Mathematics and Modeling: AMa 105, AMa 153, AMa 204, CS 257, Ph 101, Ph 127, Ph 222, APh 105

Master's Degree in Computation and Neural Systems
Students will be admitted to the option who expect to pursue the Ph.D. degree. The master's degree may be awarded in exceptional cases. The awarding of this degree requires fulfilling the Institute requirements for a master's degree, the option breadth requirements (see below), and receiving a recommendation for awarding of the degree by a candidacy examination oral committee.

Degree of Doctor of Philosophy in Computation and Neural Systems
Candidacy. To be recommended for candidacy for the Ph.D., the applicant must satisfy a breadth requirement. This consists of satisfactorily taking at least two course-quarters from each of the four course categories and in addition, one quarter of CNS 128, Neurobiology and Computation. Candidates with a weak background in a category may find it necessary to take courses in preparation for those listed. The committee may, under special circumstances, adjust this requirement to fit background or need of a student with the consent of the option representative. Participation in the weekly seminar/colloquium on computation and neural systems is also an integral part of the educational program. To be recommended to candidacy, a student takes an oral candidacy examination in depth on the sub-area on which he or she is embarking in research and on the associated plan of research. This examination must be completed before the close of the second year of residence. The student must have been accepted for thesis research by a research adviser (contingent on passing the examination) before the candidacy examination will be given. The examination committee will consist of five members, including the research adviser and at least three faculty members associated with the option. If the research adviser is not from the option, the general nature of the proposed thesis research must be examined for its appropriateness to the option at the time of the candidacy examination, and must be approved by a majority of the option members on the candidacy committee.

Thesis and final examination. The candidate is required to take a final oral examination covering his or her doctoral thesis. It will consist of a public thesis seminar and an associated oral examination on the thesis and related fields. This examination will be held at least two weeks after the doctoral thesis has been presented in final form, and prior to its approval.

Computer Science

Graduate study in computer science is oriented principally toward Ph.D. research. The course work and thesis requirements for the M.S. degree are a required part of the Ph.D. program. Students entering the graduate program with an M.S. degree from another school may transfer credit for course work as appropriate, but must complete the Caltech M.S. requirements, including the M.S. thesis.

The Ph.D. program requires a minimum of three academic years of residence and rarely takes more than five years. The first two years are typically devoted to course work and M.S. thesis research as preliminaries to the candidacy examination and Ph.D. thesis research.

Students must maintain high academic standards during their graduate residence. A student's

Ph.D. research must exhibit originality in the formulation, analysis, and solution of a problem that is significant to the field of study.

Master's Degree in Computer Science
There are five requirements to fulfill for the M.S. in computer science:

1. *Total units.* Completion of a minimum of 135 units of courses numbered 100 or greater, including M.S. thesis research (CS 180).
2. *Advanced courses in computer science.* Completion of a minimum of 54 units of advanced CS courses in addition to units earned for reading, research, projects, and the M.S. thesis. The student's adviser will assure that this course work represents a balance between theoretical/experimental and hardware/software courses.
3. *Units outside computer science.* Completion of a minimum of 27 units outside computer science. Courses jointly listed with computer science cannot be used to fulfill this requirement.
4. *B.S. equivalent preparation.* As an assurance of reasonable breadth in a student's preparation, M.S. students must demonstrate competence in at least four of the five following areas: (a) theory, (b) hardware, (c) systems, (d) software, (e) applications. Competence can be demonstrated by completion of a corresponding course at Caltech or by undergraduate preparation.
5. *M.S. thesis.* Completion of a minimum of 45 units of CS 180 and of an M.S. thesis approved by a computer science faculty member.

Although it is possible for a well-prepared student to complete the M.S. requirements in one academic year, a period of four to five quarters provides an opportunity for a greater variety of courses than the minimum required, and for a deeper involvement in the M.S. research.

Degree of Doctor of Philosophy in Computer Science
The M.S. requirements are part of the Ph.D. requirements.

Candidacy. To be admitted to candidacy, a student must have completed the M.S. program, have entered upon a course of research approved by his or her thesis adviser, and have passed a candidacy oral examination on general knowledge of computer science.

Thesis and Final Examination. A final oral examination will be scheduled and given after the Ph.D. thesis has been submitted for review to the student's adviser and thesis committee. This thesis examination is a defense of the thesis research and a test of the candidate's knowledge in his or her specialized fields of research.

Subject Minor in Computer Science
A subject minor is not required for the Ph.D. degree in computer science. However, students majoring in other fields may take a subject minor in computer science, provided the program is supervised by a computer science faculty adviser, is approved by the computer science option representative, and consists of 45 units sufficiently removed from the student's major program of study.

Electrical Engineering

Aims and Scope of Graduate Study in Electrical Engineering
The Bachelor of Science degree may be followed by graduate study leading either to the Master of Science degree in electrical engineering, usually completed in one year, or the more advanced degrees of Electrical Engineer or Doctor of Philosophy, usually completed in three to five years. The doctoral candidate may first obtain the Master of Science degree or may enter directly into studies for the degree of Doctor of Philosophy. In judging admission for the Ph.D. degree, the

EE faculty places particular emphasis on any evidence of future research potential. The graduate curriculum is flexible. Students participate in graduate seminars and in research projects. Applicants for graduate study should submit Graduate Record Examination scores with their applications.

Master's Degree in Electrical Engineering
135 units are required as approved by the electrical engineering graduate student adviser. E 150 abc, Engineering Seminar, is required. Students are urged to consider including a humanities course in the remaining free electives.

The attention of students interested in energy-related studies is drawn to EE 114 abc, Electronic Circuit Design; EE 117, Power Electronics; EE 291, Advanced Work in Electrical Engineering (in the Power Electronics Laboratory); ME 102 abc, Principles of Energy Conversion and Distribution; and to additional courses listed under other engineering options.

Degree of Electrical Engineer
To be recommended for the degree of Electrical Engineer the applicant must pass the same subject requirements as listed for the doctor's degree.

Degree of Doctor of Philosophy in Electrical Engineering
Admission. A student may apply for admission to work directly for the degree of Doctor of Philosophy, or he or she may first enroll in study for the Master of Science degree and later apply for admission. This application will be judged in part on the academic performance during B.S. or M.S. studies, but great weight will be given to his or her future research potential. New Ph.D. students, and M.S. students who wish to transfer to Ph.D. studies, are required to make an oral presentation to a faculty committee at the beginning of the second term.

Candidacy. To be recommended for candidacy for the doctor's degree, the applicant must satisfy the following requirements:

a. complete 18 units of research in his or her field of interest.
b. obtain approval of a course of study consisting of at least 189 units of advanced courses in electrical engineering or the related subjects listed under the master's degree, except that units in research (e.g., EE 191 and 291) may not be counted in this total. The course taken to satisfy requirement (c) may be included in this total. Courses taken to fulfill the requirements for the Master of Science degree may be included also.
c. pass one of the following subjects with no grade lower than C: AMa 101 abc, AM 125 abc, Ma 108 abc, Ph 129 abc. An applicant may also satisfy any of the above course requirements by taking an examination in the subject with the instructor in charge. This examination will cover the whole of the course specified, and the student may not take it either in parts or more than twice.
d. pass a qualifying oral examination covering broadly his or her major field and minor program of study. This examination is normally taken near the end of the second year of graduate study.

Thesis and Final Examination. The candidate is required to take a final oral examination covering the doctoral thesis and its significance in and its relation to his or her major field. This final examination will be given not less than two weeks after the doctoral thesis has been presented in final form, and before its approval. This examination must be taken at least four weeks before the commencement at which the degree is to be granted.

Subject Minor in Electrical Engineering
A student majoring in another option at the Institute may elect a subject minor in electrical engineering. He or she must obtain approval from the electrical engineering faculty of a course of study containing at least 45 units of advanced courses with an EE listing (excluding EE 191 and 291). In addition, an oral examination is required, normally taken following completion of the course of study.

Engineering Science

Aims and Scope of Graduate Study in Engineering Science

The engineering science option at Caltech is designed for students of subjects that form the core of new "interdisciplinary" sciences. These branches of science provide the basis for modern technology. Students may choose physics and applied mathematics as their minor subjects and choose a thesis adviser within the Division of Engineering and Applied Science.

Master's Degree in Engineering Science

One of the following courses in mathematics is required: AMa 101 abc, Methods of Applied Mathematics I; AM 125 abc, Engineering Mathematical Principles; or Ph 129 abc, Mathematical Methods of Physics.

A minimum of 54 units of courses must have the approval of the student's adviser and the faculty in engineering science.

Degree of Doctor of Philosophy in Engineering Science

Admission to Candidacy. To be recommended for candidacy for the Ph.D. degree in engineering science, the student must, in addition to meeting the general Institute requirements:

a. complete 12 units of research;
b. complete at least 50 units of advanced courses arranged by the student in conference with his or her adviser and approved by the faculty in engineering science;
c. pass with a grade of at least C an advanced course in mathematics or applied mathematics such as AM 125 abc, Ph 129 abc, or AMa 101 abc, acceptable to the faculty in engineering science. This requirement shall be in addition to requirement (b) above, and shall not be counted toward any minor requirements.
d. pass an oral candidacy examination on the major subject; if the student has a subject minor, examination on the minor subject may be included at the request of the discipline offering the minor.

Language Requirements. Students are encouraged to discuss with their advisers the desirability of taking foreign languages. Foreign languages are not required.

Thesis and Final Examination. A final oral examination will be given after the thesis has been formally completed. This thesis examination will be a defense of the doctoral thesis and a test of the candidates' knowledge in their specialized fields of research.

Subject Minor in Engineering Science

A subject minor is not required for the Ph.D. degree in engineering science; however, students majoring in other fields may take a subject minor in engineering science, provided the program consists of 45 units sufficiently far removed from their major program of study and is approved by the appropriate faculty group and by the option representative.

Environmental Engineering Science

Aims and Scope of Graduate Study in Environmental Engineering Science

Environmental problems cut across many disciplines. Graduate study in environmental engineering science emphasizes environmental problem areas and the application of information from several fields in achieving solutions. Opportunities for interactions among several branches of engineering, science, and social science are numerous.

In selecting courses and research topics, each student is advised to plan for both breadth of study of the environment and depth of understanding in a particular subject area. The curriculum has been developed primarily for students pursuing the Ph.D. degree. The purpose of the Ph.D. program is to prepare students for careers in specialized research, advanced engineering, and management in various aspects of the environment, including, for example, energy-environment relationships. The M.S. degree is also offered for students who plan careers in engineering or in management in some aspect of environmental engineering. Although all graduate students are encouraged to develop an awareness of the wide range of environmental problems, the environmental engineering science program is not designed to train environmental generalists.

Admission
Students with a bachelor's degree in engineering, science, or mathematics may apply for admission to work for either the M.S. or Ph.D. degree. Programs of study are arranged individually by each student in consultation with a faculty adviser. In some instances a student may need to take additional undergraduate courses in preparation for graduate work in this field.

Master's Degree in Environmental Engineering Science
For the M.S. degree a minimum of 135 units of work in advanced courses is required. Each student selects a program with the approval of a faculty adviser. The program should be well-balanced, with courses in several areas of concentration to avoid too narrow specialization.

The M.S. program has been approved by the Accreditation Board for Engineering and Technology (ABET). For an ABET-accredited degree, students must fulfill certain ABET-stipulated requirements with respect to the content of humanities and social science and engineering design in their combined B.S. and M.S. degrees. Students must consult with their faculty advisers to be sure their planned programs satisfy these criteria.

The program must contain at least 63 units of electives chosen from *Group A* below, including 3 units of Seminar (Env 150 abc), plus at least 45 units chosen from *Group A* or *Group B*. Substitutions may only be made under exceptional circumstances with the approval of the environmental science faculty. The remaining units are for free electives of any graduate courses at the Institute. Students who have not had AMa 95 abc or its equivalent are required to include AM 113 abc as part of their *Group B* or free elective units.

Group A. Env 112 abc, Env 116, Env 142 ab, Env 143, Env 144, Env 145 ab, Env 146, Env 147, Env 150 abc, ChE/Env 157 abc, Env 170, Env 242 abc.
Group B. Env 100, Env 200, Env/Ge 203 abc, Env 206, Env 214 abc, Env 250, Env 300, AMa 101 abc, AMa 104, AMa 105 ab, AMa 181 abc, AM 113 abc, AM 125 abc, Bi/Ch 110 ab, Bi/Ch 132 ab, ChE 101, ChE 103 abc, ChE 162, ChE/Ch 164, ChE 165 ab, ChE 173 ab, Ch 117, Ch 118 ab, CE 115 ab, Ec 115, Ec 118, Ec 122, EE/ChE 170 abc, Ge 103 abc, GE 111 ab, Ge 140 a, Hy 101 abc, Hy 111, Hy 113 ab, Hy 121, Hy 213, CS/SS 142 abc, SS 132, H/SS 150, SS 222 ab.

Degree of Doctor of Philosophy in Environmental Engineering Science
Upon a student's admission to work toward the Ph.D. degree in environmental engineering science, a faculty adviser is appointed to assist in the design of an academic program. The faculty adviser will act as chairman of the three-member counseling committee appointed for each student. The student chooses a thesis adviser at a time when his or her major research interest has become clearly defined, usually before the end of the first year at Caltech.

The program of courses for the Ph.D. should be designed to meet the student's need in preparation for research, to provide depth in the major area, and to give breadth of outlook. Each Ph.D. program must receive the approval of the environmental engineering science faculty, upon the recommendation of the faculty adviser and the counseling committee. Students should submit their proposed schedules of courses for the Ph.D. to the faculty for approval during the first term of enrollment.

Major Areas of Specialization. Students may do major study in the following areas: air pollution control, aerosol physics and chemistry, water quality control, aquatic chemistry, marine ecology, environmental fluid mechanics, water resources, environmental health engineering, hydraulic engineering, coastal engineering.

Admission to Candidacy. To be recommended for admission to candidacy for the Ph.D. degree in environmental engineering science, the student must, in addition to meeting the general Institute requirements:

a. complete most of the program of courses as arranged in consultation with the advisory committee to satisfy the guidelines described below, and approved by the faculty of environmental engineering science.
b. pass at least 27 units of course work in advanced mathematics in one of the following courses or sequences: AMa 101 abc; AMa 104, 105 ab, and AM 110; AM 125 abc; Ph 129 abc; or a satisfactory substitute.
c. pass the oral candidacy examinations.

Major Course Requirements. The major program should be tailored to meet the student's needs in preparation for research and yet provide some breadth as well as depth. For breadth the student must take course work in at least two of the following three areas: water quality; air quality; and fluid mechanics and transport processes. Major courses will normally be selected from the lists given above (designated as Groups A and B), although other suitable courses may be proposed.

Minor Course Requirement. Each student is expected to take a subject minor of 45 or more units, for which the requirements in each subject area are delineated in the catalog. Normally, the subject minor will be administered by a division other than Engineering and Applied Science, but it can be taken in another program within this division that is sufficiently different from EES.

Oceanography may be chosen as a subject minor when the required number of course units are taken in approved courses at the Scripps Institution of Oceanography under the exchange arrangement described on page 117. In this case, a professor from SIO will be invited to be a member of the committee for the final examination.

Under exceptional circumstances, in lieu of a subject minor, the EES faculty may approve an alternative program of 45 or more units comprising two or three closely related courses given by two divisions or options, provided that the program has rationale and coherence. If a full-year course is dropped after the first term, that term's work may not be used as credit toward the alternative requirement. A three-term course may be dropped after two terms, and credit received in special circumstances. If humanities or social science courses are elected as part of an alternative program, at least 18 units must be taken in a specific subject. Reading courses or seminars may not be counted as part of this 45-unit requirement.

Minimum Number of Units. The minimum number of units of graduate work is 162, including the major, minor, and required advanced math courses, but excluding research units. Students may not count AM 113 abc as part of the required minimum for satisfying this requirement. Only students with significant prior course work in the environmental field will be able to propose a satisfactory program of the minimum 162 units. If students have taken substantial graduate course work at other institutions, the EES faculty may allow a reduced unit total of Caltech courses.

Candidacy Examinations. The candidacy examinations consist of two parts. Part A must be passed before registration day of the *spring* quarter of the *second* year of graduate study; however, for students entering with an M.S. (or equivalent), the time limit is June 30 following the *first* year of their graduate study at Caltech. Part A of the examination will require the student to provide an oral defense of his or her preparation to be admitted to candidacy for the Ph.D.

Part B of the examination must be passed before registration day of the *winter* quarter of the *third* year of graduate study; however, for students entering with an M.S. (or equivalent), the time limit is registration day of the *winter* quarter of the *second* year of their graduate study at Caltech. The examination will comprise a critical discussion of a brief written research report provided by the student to the examining committee at least ten days before the examination. The report will describe accomplishments to date, including reading, study, and plans for future research.

Thesis and Final Examination. Copies of the completed thesis must be provided to the examining committee two weeks before the examination. The final oral examination covers principally the work of the thesis and, according to Institute regulations, must be held at least two weeks before the degree is conferred. Two copies of the thesis are required of the graduate, one of which is deposited in the Institute library and one with University Microfilms.

Subject Minor in Environmental Engineering Science
A doctoral student in another major field who wishes to take a subject minor in environmental engineering science should submit a proposed minor program to the executive officer for approval. The proposed program must consist of 45 or more units in Env courses or in closely related courses of other options. Upon completion of these courses the student must pass an oral examination.

Geological and Planetary Sciences

Aims and Scope of Graduate Study
Graduate students in the Division of Geological and Planetary Sciences enter with very diverse undergraduate preparation—majors in physics, astronomy, chemistry, and mathematics, as well as in geology, geophysics, and geochemistry. Graduate study and research within the division is equally diverse, and the graduate program aims to provide for students a depth of competence and experience in their major field, sufficient strength in the basic sciences to allow them to continue self-education after their formal training has been completed, and the motivation and training to keep them in the forefront of their field through a long and productive career.

Graduate Record Examination Test Scores
All North American applicants for admission to graduate study in the Division of Geological and Planetary Sciences are required to submit Graduate Record Examination test scores for verbal and quantitative aptitude tests and the advanced test in geology, or their field of undergraduate specialty if other than geology. Applicants from outside North America are very strongly urged to submit Graduate Record Examination scores and TOEFL (Test of English as a Foreign Language) scores to assist in proper evaluation of the applications.

Placement Examinations
On Tuesday of the week preceding registration for the first term of graduate work, students will be required to take written placement examinations covering basic aspects of the earth sciences, including elementary physics, mathematics, and chemistry. These examinations will be used to determine the students' understanding of basic scientific principles and ability to apply these principles to specific problems. A degree of proficiency comparable to that attained by undergraduate students at Caltech is expected. Students who have demonstrated proficiency in earlier residence at the Institute may be excused from these examinations. The past record and performance in the placement examinations will be used to determine whether the student should register for certain undergraduate courses.

Adviser
Each member of the division faculty serves as an academic adviser to a small number of graduate students. All graduate students will be notified, prior to arrival, who their advisers will be, and prior to registration day they should seek the counsel of their advisers in planning a program for each term. Students can and should consult with other staff members concerning this program of study and research. It is the responsibility of the advisers to see that students register at the earliest possible time for the proper courses to fulfill the division requirements and to correct any deficiencies indicated by the placement exam. It is the responsibility of the students to seek and consider their advisers' advice. If students elect to do a Ph.D. thesis under their academic

adviser, another staff member will then be appointed as their academic adviser, as distinct from the thesis adviser.

Registration for Early Research
It is the wish of the division that its graduate students become engaged in productive research as early as possible. To that end, it is strongly recommended that each student register for not less than 8 units of research in two out of the first three terms of residence. Each of these terms of research should be under the direction of *different* staff members. Guidance in arranging for research should be sought from the student's adviser and from individual members of the staff. The primary objective is to communicate to the students the excitement of discovery based on original investigations. An important by-product can be formulation of propositions for the Ph.D. oral examination or orientation toward Ph.D. thesis research.

Master's Degree in the Geological and Planetary Sciences
Master's degree students in geology, geochemistry, geophysics, or planetary science will be expected to have satisfied, either before arrival or in their initial work at the Institute, the basic requirements of the Caltech undergraduate curriculum. Particular attention is called to requirements in petrology, field geology, chemistry, physics, and mathematics; competence in these subjects will be evaluated during the placement examination. Students in geophysics or planetary science may petition the Academic Officer for permission to satisfy the basic division requirement for the Ph.D. program in place of the undergraduate petrology and field geology requirement. The Institute requires a year of residence and a total of 135 graduate units for a master's degree. These 135 units of courses numbered over 100 may include as many as 27 units of courses required in the appropriate undergraduate option and may include as many as 27 units of humanities or other free electives. For most students, two years will be required to meet the master's degree requirements.

Degree of Doctor of Philosophy in the Geological and Planetary Sciences
Major Subject. The work for the doctorate in the Division of Geological and Planetary Sciences shall consist of advanced studies and of research in some discipline in the geological sciences that will be termed the "major subject" of the candidate. The division will accept as major subjects the following disciplines: geology and geobiology, geochemistry, geophysics, and planetary science.

Admission to Candidacy. Division approval for candidacy for the Ph.D. degree is based upon meeting the following requirements:

a. Pass the qualifying examination;
b. Satisfy minimum course requirements in their major and minor subjects;
c. Satisfy the language and oral presentation requirements;
d. Satisfy their academic and thesis advisers that their course work has prepared them to undertake research in their major subject;
e. Be accepted for thesis research by a division staff member.

Students admitted to work for the Ph.D. degree must file with the division before the end of the ninth term of residence the regular form for admission to candidacy with evidence of having met these requirements. Subsequent to completion of the qualifying examination, the Ph.D. program of each student will be monitored by the faculty of one of the four major subjects within the division. All students must choose one of these options during their second year. The faculty of each option will formally review each year the progress of the students in the option; students may be asked to present to the faculty their research work and other evidence of progress. For students in their sixth year of graduate residence (or fifth year beyond the M.S.), such a presentation and review is specifically required before the faculty may vote to continue to award financial aid for, at most, one additional year. The option representatives have the responsibility to organize these reviews and to make recommendations to the full division faculty, which may deny permission to continue in the Ph.D. program for any student showing inadequate progress. For a student who has passed the Ph.D. qualifying examination, permission to continue toward the Ph.D. degree may be withdrawn only upon action of the division as a whole.

Qualifying Examination. This examination will consist of the oral defense of two propositions, each supported by a succinct one-paragraph statement of the problem and of the candidate's specific approach to it. The propositions offered must represent a knowledge and breadth of interest judged acceptable by the qualifying examination committee. Students have the privilege of consultation and discussion with various staff members concerning their ideas on propositions, but the material submitted must represent the work of the student and not a distillation of comments and suggestions from the staff. Candidates should realize that propositions based on field investigations are just as acceptable as those arising from laboratory or theoretical work. In general, the examination is designed to evaluate the student's background in the earth sciences and allied fields, and his or her capabilities in applying scientific principles to the solution of specific problems. The ideal candidate will display originality and imagination as well as scholarship.

All first-year students must submit by May 15 a preliminary status report of their choice of proposition topics. The statement should be as specific as possible, and should preferably give the specific titles of propositions already formulated. The qualifying examination committee will review the preliminary status report for the required breadth, scope, and substance and will make appropriate recommendations. Final propositions must be submitted to the division office at least one week before registration day of the fourth term of residence, and the examination will be taken within the ensuing two-week period, at a time, and before a committee, arranged by the division.

Graduate students are encouraged to register for as many as 15 units per term of advanced study (Ge 297) under appropriate staff members to gain experience and background for preparation of their propositions.

Minimum Course Requirements for the Ph.D.

Basic Division Requirement: The solution of many problems in each of the subdisciplines or major subjects included within the division requires some basic understanding of the other subdisciplines. Therefore all graduate students are required to take at least 45 units within the division in subjects other than their own major subject. The courses are chosen in consultation with the student's adviser, and are subject to the approval of the staff at admission to candidacy. Ge 101 abc is specifically required and should be taken during the first year. Ge 104 ab and Ge 160 are especially recommended as part of these courses. Students in geophysics and planetary sciences may take Ge 105 in lieu of Ge 101 b. Students may be exempted from one or more quarters of Ge 101 by the instructor and the Academic Officer on the basis of previous work taken. Where appropriate, these 45 units may be counted as part of a subject minor within the division. Students who take a subject minor in another division or who show evidence of similar graduate course work elsewhere may, by petition to the Academic Officer, be excused from up to 27 units of such courses. Throughout their graduate work, students are expected to participate in departmental seminars and in seminar courses led by distinguished visitors.

Geology and Geobiology: In addition to the general Institute and basic division requirements, candidates for the Ph.D. in geology or geobiology must successfully complete a minimum of 90 units of 100-200-level courses, including the 200-level courses most pertinent to their major field, but excluding languages, research and reading courses, and certain courses constituting basic preparation in their field as follows: Ge 104, Ge 105, Ge 106, Ge 114, Ge 115, Ge 123. At least 36 of the 90 units must be taken outside the geology division (with a grade of C or better) and may be used as part of the minor; Ch 21 abc may be included as part of these units. Knowledge of field geology equivalent to Ge 121 abc is required of all majors. For good work in most modern earth science fields, a proficiency in mathematics equivalent to that represented by AM 113 abc (Engineering Mathematics) is essential. Summer study and research at a marine biology laboratory are required of most candidates in geobiology.

Geochemistry: In addition to the basic Institute and division requirements, students in the geochemistry academic program must satisfy course requirements in the following areas, either by taking these courses or by equivalent course work elsewhere: (a) Core courses in geological sciences: Ge 104 ab, Ge 105, Ge 140 ab, one term of field geology (Ge 107, Ge 123 a or one term of Ge 121); (b) Core chemistry courses: Ch 14, Ch 21 abc; (c) 27 units of advanced chemistry or physics with course numbers greater than 100; (d) Advanced mathematics through differential equations (AM 113 abc or Ph 129 abc acceptable); (e) Advanced geochemistry courses: 18 units from Ge 203, Ge 212, Ge 214, Ge 232, Ge 240, Ge 242; (f) Science electives: 54 units of physical or biological science, courses greater than 100. Courses (a) and (f) can be used to satisfy the basic division requirements (above).

Thesis Proposal: Students completing the geology, geobiology, or geochemistry academic programs are required to submit a tentative proposal for thesis research no later than May 1 of the second year in residence. This proposal should document the scientific importance of the project, relation to previous work, feasibility of completion within an allowable graduate student tenure and, if any, preliminary results. The proposals will be reviewed by the geology and geochemistry faculties.

Geophysics: In addition to the general Institute and basic division requirements, the Ph.D. candidate in geophysics must successfully complete a minimum of 90 units of 100-200-level courses chosen from the three categories listed below. At least 18 units must be completed in each group.

Group A. Courses in mathematics and applied mathematics: Ph 129, AMa 101, AMa 110, AMa 151, AMa 201, AMa 204, Ma 142, Ma 143, AM 113, EE 255. A minimum proficiency in basic mathematical methods at the level of Ph 129 or AMa 101 is required.

Group B. Courses in physics, applied physics, and chemical physics: Ph 106, Ph 125, AM 141, APh 114, APh 214, Ph 127, Ph 205, Ph 236, MS 205, Ch 21, Ch 125. Geophysics courses cannot be substituted for courses in this group.

Group C. Courses in geophysics: Ge 160, Ge 166, Ge 176, Ge 177, Ge 260, Ge 261.

The recommended courses in these three categories are only representative of the required level, and substitutions may be made upon consultation with the student's adviser. Students with an exceptionally strong background in one or more of the areas represented by these groups may, upon petition to the option representative, be excused from up to 18 units of the overall 90-unit requirement. Research and reading courses cannot be used to satisfy these requirements but are highly recommended as preparation for the oral qualifying examination.

Planetary Science: In addition to general Institute and basic division requirements, the candidate for a Ph.D. degree in planetary science shall acquire at least a minimum graduate background in each of three categories of course work: (1) The Earth Sciences, (2) Physics, Mathematics, Chemistry, and Astronomy, and (3) Planetary Science.

These requirements may be met by successful completion of at least 45 units of suitable course work at the 100 or higher level in each category. The requirements in the first category coincide with the basic division requirement. Reading and research courses may not be used, although students are expected to take such courses and to devote each summer to research in planetary science. Planetary Science Seminar (Ge 225 abc) is required each year for all planetary science students.

Students shall demonstrate professional competence in a second scientific field distinct from their specialization within planetary science. This may be accomplished either by: (1) satisfactory completion of a subject minor or (2) submission of publications that demonstrate an equivalent competence. Courses used to satisfy this secondary requirement may also be used to satisfy the requirements in one of the 45-unit categories.

Four academic years should normally be adequate for completion of the Ph.D. in planetary science. Accordingly, students are expected to meet the following schedule unless specific written waivers are obtained from the Academic Officer or planetary science option representative.

End of second academic year: 1) satisfactory completion of divisional oral examination; 2) approval of courses in the major and minor fields; 3) tentative thesis topic in planetary science.

End of third academic year: 1) satisfactory completion of major requirements; 2) satisfactory completion of secondary requirements; 3) satisfactory progress on thesis; 4) admission to candidacy; 5) submission of a paper, of which the student is the senior author, to a refereed journal, following satisfactory review by a faculty member.

End of fourth academic year: completion of Ph.D. thesis.

Fifth academic year or beyond: satisfactory thesis progress required each quarter.

Minor Requirement. A minor is required in the planetary science option to give diversification of training and a broadening of outlook. It should involve basic approaches, techniques, and knowledge distinct from those of the major field. A minor must be comprehensive enough to give students a fundamental knowledge of the field, and their diplomas and degrees will indicate both the major and minor fields. The division prefers that students take a subject minor in other divisions of the Institute, but students may take a subject minor within the division in a different field from their major.

Students taking a minor within the division must then demonstrate a competency in the minor field markedly exceeding the minimum requirements for their major fields and markedly exceeding the undergraduate requirements in the field. Such a minor will include at least 45 units, normally including one or more 200-level courses as well as the 100-level supporting courses.

A proposed minor program should be discussed with the adviser and the option representative and submitted to the staff for preliminary evaluation before the end of the sixth term of residence. Final approval will be given only after completion of all courses.

Language Requirement. Due to the diversity of fields within geological and planetary sciences, the division does not have a uniform language requirement. All entering graduate students are expected to have some knowledge of French, German, or Russian. (Other languages may be acceptable in particular cases.) A student who has not had either one year of college study in one of these languages or the equivalent thereof will be expected to make up this deficiency in the first two years. In some fields of study, additional linguistic skills are important and may be required by a student's thesis adviser in consultation with the student. However, the division *strongly encourages* the acquisition of additional language skills.

Oral presentation (Ge 102) is required of all candidates for degrees in the division.

Thesis and Paper for Publication. Doctoral candidates must complete a thesis in their option and submit it in final form by May 10 of the year in which the degree is to be conferred. A first draft of the thesis *must* be submitted to the division chairman by March 1 of the year in which it is proposed to take the degree.

Candidates are expected to publish the major results of their thesis work. The manuscript should be reviewed by the member of the staff supervising the major research before being submitted for publication. The published paper should have a California Institute of Technology address and a Division of Geological and Planetary Sciences contribution number, and at least five reprints should be sent to the division.

Final Examination. The final oral examination for the doctorate will be scheduled following submission of the thesis and, in conformity with an Institute regulation, it must be scheduled at least two weeks before the degree is to be conferred.

Minor in Geological and Planetary Sciences

A student majoring in another division of the Institute may, with the approval of the Division of Geological and Planetary Sciences, elect a minor in any one of the major subjects listed above. Such a subject minor will include at least 45 units normally, including one or more 200-level courses as well as the 100-level supporting courses. Normally, a member of the division faculty will participate in the oral thesis defense.

History

The program for a subject minor in history must be approved by the department before the admission to candidacy. In addition to meeting general Institute requirements, the student must complete satisfactorily, with a grade of C or better, 45 units in advanced courses in history.

Materials Science

Aims and Scope of Graduate Study in Materials Science
Students may enter the graduate program in materials science with undergraduate preparation in physics, chemistry, or engineering, as well as materials science. The program is designed to give the students a thorough grounding in areas fundamental to an understanding of materials properties, with strong emphasis on research in the areas of ongoing faculty work. This work includes studies of defects in crystals and the structure and properties of amorphous materials. Energy-related studies include radiation damage problems relevant to fast breeder and controlled thermonuclear reactor systems, and studies of amorphous and crystalline silicon relevant to solar cell technology.

Master's Degree in Materials Science
Study for the degree of Master of Science in Materials Science ordinarily will consist of three terms of course work totaling at least 135 units. Each student is assigned to a member of the faculty, who will serve as the student's adviser and who will assist the student in planning his or her course of study. The original program of study and any subsequent changes must be approved by the adviser and by the option representative.

Requirements
a. E 150 abc, seminar, total of 3 units
b. At least 54 units chosen from:
   MS 105, Mechanical Behavior of Metals
   MS 120, Kinetics of Crystal Imperfections
   MS 130, Metallography and Pyrometry
   MS 131, Crystal Defects
   MS 132, X-Ray Metallography Laboratory
   APh 105 abc, States of Matter
   APh 114 abc, Solid State Physics
   APh/MS 126 abc, The Electronic Structure of Metals and Alloys
   At least 18 of these 54 units must be in the laboratory courses MS 130, MS 131, or MS 132.
c. Electives sufficient to give a total of at least 135 units for the year.

Electives
Students who have not had the equivalent of AMa 95 abc are required to include AM 113 abc among the elective units.

Electives that are particularly encouraged are courses in mathematics, applied mathematics, and applied mechanics: Ma 112 ab, AMa 101 abc, AMa 104, AMa 105 ab, Ae/AM 102 abc, AM 125 abc, AM 141 abc, AM 151 abc, AM 155; courses in applied physics: APh 153 abc, APh 181 abc; courses in physics: Ph 106 abc, Ph 125 abc, Ph 129 abc; courses in aeronautics: Ae/AM 102 abc, Ae 213, Ae 221; courses in mechanical engineering: ME 101 abc, ME 118 abc; and courses in chemical engineering: ChE 166 ab, ChE 167.

Students admitted for study toward a master's degree but interested in pursuing subsequent study toward a Ph.D. degree in materials science should also read the following section concerning the Ph.D. degree.

Degree of Doctor of Philosophy in Materials Science

Work toward the degree of Doctor of Philosophy in Materials Science requires a minimum of three years following completion of the bachelor's degree or the equivalent. Approximately two years of this time are devoted to research work leading to a doctoral thesis.

Counseling. A counseling committee of three faculty members is appointed for each student upon his or her admission to work toward a Ph.D. degree in materials science in order to advise the student on a suitable course program. The committee member closest to the student's current interests acts as committee chairman and interim adviser until this responsibility is assumed by the dissertation supervisor.

In addition, a special joint faculty committee is appointed annually by the faculties in applied mechanics, civil engineering, materials science, and mechanical engineering, which meets both collectively and individually with first-year graduate students aiming at the doctoral degree in order to provide further perspective on graduate study and research, as well as to discuss the student's evolving interests.

Admission to or Continuation in Ph.D. Status. All new students admitted for study toward the Ph.D. degree in materials science, and all other graduate students wishing to become eligible for study toward this degree, are required to take a short oral examination early in the third term of their first year of graduate study at the Institute. This examination, which is conducted by the special joint faculty committee referred to above, is confined to elementary but basic topics in the general areas represented by the committee. One purpose of this examination is to identify possible deficiencies in the student's background with a view toward appropriate remedial measures; in addition, the examination contributes to the information used in assessing the student's promise for successful doctoral studies.

To be recommended for candidacy for the Ph.D. degree in materials science, the student must, in addition to the general Institute requirements:

a. complete 12 units of research;
b. complete at least 108 units of advanced courses arranged by the student in conference with his or her adviser and approved by the counseling committee and the faculty in materials science. If the student chooses to take a subject minor, the units thereof may be included in the total of 108, subject to the approval of the faculty in materials science;
c. pass with a grade of at least C an advanced course in mathematics or applied mathematics, such as AM 125 abc, Ph 129 abc, or AMa 101 abc, acceptable to the student's committee and the faculty in materials science. The requirement in mathematics shall be in addition to requirement (b) above, and shall not be counted toward a minor;
d. pass an oral examination on the major subject, and if the student has chosen a subject minor, examination on the subject of that program may be included at the request of the discipline offering that subject minor.

A final oral examination will be given after the thesis has been formally completed. This examination will be a defense of the doctoral thesis and a test of the candidate's knowledge in his or her specialized field of research.

Subject Minor in Materials Science

A student majoring in another branch of engineering or another division of the Institute may, with the approval of the faculty in materials science and the faculty in his or her major field, elect materials science as a subject minor. The group of courses shall differ markedly from the major subject of study or research, and consist of at least 54 units of advanced work. The student shall pass an oral examination that is separate from the examination in the student's major.

Mathematics

Aims and Scope of Graduate Study in Mathematics
The principal aim of the graduate program is to equip the student to do original research in mathematics. Independent and critical thinking is encouraged by participation in seminars and by direct contact with faculty members; an indication of the current research interests of the faculty is found on page 54. In order to enable each student to acquire a broad background in mathematics, individual programs of study and courses are mapped out in consultation with faculty advisers. The normal course of study leads to the Ph.D. degree.

Admission
Each new graduate student admitted to work for an advanced degree in mathematics will be given an interview on Thursday or Friday of the week preceding the beginning of instruction in the fall term. The purpose of this interview is to ascertain the preparation of the student and assist him or her to map out a course of study. The work of the student during the first year will include independent reading and/or research.

Course Program
The graduate courses offered, listed in Section 5, are divided into three categories. The courses numbered between 100 and 199 are basic graduate courses open to all graduate students. The three core courses at the graduate level—Ma 110 in Analysis, Ma 120 in Algebra, and Ma 151 in Geometry and Topology—are required of all graduate students unless waived by the Graduate Committee. Students are expected to complete these basic core courses during the first two years, and are encouraged to take additional advanced courses while doing their thesis research. The seminar Ma 190 is required of all first-year graduate students and restricted to them. It is intended to stimulate independent work, to train students in the presentation of mathematical ideas, and to develop an independent critical attitude. In addition to Ma 190, the first-year graduate program normally consists of two or three 100-series courses.

The courses in the second category are numbered between 200 and 290. They are taken normally by second-year and more advanced graduate students. They are usually given in alternate years. The 300 series includes the more specialized courses, the research courses, and the seminars. They are given on an irregular basis depending on demand and interest.

Beginning with the second year at the latest, the student will be expected to begin independent research work and will be strongly encouraged to participate in seminars.

Bohnenblust Travel Grants in Mathematics
Special grants may be awarded to outstanding graduate students in mathematics to enable them to travel here or abroad to further their mathematical education. The mathematics faculty established these awards in 1978 to honor H. F. Bohnenblust, who served Caltech as Professor of Mathematics, Executive Officer for Mathematics, and Dean of Graduate Studies. Application forms and further details are available in the Mathematics Office, 253 Sloan.

Master's Degree in Mathematics
Entering graduate students are normally admitted directly to the Ph.D. program, since the Institute does not offer a regular program in mathematics leading to the master's degree. This degree may be awarded in exceptional circumstances either as a terminal degree or as a degree preliminary to the Ph.D. degree. Sufficiently advanced undergraduates may be admitted to graduate standing to pursue a master's degree simultaneously with the bachelor's program.

The recipient of a master's degree will be expected to have acquired, in the course of studies as an undergraduate or graduate student, a comprehensive knowledge of the main fields of mathematics comparable to 180 units of work in mathematics at the Institute with course numbers greater than 90.

The general Institute requirements specify that the recipient of a master's degree must have taken at least 135 units of graduate work as a graduate student at the Institute, including at least 81 units of advanced graduate work in mathematics. This advanced work is interpreted as work with a course number greater than 109 and may include a master's thesis.

Degree of Doctor of Philosophy in Mathematics

Candidacy Examination. Before being admitted to candidacy for the Ph.D. in mathematics, the student is expected to have acquired an understanding of the main fields of modern mathematics and to have demonstrated an ability to do competent research in a particular field.

The first graduate year is usually spent in acquiring basic background knowledge. In order to determine as early as possible the candidate's progress toward this objective, candidacy examinations will be given toward the end of the first year of graduate study. Students must take two of three examinations: one covering the field of algebra, one covering real and complex analysis, and one covering geometry and topology. These emphasize the ability to apply basic mathematical ideas and theorems to specific cases. The three core courses should be adequate preparation for these examinations. Before being admitted to candidacy, students must pass two of these three examinations and, in the one not taken, must take and pass the corresponding core course with a grade of B or better.

Sometime during the second or third year the student is expected to give an oral presentation, to a committee of faculty members, which will describe the general subject matter of the proposed area of thesis research, and describe the tentative thesis problem. A satisfactory performance on this oral presentation is required for admission to candidacy.

During the summer following the first year of graduate work, each graduate student in mathematics is expected to plan a program of independent study and research work under the guidance of some member of the mathematics staff. This summer program should provide the student with an opportunity to acquire new mathematical knowledge and to generate new mathematical ideas. Shortly after the beginning of the fall term, the faculty will make an overall evaluation of the progress and research potential of these graduate students. The results of this evaluation will be reported to the student and will be used in consultation with the student to plan a subsequent academic program. At this time each student is expected to arrange with a member of the faculty to act as a research adviser.

Language Requirement. The language requirement for mathematics may be satisfied by demonstrating a good reading knowledge of at least two foreign languages or an extensive knowledge of at least one foreign language, chosen among French, German, and Russian. Credit will be given for previous language study.

Thesis and Final Examination. On or before the first Monday in May of the year in which the degree is to be conferred, candidates for the degree of Doctor of Philosophy must deliver typewritten or reproduced copies of their thesis to their supervisors. These copies must be complete and in the exact form in which they will be presented to the members of the examining committee. Candidates are also responsible for supplying the members of their examining committee, at the same time or shortly thereafter, with reproduced copies of their thesis. The final oral examination on the thesis will be held within three weeks from the date the thesis is handed in.

Subject Minor in Mathematics

Students majoring in other fields may take a subject minor in mathematics. Minor programs must include 54 units of advanced work approved by a representative of the mathematics department who will insure that the work represents a concentrated study in one or more of the main fields of mathematics. A special oral examination in the subject minor will be given soon after completion of the minor program.

Mechanical Engineering

Master's Degree in Mechanical Engineering

Study for the degree of Master of Science in Mechanical Engineering ordinarily will consist of three terms of course work totaling at least 135 units. The program is intended to be completed within the nine months of the academic year, even by students who hold assistantships. Each student is assigned to a member of the faculty, who will serve as the student's adviser and who will assist the student in planning a course of study. The program of study must be approved by the adviser, and any subsequent changes must also have the adviser's approval.

Students admitted for study toward a master's degree but interested in pursuing subsequent study toward a Ph.D. degree in mechanical engineering should also read the following section concerning the Ph.D. degree.

The schedules of courses for the master's degree are given below:

Mechanical Engineering

		Units per term		
E 150 abc	Seminar (1-0-0)	1	1	1
	Approved electives[1]	Minimum 81 per year		
	Free electives[2]	Minimum 51 per year		
	Total	Minimum 135 per year		

Approved electives: Courses from Ae, AM, AMa, E, ME, JP, MS, and Hy with numbers of 100 and above will generally meet the conditions for the approved electives.

Program Suggested for Propulsion

E 150 abc	Seminar (1-0-0)	1	1	1
JP 121 abc	Jet Propulsion Systems and Trajectories (3-0-6)	9	9	9
	Approved electives[1]	Minimum 98 per year		
	Free electives[2]	Minimum 27 per year		
	Total	Minimum 135 per year		

Approved electives: Ae/AM 102, Ae 104, AM 151, Hy 101, JP 131, JP 170, ME 102, ME 118, ME 126.

Program Suggested for Energy

E 150 abc	Seminar (1-0-0)	1	1	1
ME 102 abc	Principles of Energy Conversion and Distribution (3-0-6)	9	9	9
	Approved electives[1]	Minimum 98 per year		
	Free electives[2]	Minimum 27 per year		
	Total	Minimum 135 per year		

Approved electives: Ae 103, APh 140, ChE 101, ChE/Env 157, EE 151, Env/Ge 103, Hy 101, JP 131, ME 118, Ph 106.

[1]Elective units may be divided among the three terms in any desired manner. Students who have not had the equivalent of AMa 95 abc are required to take AM 113 abc, which *must* be included in the free electives and *cannot* be included in the approved electives. Substitution for approved electives may be made with the approval of the student's adviser and the faculty in mechanical engineering.

[2]Students are urged to consider including a humanities course in the free electives.

Degree of Mechanical Engineer
Work toward the degree of Mechanical Engineer requires a minimum of two years following completion of the bachelor's degree or the equivalent. Upon a student's admission to work toward the M.E. degree, a counseling committee of three members of the faculty is appointed. The member of the committee who is most closely related to the student's field of interest serves as the adviser and the chairman. The student should meet with the committee before registration for the purpose of planning his or her work.

Not less than 55 units of work shall be for research and thesis; the exact number shall be determined by a supervising committee, appointed by the Dean of Graduate Studies, which succeeds the counseling committee. Courses should be closely related to mechanical engineering. The specific courses (to be taken and passed with a grade of C or better by the candidate) will be planned with the counseling committee and finally determined by the supervising committee. The courses must include an advanced course in mathematics or applied mathematics, such as AM 125 abc or AMa 101 abc, that is acceptable to the faculty in mechanical engineering. A suitable course program may usually be organized from the more advanced courses listed under AM, AMa, Hy, JP, ME, MS, and Ae.

Degree of Doctor of Philosophy in Mechanical Engineering
Work toward the degree of Doctor of Philosophy in Mechanical Engineering requires a minimum of three years following completion of the bachelor's degree or the equivalent. Approximately two years of this time are devoted to research work leading to a doctoral thesis.

Counseling. A counseling committee of three faculty members is appointed for each student upon his or her admission to work toward a Ph.D. degree in mechanical engineering in order to advise the student on a suitable course program. The committee member closest to the student's current interests acts as committee chairman and interim adviser until this responsibility is assumed by the dissertation supervisor.

In addition, a special joint faculty committee is appointed annually by the faculties in applied mechanics, civil engineering, materials science, and mechanical engineering, which meets both collectively and individually with first-year graduate students aiming at the doctoral degree in order to provide further perspective on graduate study and research, as well as to discuss the student's evolving interests.

Admission to or Continuation in Ph.D. Status. All new students admitted for study toward the Ph.D. degree in mechanical engineering, and all other graduate students wishing to become eligible for study toward this degree, are required to take a short oral examination early in the third term of their first year of graduate study at the Institute. This examination, which is conducted by the special joint faculty committee referred to above, is confined to elementary but basic topics in the general areas represented by the committee. One purpose of this examination is to identify possible deficiencies in the student's background with a view toward appropriate remedial measures; in addition, the examination contributes to the information used in assessing the student's promise for successful doctoral studies.

To be recommended for candidacy for the Ph.D. degree in mechanical engineering, the student must, in addition to meeting the general Institute requirements:

a. complete 12 units of research;
b. complete at least 108 units of advanced courses arranged by the student in conference with his or her adviser and approved by the counseling committee and the faculty in mechanical engineering. If the student chooses to take a subject minor, the units thereof may be included in the total of 108, subject to the approval of the faculty in mechanical engineering;
c. pass with a grade of at least C an advanced course in mathematics or applied mathematics, such as AM 125 abc, or AMa 101 abc, acceptable to the student's committee and the faculty in mechanical engineering. The requirement in mathematics shall be in addition to requirement (b) above, and shall not be counted toward a minor;

d. pass an oral examination on the major subject, and if the student has chosen a subject minor, an examination on the subject of that program may be included at the request of the discipline offering that subject minor.

A final oral examination will be given after the thesis has been formally completed. This thesis examination will be a defense of the doctoral thesis and a test of the candidate's knowledge in the specialized field of research.

Subject Minor in Mechanical Engineering

A student majoring in another branch of engineering or another division of the Institute may, with the approval of the faculty in mechanical engineering and the faculty in his or her major field, elect mechanical engineering as a subject minor. The group of courses shall differ markedly from the major subject of study or research, and shall consist of at least 54 units of advanced work. The student shall pass an oral examination that is separate from the examination in the student's major.

Physics

Aims and Scope of Graduate Study in Physics

The physics department offers a program leading to the degree of Doctor of Philosophy in Physics. This program prepares students for careers in scientific research or research combined with teaching, and so its most important part is independent research. Courses are offered that give a broad and sound treatment of both fundamental physics and specialized physics research topics. These are intended both to help a beginning graduate student prepare for research and to broaden an advanced student's knowledge of physics. The only course requirements are two terms of Physics Seminar, which provides an overview of physics research at Caltech, and 27 units (equivalent to 6 semester-hours) of advanced physics courses outside a student's research specialty. In addition, certain courses may be taken to satisfy part of the candidacy requirements, as detailed below.

A Master of Science degree may be awarded upon completion of what is typically a four-term program of courses. A student is not normally admitted to work toward the M.S. degree in physics unless he or she is also working for a Ph.D.

Admission

Application blanks for admission to graduate standing and for financial assistance should be obtained from the Dean of Graduate Studies, California Institute of Technology, Pasadena, CA 91125, and submitted as early as is convenient. While late applications will be considered, applications should whenever possible reach the Graduate Office by January 15. Special inquiries will be welcomed by the chairperson of the Physics Graduate Admissions Committee. Applicants must take the Graduate Record Aptitude Test and Advanced Physics Test. Information may be obtained from the Educational Testing Service, 20 Nassau Street, Princeton, NJ 08540.

Placement Examinations

On the Thursday preceding the beginning of instruction for his or her first term of graduate study, a student admitted to work for an advanced degree in physics is required to take placement examinations to be used as a guide in selecting the proper course of study. These examinations will cover material in mechanics and electromagnetism, quantum mechanics, and mathematical physics, approximately as covered in Ph 106, Ph 125, and Ph 129. In general, they will be designed to test whether the student possesses an understanding of general principles and the ability to apply these to concrete problems, rather than detailed informational knowledge. The results of the placement exam are not formally recorded as a part of the student's record. In cases in which there is a clear basis for ascertaining the status of the entering graduate student, the placement examinations may be waived.

Master's Degree in Physics
A Master of Science degree in physics will be awarded upon satisfactory completion of a program approved by the departmental representative that fulfills the following requirements:

Ph 125 abc .... 27 units
(If this course was taken as part of an undergraduate program or an equivalent course was taken elsewhere, it may be replaced by 27 units of any graduate courses.)

Physics electives.. 81 units
These must be selected from Ph 118, Ph 127, Ph 129, Ph 135, Ph 136, Ph 203, Ph 205, Ph 209, Ph 213, Ph 222, Ph 224, Ph 228, Ph 229, Ph 230, Ph 231, Ph 234, Ph 236, Ph 237, Ph 240, Ph 242.
Other electives .... 27 units
These must be graduate courses from physics or any other option, including humanities.

With the approval of the department representative, a student who has the proper preparation may substitute other graduate courses in science or engineering for some of those listed above.

Doctor of Philosophy Degree in Physics
In addition to the general Institute requirements for a Ph.D., the particular requirements for a doctorate in physics include admission to candidacy as described below, passing 27 units of advanced courses in physics, writing a thesis that describes the results of independent research, and passing a final oral examination based on this thesis and research. Students working toward the Ph.D. degree should complete the requirements for admission to candidacy and the course work as soon as possible.

Admission to Candidacy. The particular requirements in physics for admission to candidacy are that the student pass two terms of Physics Seminar, Ph 242, pass two written examinations covering fundamental classical and quantum physics, demonstrate proficiency in any three of several subjects as described below, and pass an oral examination in the area in which he or she proposes to do research. No course work other than Physics Seminar is specifically required for candidacy, but the average student will profit from taking several of the basic graduate courses, such as Ph 125, Ph 129, Ph 135, Ph 136, and Ph 209.

A student must demonstrate proficiency in any three of the following four areas: the mathematical methods of physics at the level of Ph 129, the applications of quantum physics at the level of Ph 135, the applications of classical physics at the level of Ph 136, and astrophysics. For each of the first three areas, the student may either pass a written candidacy examination similar to the two required exams or pass (with a grade of C or better) all three terms of the corresponding course. Those students choosing astrophysics must pass the written astrophysics examination that is given yearly by the astronomy department.

A physics graduate student who has not been admitted to candidacy by the end of the third year of graduate study at the Institute will not be permitted to register for a subsequent academic year. In addition, it is required that the two mandatory written exams be attempted in a student's first year of graduate study and be passed by the end of the second year. Furthermore, the requirement of demonstrating proficiency in the other three subjects must be attempted by the end of the second year and satisfied by the end of the third year. If these deadlines are not met, a student must petition the Physics Graduate Committee before he or she may register for subsequent terms. Further guidelines concerning the expected rate of progress in satisfying these requirements are available in the Physics Graduate Office.

The vast majority of students admitted for graduate study in the physics option pass the candidacy requirements. Their purpose is not to "weed out" students, but rather to ensure that, before beginning research, they have both adequate preparation in their research specialty and a broad general knowledge of physics.

Written Candidacy Examinations. Each written candidacy exam is three hours long and covers a particular part of physics that is considered essential, no matter what the candidate's ultimate field of specialization may be. The examinations are offered at frequent intervals, typically once per term, and the separate sections may be taken at different times. This flexible scheduling of the written exams allows students to prepare for the separate sections while simultaneously learning about research areas through either advanced courses or reading and research courses.

Oral Candidacy Examination. This exam is primarily a test of the candidate's suitability for research in his or her chosen field. Normally a student will have engaged in research (Ph 172 or Ph 173) with the professor who chairs the examination committee. The examination normally covers the student's research work and its relation to his or her general field of specialization. Before being allowed to take this exam, a student must have satisfied all of the other requirements for admission to candidacy.

Course Requirements. The requirement that students pass two terms of Physics Seminar, Ph 242, before being admitted to candidacy is intended to provide them with a general overview of modern physics research. This course is usually offered in the first two terms of the academic year, and consists of weekly seminars on physics research at Caltech. There is an oral exam based on this material at the end of the term. It is strongly recommended that students take this course in their first year of graduate study at the Institute.

The requirement of 27 units (3 terms of the usual 9-unit course) of advanced physics courses outside a student's specialty may be satisfied by any of the courses in the following list: Ph 118, Ph 127, Ph 203, Ph 205, Ph 213, Ph 222, Ph 224, Ph 228, Ph 229, Ph 230, Ph 231, Ph 234, Ph 236, Ph 237, APh 140, APh 156, APh 190, APh 214, Ay 151–156, Ay 218. The appropriate course or courses for this requirement will normally be clear, but the chairperson of the Physics Graduate Committee will advise students in cases of doubt. The required 27 units may be satisfied with three terms of one course or spread over several courses. Normally, students take many more than the required 27 units of advanced courses, especially courses in their own specialty.

The student is expected to obtain a grade of C or better in each course. If he or she obtains grades below C, the Physics Graduate Committee may review the student's entire record, and if it is unsatisfactory will refuse permission to continue work toward a Ph.D.

Research Requirements. There are no specific research requirements, but in general a substantial effort is required to master the techniques in a given field and carry out a significant piece of original research. Students are strongly advised to start research as soon as possible and to carry it on in parallel with formal course work; they are advised to take reading and research units (Ph 171–173) prior to being admitted to candidacy. Typically, students will find it desirable to continue graduate study and research for two years after admission to candidacy.

The Minor. A minor is not required, but a student may elect to pursue a minor in another option.

Language Requirements. There are no language requirements for a Ph.D. in physics, but mastery of one or more foreign languages will be highly advantageous.

Thesis and Final Examination. A final oral examination will be given not less than two weeks after the thesis has been presented in final form. This examination will cover the thesis topic and its relation to the general body of knowledge of physics. The candidate is responsible for completing the thesis early enough to allow the fulfillment of all division and Institute requirements, having due regard for possible conflicts in the scheduling of more than one final oral examination per day.

Subject Minor in Physics

Students desiring a subject minor in physics should discuss their proposed program with the chairperson of the Physics Graduate Committee. Forty-five units are required for approval of a subject minor in physics. Physics courses with numbers over 100 will be allowed for the subject minor. At least 18 of the 45 units must be chosen from the physics electives list (see list under *Master's Degree in Physics*), excluding Ph 129 and any specific courses in physics required for the student's major program. An oral exam will normally be required and this should be arranged with the chairperson of the Physics Graduate Committee. This exam will include both academic topics and those on current physics research areas. The oral exam may be waived if at least one term of Ph 242 has been taken successfully.

Social Science

Aims and Scope of Graduate Study in Social Science

Business and government are confronted with problems of growing complexity. In addressing these problems, decision-makers have come to place increasing value upon social scientific analysis. The graduate program in social science is designed to produce scholars who can apply both the theoretical perspectives and quantitative techniques of the social sciences to the problems that organizations face in both the private and public sectors.

Recent graduates of the program, depending on their fields of specialization, have taken positions in departments of economics or political science, schools of public policy, or in schools of business of several major universities. Others have taken positions as economic analysts, program evaluators, and planners for government or private business. In addition, a special program enables students to obtain joint degrees in social science from Caltech and in law from cooperating professional schools. Graduates of this latter program are qualified for teaching positions in schools of law, for legal practice, and for other positions in academia and government.

Admission

The requirements for admission to the graduate program in social science are in the field of mathematics. Entering students are expected to have completed (1) courses in calculus at the levels of Ma 2 abc; (2) a course in linear algebra and/or matrix algebra; and (3) a course in elementary mathematical statistics. Students who have not completed some of these courses may be admitted with the understanding that they will complete these mathematical requirements after entering the program. Entering students may be asked to take placement examinations in mathematics to determine their level of achievement. The extent of remedial work, if any, will be determined by the division director of graduate studies in consultation with the student.

Students are also expected to take any additional mathematics courses relevant to their research. For example, research in many areas of social science requires mathematical competence at the level of Ma 108.

Course Program

Within the first two years of residence, every student is expected to (a) demonstrate adequate competence in the core academic areas of microeconomics, analytical politics, and econometrics; (b) pass satisfactorily the preliminary examinations; (c) complete six research workshops with a minimum grade of B, and (d) present the results of at least one research project to an option-wide colloquium.

a. The core curriculum consists of the following eleven one-quarter courses: SS 201 (game theory), SS 202, 203, 204 (analytical politics); SS 205, 206, 207 (microeconomics); SS 222a, 222b, 222c (econometrics); and SS 240 (policy analysis).

   Students are expected to complete these courses by the end of the first year of study. While these courses are not specifically required for a degree, the student must demonstrate competence in each area and must show that omission of one or more of these courses will not impede normal progress toward the degree. A decision to omit a course requires written approval by the division director of graduate studies and should be made in consultation with the director and the appropriate faculty. Successful progress during the first three quarters of residency requires that the student complete a minimum of 36 units of work in each quarter, with an average grade of B or better, and with no grade less than C.

b. At the end of the spring term of the first year, all students must take the preliminary examination. This written exam is given in three parts and covers the areas of analytical politics, microeconomics, and econometrics. To pass the examination, the student must pass all three parts. Students who fail the examination in their first attempt may take it a second time, but that attempt must be made before the beginning of the second year.

c. During the second year, each student must complete a minimum of 36 units of work each quarter (with an average grade of B or better), and in that total of 108, a student must successfully complete at least six one-quarter workshops (54 units) and have earned at least a B in each. These research-oriented courses are designed to introduce students to independent research, and all require research papers. The six workshops should be chosen in consultation with the division director of graduate studies and faculty members in the area in which the student wishes to do his or her thesis research, and with the student's long-term research goals in mind. Students should take at least three workshops in the discipline that they expect to pursue, with a focus on the specific fields in which they will specialize, e.g., applied or theoretical microeconomics or politics, or social scientific history. Students should also bear in mind that a major strength of the program is its multidisciplinary nature, and they are encouraged to sample a variety of fields. In each year there will be workshops in economic theory, applied economics, formal political theory, some substantive area of political science, and econometrics. In addition, although all may not be offered each year, there will be workshops in law, quantitative history, and public policy.

All research papers from the six workshops must be finished and submitted to the social science faculty no later than the end of the spring term of the second year. In addition, the student must present the results on one research project in an option-wide colloquium.

After the completion of the second year, the student's overall performance and research potential will be evaluated by the social science faculty. The student will be admitted to candidacy for the Ph.D. if this evaluation is favorable and if he or she has been accepted for thesis research by an option staff member.

Degree of Doctor of Philosophy in Social Science

Requirements for the Ph.D. include passing a written examination covering the core material in social science, gaining admission to candidacy, writing a thesis that reports the findings of independent research, and passing a final oral examination based on the thesis and research. It is expected that students will have completed all requirements for the Ph.D. degree by the end of their fourth year of residency.[1]

Master's Degree in Social Science

Entering graduate students are admitted to the Ph.D. program. The M.S. degree is awarded in exceptional cases. Of the 135 units of graduate work required by Institute regulations, at least 81 units should be advanced work in social science. Students petitioning for an M.S. are required to take an examination.

Subject Minor in Social Science

Graduate students taking social science as a subject minor shall complete a program of not less than 45 units in advanced courses in a coherent program of study that has been approved by the director of graduate studies.

[1]A comprehensive description of the option's academic policies can be found in "Information for Students and Advisors in the Social Science Ph.D. Program," available upon request from the Division of the Humanities and Social Sciences.

COURSES

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Courses numbered below 100 are taken primarily by undergraduate students. Those numbered from 100 to 199 are taken by both undergraduates and graduates, and those numbered 200 and above are taken primarily by graduate students.

The school year is divided into three terms. The number of units assigned in any term to any subject represents the number of hours spent in class, in laboratory, and estimated to be spent in preparation per week. In the following schedules, figures in parentheses denote hours in class (first figure), hours in laboratory (second figure), and hours of outside preparation (third figure).

At the end of the seventh week of each term, a list of courses to be offered the following term is published by the Registrar's Office. On the day of registration (see Academic Calendar), an updated and revised course schedule is published announcing the courses, class hours, and room assignments for the term.

ABBREVIATIONS

Ae	Aeronautics
An	Anthropology
AMa	Applied Mathematics
AM	Applied Mechanics
APh	Applied Physics
Art	Art
Ay	Astronomy
Bi	Biology
BEM	Business Economics and Management
CCO	Campus Computing Organization
ChE	Chemical Engineering
Ch	Chemistry
CE	Civil Engineering
CS	Computer Science
Ec	Economics
EE	Electrical Engineering
E	Engineering
Gr	Engineering Graphics
ES	Engineering Science
En	English
Env	Environmental Engineering Science
Ge	Geological and Planetary Sciences
H	History
Hum	Humanities
HSS	Humanities and Social Sciences
Hy	Hydraulics
ISP	Independent Studies Program
JP	Jet Propulsion
L	Languages
Lin	Linguistics
Lit	Literature
MS	Materials Science
Ma	Mathematics
ME	Mechanical Engineering
Mu	Music
PA	Performance and Activities
Pl	Philosophy
PE	Physical Education
Ph	Physics
PS	Political Science
Psy	Psychology
SS	Social Science

AERONAUTICS

Ae 100. Research in Aeronautics. *Units to be arranged.* Open to suitably qualified undergraduates and first-year graduate students under the direction of the staff.

Ae/APh 101 abc. Fluid Mechanics. *9 units (3-0-6); first, second, third terms.* The course begins with the study of one-dimensional flows and then moves to consideration of flows with progressively more complex dimensionality. During the third term viscous flows are treated. Topics include thermodynamics of fluid flow, equations of motion; one-dimensional compressible flow, shock waves, nonsteady flow; acoustics, thin airfoil theory; potential flow; kinematics of fluid flow, stress, vorticity; vortex flows; dynamics of real fluids, viscous flow, boundary layer theory. Instructor: Roshko.

Ae/AM 102 abc. Mechanics of Structures and Solids. *9 units (3-0-6); first, second, third terms. Prerequisite: AM 35 abc or equivalent.* Static and dynamic stress analysis. Two- and three-dimensional theory of stressed elastic solids. Analysis of structural elements with applications in a variety of fields. Variational theorems and approximate solutions, finite elements. A variety of special topics will be discussed in the third term. Instructor: Scott.

Ae 103 abc. Vehicle Performance and Dynamics. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 abc.* Performance and dynamic behavior (stability and control) of vehicles moving in a continuum (air or water) will be discussed. Examples include the dynamics and performance of vehicles such as submarines, VTOL and STOL aircraft, subsonic and supersonic aircraft and rockets. Topics include speed performance, climb and descent, range, take-off and landing distances, static longitudinal and lateral stability, equations of unsteady motion, dynamic stability, responses to controls and disturbances. Instructor: Staff.

Ae/APh 104 abc. Experimental Methods. *9 units (3-0-6 first term; 1-3-5 second and third terms). Prerequisites: AMa 95 abc or equivalent (may be taken concurrently), Ae/APh 101 abc (may be taken concurrently).* Lectures on experiment design and implementation. Measurement methods, transducer fundamentals, instrumentation, optical systems, signal processing, noise theory, analog and digital electronic fundamentals, data acquisition and processing systems. Experiments (second and third terms) in solid and fluid mechanics with emphasis on current research methods, low-speed and high-speed aerodynamics, laser Doppler velocimetry, signal noise. Instructor: Dimotakis.

Ae 107 abc. Case Studies in Engineering. *9 units (3-0-6); first, second, third terms. Prerequisite: graduate status or instructor's permission.* Each term, the case history of a major engineering project will be treated in detail. Cases will include aerospace projects and other current engineering programs. Lecturers will, in general, be specialists in their fields from industrial or research organizations. Starting with the economic, political, and technological environment in which the concept originated, the course will proceed to the project initiation, detailed engineering and design, manufacturing operations, and future growth potential. Both project successes and difficulties will be discussed. Instructor: Sturtevant.

Ae/AM 108 abc. Finite Element Methods. *9 units (3-0-6); first, second, third terms. Prerequisite: instructor's permission.* Numerical analysis by the finite element method covering fundamental concepts and computer implementation. Solution of systems of linear equations and eigenvalue problems. Solution of the partial differential equations of heat transfer, solid and structural mechanics, and fluid mechanics. Transient and nonlinear problems. Instructor: Hall.

Ae 150 abc. Aeronautical Seminar. *1 unit (1-0-0); first, second, third terms.* Speakers from campus and outside research and manufacturing organizations discuss current problems and advances in aeronautics. Graded pass/fail only. Instructor: Knauss.

Ae 200. Advanced Research in Aeronautics. *Units to be arranged.* Ae.E. or Ph.D. thesis level research under the direction of the staff.

Ae 201 abc. Advanced Fluid Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ae/APh 101 abc or Hy 101 abc; AM 125 abc or AMa 101 abc (may be taken concurrently).* Foundations of the mechanics of real fluids. Basic concepts will be emphasized. Subjects covered (not necessarily in the order listed) include physical properties of real gases; the equations of motion of viscous and inviscid fluids; the dynamical significance of vorticity; exact solutions; motion at high Reynolds number; inviscid compressible flow theory; shock waves; similarity for subsonic, transonic, supersonic and hypersonic flows. Instructor: Saffman.

Ae 204 abc. Technical Fluid Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ae/APh 101 abc, Hy 101 abc or equivalents.* External and internal flow problems encountered in engineering for which only empirical methods exist. Turbulent shear flow, separation, transition, three-dimensional and nonsteady effects. Basis of engineering practice in design of devices such as mixers, ejectors, diffusers, control valves. Studies of flow-induced oscillations, wind effects on structures, vehicle aerodynamics. Instructor: Coles.

Ae 208 abc. Fluid Mechanics Seminar. *1 unit (1-0-0); first, second, third terms.* A seminar course in fluid mechanics. Weekly lectures on current developments are presented by staff members, graduate students, and visiting scientists and engineers. Instructor: Coles.

Ae/AM 209 abc. Seminar in Solid Mechanics. *1 unit (1-0-0); first, second, third terms.* A seminar for staff and students of all divisions whose interests lie in the general field of solid mechanics. Reports on current research by staff and students on the campus are intermixed with seminars given by invited lecturers from companies and other research institutions. Instructors: Staff.

Note: The following courses, with numbers greater than 210, are one-, two-, or three-term courses offered each year to interested students. Depending on conditions, some of the courses may be taught as tutorials or reading courses, while others may be conducted more formally.

Ae 212. Shell Theory. *9 units (3-0-6); first term. Prerequisite: instructor's permission.* General mathematical formulation of the theory of thin elastic shells. Membrane and bending stresses in shells. Elastic stability. Surveys of recent advances in the nonlinear theories of stressing and buckling of shells. Not offered in 1986–87.

Ae/AM 213 abc. The Mechanics of Fracture. *9 units (3-0-6); first, second, third terms. Prerequisites: Ae 202 abc or equivalent and instructor's permission.* The currently practiced analytical and experimental techniques used in the study of fracture in metallic and nonmetallic solids. Topics could include the mechanics of brittle and ductile fracture in structural materials, the modeling of brittle fracture, near-tip elastic fields, techniques of stress analysis. Elastic-plastic analysis of crack extension, dislocation mechanisms, cleavage, ductile fracture by void growth, the establishment of relevant fracture criteria. Transitional behavior, rate sensitivity, running cracks. Static and dynamic fracture testing and structural design considerations. Not offered in 1986–87.

Ae 221. Theory of Viscoelasticity. *9 units (3-0-6); third term. Prerequisites: Ae 102 abc or equivalent and instructor's permission.* Material characterization and thermodynamic foundation of the stress-strain laws. Correspondence rule for viscoelastic and associated elastic solutions and integral formulation for quasi-static boundary value problems. Treatment of time-varying boundary conditions such as moving boundaries and moving loads. Stress waves. Approximate methods of viscoelastic stress analysis. Not offered in 1986–87.

Ae/AM 223 abc. Plasticity. *9 units (3-0-6); first, second, third terms. Prerequisite: Ae/AM 102 abc or instructor's permission.* Theory of dislocations in crystalline media. Characteristics of dislocations and their influence on the mechanical behavior in various crystal structures. Application of dislocation theory to single and polycrystal plasticity. Theory of the inelastic behavior of materials with negligible time effects. Experimental background for metals and fundamental postulates for plastic stress-strain relations. Variational principles for incremental elastic-plastic problems, uniqueness. Upper and lower bound theorems of limit analysis and shakedown. Slip line theory and applications. Additional topics may include soils, creep and rate-sensitive effects in metals, the thermodynamics of plastic deformation, and experimental methods in plasticity. Not offered in 1986–87.

Ae 225. Special Topics in Solid Mechanics. *9 units (3-0-6); first, second, third terms.* Subject matter will change from term to term depending upon staff and student interest but may include such topics as structural dynamics; aeroelasticity; thermal stress; mechanics of inelastic materials; and nonlinear problems. Instructors: Staff.

Ae 232 abc. Numerical Methods in Fluid Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ae/APh 101 abc, Hy 101 abc or equivalent; AM 113 abc or equivalent.* Problem-oriented review of numerical methods for inviscid and viscous incompressible flows. Topics will cover both free and wall-bounded flows and include a discussion of vortex methods in two and three dimensions, and spectral methods. Problems discussed will include: vortex merging and roll-up, free shear layers, representation of viscous effects, simulation of separated flows, motion of a vortex filament, aircraft wake vortices, interaction of ring vortices, turbulent spot in a laminar boundary layer, applications to homogeneous turbulence and wall-bounded transitional flows. Instructor: Leonard.

Ae 233 ab. Shear Flow Stability. *9 units (3-0-6); first, second terms. Prerequisites: Ae/APh 101 abc, AMa 101 abc.* Laminar stability theory as a guide to laminar-turbulent transition. "Inertial" instability illustrated first by the response of two-dimensional compressible free-shear flows to small inviscid disturbances. Distinctive behavior of "subsonic," "sonic" and "supersonic" disturbances. Importance of modern computational techniques in the discovery of unstable modes. Laminar boundary layer stability and the dual role of viscosity; effects of pressure gradient, suction and heat transfer in liquids and gases. Recent work on the control of laminar oscillations by utilizing "feedback." Axisymmetric and three-dimensional disturbances. Unresolved problems of the response of laminar shear flows to "external" disturbances. Instructor: Kubota.

Ae 234. Hypersonic Aerodynamics. *9 units (3-0-6); third term. Prerequisites: Ae/APh 101 abc, AM 125 abc, or instructor's permission.* An advanced course dealing with aerodynamic problems of flight at hypersonic speeds. Topics are selected from: hypersonic small-disturbance theory, blunt body theory, boundary layers and shock waves in real gases, heat and mass transfer, testing facilities and experiment. Instructor: Kubota.

Ae 237. Non-Steady Gasdynamics. *9 units (3-0-6); second term. Prerequisite: Ae/APh 101 abc or equivalent.* Review of shock waves, simple expansion waves. Real gas effects. Basic shock-tube performance. Wave interactions and geometrical effects. Non-ideal behavior in shock tubes. Shock-tube techniques and applications. Blast and detonation waves. Shock Hugoniots in various media. Instructor: Sturtevant.

Ae 239. Turbulent Shear Flows. *9 units (3-0-6); third term.* Similarity arguments for classical shear flows; jet, wake, plume, mixing layer, boundary layer. Survey of current research on large coherent structures. Role of such structures in mixing, entrainment, and transport. Not offered in 1986–87.

Ae 240. Special Topics in Fluid Mechanics. *9 units (3-0-6); first, second, third terms.* Subject matter will change from term to term depending upon staff and student interest. Instructors: Staff.

ANTHROPOLOGY

An 22. Introduction to the Anthropology of Development. *9 units (3-0-6); second term.* Introduction to the study of social change in contemporary tribal and peasant societies. Emphasis will be placed on the impact of modernization, especially through urbanization, industrialization and the intensification of agriculture. Instructor: Scudder.

An 101 abc. Selected Topics in Anthropology. *9 units (3-0-6).* Not offered in 1986–87.

An 123. The Anthropology of Rapid Social Change. *9 units (3-0-6); third term. Prerequisite: An 22.* Detailed studies of selected peasant and tribal societies in developing areas, focusing on two types of rapid social change: that which is induced from outside through the efforts of government and other planning organizations, and that which is induced from within through local experimentation, innovation, revitalization and migration. Instructor: Scudder.

An 124. The Evolution and Current Status of Small-Scale Human Societies. *9 units (3-0-6); third term. Prerequisite: An 22.* Lectures deal with human and cultural evolution prior to the rise of the pre-industrial city; reading and student projects deal with the implications of the contemporary world for small-scale human societies, and for the Navajo in particular. Instructor: Scudder.

An 125. The History of Anthropology. *9 units (3-0-6); second term.* A general history of the development of anthropological theory and practice. The course will examine the developing concerns and professionalization of the discipline, the methods of field work, and some of the possible implications and applications of anthropological knowledge. Instructor: Dirks.

An 126. The Anthropology of South Asia. *9 units (3-0-6); second term.* With village enthnographies and general overviews, this course will examine the range of village forms, caste systems, and agrarian relations in South Asia. Recent social and political change will be analyzed in historical perspective and in the light of other analyses of the political and economic dimensions of peasant underdevelopment. Instructor: Dirks.

APPLIED MATHEMATICS

AMa 95 abc. Introductory Methods of Applied Mathematics. *12 units (4-0-8); first, second, third terms. Prerequisites: Ma 1 abc, Ma 2 abc, or equivalents.* Introduction to: functions of complex variables; linear ordinary differential equations; special functions; eigenfunction expansions; integral transforms; linear partial differential equations and boundary value problems. Instructors: Cohen, Wu.

AMa 98 ab. Differential Equations and Perturbation Methods. *9 units (3-0-6). Prerequisite: Ma 2.* Special methods for solving ordinary and partial differential equations; phase plane, limit cycles, Floquet theory, similarity solutions, method of characteristics, difference differential equations, generating functions. Asymptotic and approximate methods for obtaining useful information about solutions of differential equations. Applications to non-linear oscillations, van der Pol equation, stability, resonance; branching processes, probability birth and death processes; fluid flow problems, diffusion, solitons. Not offered in 1986–87.

AMa 101 abc. Methods of Applied Mathematics I. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 or Ma 108.* Review of basic complex variable analysis; asymptotic expansions; ordinary linear differential equations; Sturm-Liouville theory; eigenfunction expansions; integral transforms; special functions; integral equations; introduction to partial differential equations; elementary theory of nonlinear differential equations. Instructor: Whitham.

AMa 104. Matrix Theory. *9 units (3-0-6); first term. Prerequisite: AMa 95 or equivalent.* Linear transforms, theory of linear vector spaces, Hilbert spaces. Matrix calculus, vector and matrix norms. Eigenvalue and eigenvector theory, canonical forms, singular value decompositions, inverses and pseudo-inverses, computational linear algebra. Instructor: Lorenz.

AMa 105 ab. Introduction to Scientific Computing. *11 units (3-2-6); second, third terms. Prerequisites: AMa 95 and 104 or equivalent.* Numerical linear algebra. Approximation theory. Numerical integration. Numerical solution of ordinary differential equations. Introduction to numerical solution of partial differential equations. Linear programming. Computer assignments will be given. Instructors: Kreiss, Lorenz.

AMa 110. Introduction to the Calculus of Variations. *9 units (3-0-6). Prerequisite: AMa 95 or Ma 108 or equivalent.* The first variation and Euler's equation for a variety of classes of variational problems from mathematical physics. Natural boundary conditions. Subsidiary conditions. The theory of extremal fields for single-variable variational problems. Conjugacy and the second variation. Hamilton-Jacobi theory. An introduction to the direct methods of Rayleigh, Ritz, and Tonelli and their application to equilibrium and eigenvalue problems. Some simple aspects of control problems. Not offered in 1986–87.

AMa/CS 138 ab. Computer Algorithms. *9 units (3-0-6). Prerequisites: CS 10 and AMa 104 or equivalent.* The design and analysis of computer algorithms. Efficiency and complexity of algorithms; NP-completeness; integer and polynomial arithmetic; pseudo-random numbers; matrix algorithms; the simplex method and newer algorithms for linear and quadratic programming; integer programming; searching; sorting; maximum flows, optimal assignment, shortest paths, and other graphical problems; dynamic programming; the greedy algorithm; backtracking; pattern matching; the fast Fourier transform. Not offered in 1986–87.

AMa 151 abc. Perturbation Methods. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 101 or equivalent; may be taken concurrently with instructor's permission.* Uniformly valid approximations in various physical problems. Generalized boundary layer technique. Coordinate straining techniques; Poincaré's method. Problems with several time scales; averaging techniques; method of Krylov Bogoliubov. Eigenvalue problems. Examples taken from various fields of science. Instructor: Wiggins.

AMa 152 abc. Linear and Nonlinear Wave Propagation. *9 units (3-0-6). Prerequisite: AMa 101 or equivalent; may be taken concurrently with instructor's permission.* Mathematical formulation, hyperbolic equations, characteristics, shocks. Combined effect of nonlinearity and diffusion. Wave propagation with relaxation effects. Dispersive waves, group velocity, geometry of waves, nonlinear dispersive waves. Diffraction theory. The emphasis is on solving physical problems, and the mathematical theory is developed through a wide variety of problems in gasdynamics, water waves, plasma physics, electromagnetism. Not offered in 1986–87.

AMa 153 abc. Stochastic Processes. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 or Ma 108.* Basic probability and probabilistic approximations; applications to stochastic population theories and stochastic epidemics. Markov chains, random walks and discrete potentials, Brownian motion. Correlations, power spectra, and application to filtering and prediction of stationary processes. Stochastic differential equations, use of Fokker-Planck and Kolmogorov equations. Markov Process methods. Instructor: Franklin.

AMa 155 ab. Numerical Optimization. *10 units (3-3-4). Prerequisites: AMa 95 and 104 or equivalent.* Linear programming and the simplex method; steepest descent methods; search algorithms; conjugate gradient methods and quasi-Newton methods. Penalty terms and methods using an extended Lagrangian function. Computer assignments will be given. Not offered in 1986–87.

AMa 156. Numerical Analysis of Ordinary Differential Equations. *11 units (3-2-6); second term. Prerequisites: AMa 95, 104 and 105 or equivalent.* Theory of numerical techniques for linear and nonlinear initial and boundary value and eigenvalue problems. The discussion of the numerical techniques will focus on consistency, accuracy, stability, stiffness, numerical efficiency, etc. Stiff equations and multiple time scales. Computer assignments will be given. Instructor: Lorenz.

AMa 157. Approximation Theory and Spectral Methods. *11 units (3-2-6). Prerequisites: AMa 95, 104 and 105 or equivalent.* Theory of approximation in least square and maximum norms. Numerical methods for the solution of overdetermined linear systems. Continuous and discrete Fourier transforms. Expansions in series of orthogonal functions. Pseudospectral methods, time differencing. Computer assignments will be given. Not offered in 1986–87.

AMa 171 abc. Dynamical Systems with Applications. *9 units (3-0-6). Prerequisite: AMa 101 or equivalent; may be taken concurrently with instructor's permission.* Studies of dynamical systems from the point of view of time-dependent ordinary differential equations. Chaos, local bifurcations, invariant manifolds, KAM theory, perturbation methods, Arnold diffusion. Applications in fluid dynamics, panel flutter, satellite dynamics, chemical reactions, mathematical biology. Various models of transition to turbulence. Not offered in 1986–87.

AMa 181 abc. Mathematical Programming and Game Theory. *9 units (3-0-6). Prerequisite: Ma 2 or equivalent.* Duality in linear programming. Variants of the simplex method. Khachian's algorithm. Perturbation theory. Integer programming and network flows. Multi-objective programming. Two-person games. Kuhn-Tucker theory of nonlinear programming. Simplex method for quadratic programming. Geometric programming. Elementary proofs of fixed-point theorems of Brouwer, Schauder, and Kakutani. Nash's theorem for *n*-person games. Applications to social science and engineering. Not offered in 1986–87.

AMa 190. Reading and Independent Study. *Units by arrangement.* Graded pass/fail only.

AMa 201 ab. Methods of Applied Mathematics II. *9 units (3-0-6). Prerequisite: AMa 101 or equivalent.* Integral equations. Volterra and Fredholm theory; Hilbert-Schmidt theory; variational characterization. Singular integral equations. Cauchy kernels; Hilbert transforms, Hilbert and Riemann problems. Special techniques. Not offered in 1986–87.

AMa 204. Numerical Solution of Differential and Integral Equations. *9 units (3-0-6); third term. Prerequisite: Some familiarity with elementary numerical methods.* Theoretical and practical study of methods for approximate solution of various linear and nonlinear ordinary and partial differential equations with the use of digital computers. Instructor: Keller.

AMa 205 abc. Numerical Fluid Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisite: Familiarity with numerical methods.* The use of numerical techniques in the analysis of problems in fluid mechanics. Emphasis on the application of numerical methods to those topics covered from the analytical point of view in AMa 251. Topics: Survey of finite difference, finite element, and spectral methods for the solution of the Navier-Stokes equation. Numerical potential theory. Simulation of flow past bodies. Vortex methods. Treatment of boundary layer flows. Numerical techniques for the solution of problems in gas dynamics, in particular, treatment of shocks and discontinuities. Numerical studies of hydrodynamic instabilities. Simulation of flow in porous media. Instructor: Meiron.

AMa 220 abc. Bifurcation Theory and Nonlinear Boundary Value Problems. *9 units (3-0-6). Prerequisite: Some knowledge of differential equations.* Theory and applications of bifurcation and nonlinear boundary value problems in mechanics, fluid dynamics and nonlinear diffusion processes. Lyapounov-Schmidt theory. Multiple bifurcations and Newton's polygons. Extension of bifurcated branches, secondary bifurcation, perturbed bifurcation and imperfection sensitivity. Hopf bifurcation of periodic solutions. Catastrophe theory. Nonlinear boundary value and eigenvalue problems. Monotonicity methods. Stability theory. Degree theory. Numerical applications and path following. Not offered in 1986–87.

AMa 251 abc. Advanced Fluid Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ae/APh 101 abc or Hy 101 abc; AM 125 abc or AMa 101 (may be taken concurrently).* For course description see Aeronautics, Ae 201.

AMa 260 ab. Special Topics in Continuum Mechanics. *9 units (3-0-6). Prerequisite: Instructor's permission.* A course designed to reflect recent and current research interests of the staff and students. Not offered in 1986–87.

AMa 290. Applied Mathematics Colloquium. *Units by arrangement.*

AMa 300. Research in Applied Mathematics. *Units by arrangement.*

Other courses particularly suitable in making up a program in applied mathematics include Ma 191, Ma 143, Ma 144, Ma 147, AM 135, AM 136, AM 175, Ph 125, and Ph 209.

APPLIED MECHANICS

AM 35 abc. Statics and Dynamics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 1 abc, Ph 1 abc.* Introduction to statics and dynamics of rigid and deformable bodies. Equilibrium of force systems, principle of virtual work, distributed force systems, friction, static analysis of rigid and deformable structures, kinematics, particle dynamics, rigid body dynamics, dynamics of deformable systems, vibrating systems, Lagrange's equations and Hamilton's principle. Instructor: Iwan.

AM 96 abc. Applied Dynamics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 1 abc, Ma 1 abc.* Basic principles and applications of classical mechanics. Analytical description of motion, including relative motion. Particle mechanics, including energy and momentum principles. Generalized coordinates, principle of virtual work, stability, Lagrange's equations and Hamilton's principle. Rigid body dynamics. Response of mechanical systems to periodic and transient excitations. Applications to such problems as planetary motion, effects of the Earth's rotation, rocket motion, impact, gyroscopic motions, vibration isolation, vibration instrumentation, etc. Not offered in 1986–87.

AM 97 abc. Analytical Mechanics of Deformable Bodies. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 1 abc and Ma 2 abc.* Introduction to the theory of stress and strain in solid bodies. Applications to beams, columns, plates and shells, torsion, inelastic behavior, numerical and experimental stress analysis, wave propagation, energy methods of analysis. Not offered in 1986–87.

Ae/AM 102 abc. Mechanics of Structures and Solids. *9 units (3-0-6).* For course description, see Aeronautics.

Ae/AM 108 abc. Finite Element Methods. *9 units (3-0-6).* For course description, see Aeronautics.

AM 113 abc. Engineering Mathematics. *12 units (4-0-8); first, second, third terms. A course for graduate students who have not had the equivalent of AMa 95 abc. Prerequisite: Ma 1 abc, Ma 2 abc, or equivalent.* Linear differential equations, including power series solutions and special functions. Introduction to complex variable theory with applications. Linear differential equations and special functions in the complex domain. Fourier series and orthogonal functions. Solution of boundary value problems for partial-differential equations by conformal mapping, separation of variables and integral transforms. Instructors: Beck, Sternberg.

AM 125 abc. Engineering Mathematical Principles. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 abc or AM 113 abc.* Topics include linear spaces, operators and matrices, integral equations, variational principles, differential equations, stability, perturbation theory. Applications to problems in engineering and science are stressed. Instructor: Knowles.

AM 135 abc. Mathematical Elasticity Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: instructor's permission.* Cartesian tensors. Kinematics and kinetics of continuous media, constitutive relations for elastic solids. Fundamental problems and related theorems of linearized elastostatics and elastodynamics. Integration theory and applications to specific problems of engineering interest. Instructor: Rosakis.

AM 136 abc. Advanced Mathematical Elasticity Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: AM 135 abc or equivalent.* Topics drawn from the more advanced linear theory and nonlinear theory. Specific content varies according to interests of students and instructor.

AM 141 abc. Wave Propagation in Solids. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 abc or AM 113 abc, or instructor's permission.* Theory of wave propagation in solids with applications. Introduction to linear elastodynamics. Waves in the infinite elastic medium. Reflection and refraction of time harmonic waves at an interface. Time harmonic waves in elastic waveguides (rods, plates, layers); wave dispersion. Transient waves in an elastic half space and a waveguide. Transient wave scattering and diffraction. Boundary value problems. Introduction to theory of waves in viscoelastic and plastic media. Not offered in 1986–87.

AM 151 abc. Dynamics and Vibrations. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 abc, or instructor's permission.* Variational principles and Lagrange's equations. Response of mechanical systems to periodic, transient, and random excitation. Free and forced response of discrete and continuous systems. Approximate analysis methods. Introduction to nonlinear oscillation theory and stability. Instructor: Caughey.

AM 175 abc. Advanced Dynamics. *9 units (3-0-6); first, second, third terms. Prerequisites: AM 125 abc and AM 151 abc or equivalents.* Topics considered will include linear and nonlinear vibrations of discrete and continuous systems, stability and control of dynamical systems, and stochastic processes with applications to random vibrations. Instructor: Staff.

AM 200. Special Problems in Advanced Mechanics. *Hours and units by arrangement.* By arrangement with members of the staff, properly qualified graduate students are directed in independent studies in mechanics.

Ae/AM 209 abc. Seminar in Solid Mechanics. *1 unit (1-0-0).* For course description, see Aeronautics.

Ae/AM 213 abc. The Mechanics of Fracture. *9 units (3-0-6); first, second, third terms. Prerequisites: Ae 202 or equivalent and instructor's permission.* For course description, see Aeronautics.

Ae/AM 223 abc. Plasticity. *9 units (3-0-6).* For course description, see Aeronautics.

AM 250 abc. Research in Applied Mechanics. *Hours and units by arrangement.* Research in the field of applied mechanics. By arrangement with members of the staff, properly qualified graduate students are directed in research.

APPLIED PHYSICS

APh 3. Solid-State Electronics for Integrated Circuits. *6 units (2-0-4); first term.* An overview of the physics that underlies the computer revolution, from metals, semiconductors, and insulators to metal-semiconductor contacts (Schottky diodes), light-emitting diodes (LED's), pn diodes, metal-oxide-metal (MOS) capacitors, MOS transistors, and MOS logic circuits. Emphasis on computer-aided layout and fabrication of integrated circuits. Students will build and test an LED and a Schottky diode. Leads to the laboratory APh 9. Graded pass/fail. Instructor: Rutledge.

APh/MS 4. Introduction to Materials Science. *6 units (2-0-4); third term.* Selected engineering systems, such as jet engines, superconducting transmission lines and nuclear reactors, are discussed in terms of the critical role played by materials in their construction and performance. Those material properties of greatest significance are explored to show how they are governed by the structure, physics, and chemistry of the material. Graded pass/fail. Instructor: Wood.

APh 9. Solid-State Electronics for Integrated Circuits Laboratory. *6 units (0-3-3); second term. Prerequisite: APh 3; six units credit allowed toward the freshman laboratory requirement.* Students design and make the devices discussed in APh 3, including MOS capacitors, pn diodes, MOS transistors, inverters, and logic circuits. The course teaches photolithography and how to use high-vacuum equipment and furnaces. Graded pass/fail. Instructor: Rutledge.

APh/ME 17 abc. Thermodynamics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 1 abc, Ph 1 abc.* Introduction to the use of thermodynamics and statistical mechanics in physics and engineering. Entropy, temperature, and the principal laws of thermodynamics. The thermodynamic identity for open and closed systems. Canonical equations of state. Applications to cycles, engines, phase and chemical equilibria. Probability and stochastic processes. Kinetic theory of perfect gases. Statistical mechanics. Applications to gases, gas degeneration, equilibrium radiation, and simple solids. Instructor: Corngold.

APh 23. Demonstration Lectures in Optics. *6 units (2-0-4); first term. Prerequisite: Ph 1 abc.* Nine lectures, covering the fundamentals of optics with an emphasis on modern optical applications, are intended to exhibit basic optical phenomena including interference, dispersion, birefringence, diffraction, and laser oscillation, and the applications of these phenomena in optical systems employing two-beam and multiple-beam interferometry, Fourier-transform image processing, holography, electro-optic modulation, optical detection and heterodyning. System examples will be selected from optical communications and radar, adaptive optical systems. Instructor: Bridges.

APh 24. Introductory Modern Optics Laboratory. *6 units; second term. Prerequisite: APh 23.* Laboratory experiments to acquaint students with the contemporary aspects of modern optical research and technology. Experiments encompass many of the topics and concepts covered in APh 23. Instructor: Bridges.

APh 50 abc. Quantum Physics of Matter. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 2 abc, Ma 2 abc, or equivalents.* Quantum mechanics and applications to problems of the three states of matter: solids, gases, and liquids. Topics: bound and free particles, the electromagnetic field, diatomic molecules, quantum systems in thermal equilibrium, and perturbation theory. Additional topics selected from plasma physics and electron transport in solids. Applications such as lasers and semiconductor electronics will be treated along with other topics in physics, depending on the instructor and interests of the students. Instructor: Vahala.

APh 77. Laboratory in Applied Physics. *9 units; term to be announced.* Selected experiments in applied physics are chosen to familiarize the student with laboratory equipment and procedures in differing areas of applied physics such as cryogenics, magnetism, plasmas, fluids, semiconductors, optics, and materials properties. Instructors: Staff.

APh 78 abc. Senior Thesis, Experimental. *9 units; first, second, third terms. Prerequisite: instructor's permission.* Supervised experimental research experience, open only to senior applied physics majors. Requirements will be set by individual faculty members, but will include a written report based upon actual laboratory experience. The selection of topic and the final report must be approved by the Applied Physics Undergraduate Committee. Students desiring additional units should register in APh 100. Not offered on a pass/fail basis. Instructors: Culick and the applied physics faculty.

APh 79 abc. Senior Thesis, Theoretical. *9 units; first, second, third terms. Prerequisite: instructor's permission.* Supervised theoretical research experience, open only to senior applied physics majors. Requirements will be set by individual faculty members, but will include a written report based upon actual laboratory experience. The selection of topic and the final report must be approved by the Applied Physics Undergraduate Committee. Not offered on pass/fail basis. This course cannot be used to satisfy the laboratory requirement in APh. Instructors: Culick and the applied physics faculty.

APh 91 abc. Experimental Projects in Applied Physics. *Units by arrangement. 6 units minimum each term. Prerequisite: Ph 7 or EE 90 abc or equivalent; open to seniors only upon acceptance by the instructor of a suitable proposal.* A non-structured project laboratory designed for the student to do original experiments in applied physics. Emphasis is placed upon the selection of significant projects, the formulation of the experimental approach and the interpretation of data as well as upon the use of modern laboratory techniques. Facilities are available for experiments in cryogenics, lasers, quantum electronics, ferromagnetism, optics, microwaves, plasma physics, and semiconducting solid state. Text: Literature references. Instructors: Staff.

APh 100. Advanced Work in Applied Physics. Special problems relating to applied physics will be arranged to meet the needs of students wishing to do advanced work. Primarily for undergraduates. Students should consult with their advisers before registering for this course. Graded pass/fail.

Ae/APh 101 abc. Fluid Mechanics. *9 units (3-0-6).* For course description, see Aeronautics.

Ae/APh 104 abc. Experimental Methods. *9 units (3-0-6).* For course description, see Aeronautics.

APh 105 abc. States of Matter. *9 units (3-0-6); first, second, third terms. Prerequisite: APh/ME 17 or equivalent.* A survey emphasizing unifying concepts, such as order parameters, scaling laws, quasi-particle excitations and correlation functions. Topics: long-range ordered states such as crystals, superfluids, and ferromagnets; phase transitions of first and higher orders; critical phenomena; band theory of solids, liquids, ideal classical and degenerate gases; fluctuations; and noise. Instructor: Johnson.

APh 107. Advanced Dynamics. *9 units (3-0-6); third term. Prerequisite: Ph 106 a, b or equivalent.* Lectures will deal with advanced topics in classical mechanics, such as integrable vs. non-integrable systems, maps and flows, and "stochasticity." An introduction to non-equilibrium statistical mechanics will follow, with examples drawn from plasma physics and from the theory of condensed matter. Instructor: Corngold.

APh 110. Topics in Applied Physics. *2 units (2-0-0); first, second, third terms.* A seminar course designed to acquaint juniors and first-year graduate students with the various research areas represented in the option. Lecture each week given by a different faculty member of the option, reviewing, in general terms, his or her field of research. Graded pass/fail. Instructors: Bellan and applied physics faculty.

APh 114 abc. Solid State Physics. *9 units (3-0-6); first, second, third terms. Prerequisite: APh 50 or Ph 92 abc or equivalent.* An introductory lecture and problem course dealing with experimental and theoretical problems in solid-state physics. The topics include crystal structure, symmetries in solids, lattice vibrations, electronic states in solids, transport phenomena, semiconductors, superconductivity, magnetism, ferroelectricity, defects, and optical phenomena in solids. Instructor: McGill.

APh/EE 130. Introduction to Optoelectronics. *9 units (3-0-6); third term. Prerequisites: APh 23, 24 or instructor's permission.* An introduction to devices and applications in optoelectronics. Gaussian beam propagation; device physics and engineering parameters of selected lasers, detectors, modulators and other optoelectronic components; system design considerations, with examples from optical communication, radar, and other applications. Instructor: Bridges.

APh 150. Topics in Applied Physics. *Units and term to be arranged.* The content of this course will vary from year to year, but at a level suitable for advanced undergraduate or beginning graduate students. Topics will be chosen according to the interests of students and staff. Visiting faculty may present portions of this course. Instructors: Staff.

APh 153 abc. Modern Optics. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 abc.* Fundamental principles of modern optics and understanding contemporary optical systems. Geometrical optics, ray matrices, and the Hamiltonian analogy will introduce the wave equation and its solutions. Topics include Fresnel and Fraunhofer diffraction, Fermat's principle, the analysis of systems based on e.m. theory, Gaussian beam propagation, interferometry, holography, speckle, van der Lugt filters, pattern recognition, fiber optics, light modulation, diffraction by sound, radiometry, detectors, sources. Not offered in 1986–87.

APh 154. Advanced Modern Optics Laboratory. *9 units (0-4-5); third term. Prerequisites: APh 23/24 for undergraduates, or APh 153 ab and/or APh 190 ab for graduate students, and consent of instructor.* Four experiments designed to provide students with theoretical background and experimental skills in selected areas of modern optics such as computer-aided lens design, laser cavities, holography, acousto-optic and electro-optic modulation, interferometry, Fourier optics, spatial filtering and fiber optics. Instructor: Psaltis.

APh 156 abc. Plasma Physics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 106 abc or equivalent.* An introduction to the principles of plasma physics, including orbits of charged particles in electric, magnetic, and gravitational fields; continuum magnetohydrodynamics and elementary stability theory; transport processes such as conductivity and diffusion, Vlasov equation, waves, and oscillations in plasmas. Examples from plasmas used in controlled thermonuclear fusion research (e.g., tokamaks, mirrors, pinches). Instructor: Bellan.

APh 181 abc. Physics of Semiconductors and Semiconductor Devices. *9 units (3-0-6); first, second, third terms.* Introduction to the concepts of semiconductor devices based on underlying physical properties of semiconductors. Electronic and chemical equilibrium in the bulk semiconductor and near interfaces, e.g., p-n junctions, surfaces. Kinetics of carrier generation-recombination and transport to first order. Traditional and novel methods of device fabrication. Applications will be made to a wide variety of devices and attention given to feasible schemes for device construction. Instructor: Nicolet.

APh 190 abc. Quantum Electronics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 125, or equivalent.* Generation, manipulations, propagation, and applications of coherent radiation. The basic theory of the interaction of electromagnetic radiation with resonant atomic transitions. Laser oscillation, important laser media, Gaussian beam modes, the electro-optic effect, nonlinear-optics theory, second harmonic generation, parametric oscillation, stimulated

Brillouin and Raman scattering. Other topics include: light modulation, diffraction of light by sound, integrated optics, phase conjugate optics, and quantum noise theory. Instructor: Yariv.

APh 200. Applied Physics Research. *Units in accordance with work accomplished.* Offered to graduate students in applied physics for research or reading. Students should consult their advisers before registering for the course. Graded pass/fail.

APh 214 abc. Advanced Solid-State Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: APh 114 abc and Ch 125 abc or Ph 125 abc.* A course in experimental and theoretical solid-state physics. Topics: phonons; electronic excitation in solids; electron-phonon interactions; optical transport and magnetic properties; superconductivity; ferroelectricity. The emphasis will be mainly theoretical with frequent comparison between theoretical predictions and experimental results. Not offered in 1986–87.

APh 250. Advanced Topics in Applied Physics. *Units and term to be arranged.* The content of this course will vary from year to year. Topics will be chosen according to the interests of students and staff. Visiting faculty may present portions of this course. Instructors: Staff.

APh 300. Thesis Research in Applied Physics. *Units in accordance with work accomplished.* APh 300 is elected in place of APh 200 when the student has progressed to the point where his or her research leads directly toward a thesis for the degree of Doctor of Philosophy. Approval of the student's research supervisor and department adviser or registration representative must be obtained before registering. Graded pass/fail.

ART

Art 1 ab. Introduction to Art History. *9 units (3-0-6).* An introduction to the elements of artistic representation from the Renaissance to the twentieth century, including perspective, description, narration, and symbolism. Works by a number of major artists, among them Michelangelo, Rembrandt, Cézanne, and Picasso, will be considered in the light of these concerns. Instructor: Staff.

Art 101. Selected Topics in Art History. *9 units (3-0-6). Advanced credit to be determined on a course-by-course basis by the instructor.* Instructors: Staff.

Art 102. British Art of the Georgian Period.* *9 units (3-0-6); first term.* An introduction to the visual arts and the vocabularies of analysis for the study of painting through an in-depth study of the British art of the Georgian period in the collection of the Huntington Art Gallery. Instructor: Wark.

Art 104. Impressionism and Post-Impressionism.* *9 units (3-0-6).* A study of French painting from c. 1860 to 1900 and of critical approaches to it. Visits to local museums are required. Instructors: Staff.

Art 105. Early Modern Art, 1900–1940.* *9 units (3-0-6); second term.* An introduction to early modern art and its major movements via selected artists, including Matisse, Picasso, Mondrian, Duchamp, and Miro. Visits to local museums are required. Instructors: Staff.

Art 106. Contemporary Art, 1940–Present.* *9 units (3-0-6); first term.* An introduction to contemporary art and its major movements via important artists, including Pollock, Rothko, Dubuffet, Rauschenberg, Stella, Warhol, and Hesse. Visits to local museums are required. Instructor: Belloli.

*Advanced courses with credit toward the 36-unit Humanities requirement. Other advanced courses receive credit toward the 36-unit H&SS requirement. See page 83.

ASTRONOMY

Ay 1. Introduction to Astronomy. *9 units (3-1-5); third term.* This course, primarily for freshmen, surveys astronomy and astrophysics, emphasizing the application of physics in astronomy. Graded pass/fail. Instructor: Schmidt.

Ay 20. Basic Astronomy and the Galaxy. *11 units (3-2-6); first term. Prerequisites: Ma 1 abc, Ph 1 abc.* Astronomical terminology. Stellar masses, distances and motions. Star clusters and their galactic distributions. Stellar spectra, magnitudes and colors. Structure and dynamics of the galaxy. Laboratory exercises including double star orbits and the use of an astrograph. Instructors: Oke, Libbrecht.

Ay 21. Galaxies and Cosmology. *9 units (3-0-6); second term. Prerequisite: Ay 20.* The extragalactic distance scale. Clusters of galaxies. Introduction to cosmology. Balance of matter and radiation in the universe. Instructor: Moffet.

Ay 22. Solar System. *9 units (3-0-6); third term.* Physics of the sun. Surface phenomena of the sun, formation of spectral lines. Solar activity, sunspots, and flares. The solar corona and solar wind. Physics of the planetary system. Planetary magnetospheres and atmospheres, surface phenomena. Comets. Instructor: Libbrecht.

Ay 30. Current Trends in Astronomy. *3 units (2-0-1); second term.* Weekly seminar designed for sophomore astronomy majors only; to be held in faculty homes in the evening. Purpose is to introduce the students to the faculty and their research. Graded pass/fail. Instructors: Staff.

Ay 42. Research in Astronomy and Astrophysics. *Units in accordance with work accomplished.* Properly qualified undergraduates may, in their senior year, undertake independent or guided research with the goal of preparing a senior thesis. Graded pass/fail.

Ay 43. Reading in Astronomy and Astrophysics. *Units in accordance with work accomplished.* Student must have a definite reading plan and obtain permission of instructor before registering. Graded pass/fail.

Ay 101. Physics of Stars. *11 units (3-2-6); second term. Prerequisite: Ay 20.* Physics of stellar atmospheres. Properties of stars, stellar spectra, radiative transfer, line formation. Stellar structure, stellar evolution, evolution of binaries. Nuclear synthesis in stars. Stellar oscillations. Instructor: Oke.

Ay 102. Physics of the Interstellar Medium. *9 units (3-0-6); third term. Prerequisite: Ay 20.* An introduction to fluid mechanics; sound waves and shock waves. Introduction to magnetohydrodynamics; Alfven waves and plasma waves with applications to the interstellar medium. Supernova remnants. The interstellar magnetic field. The physics of H I and H II regions. Instructor: M. Cohen.

Ay 110. Senior Seminar in Astrophysics. *6 units (2-0-4); third term.* Designed for Ay seniors. Seminar on astrophysical topics of current interest. The lectures will be given by the students. The emphasis will be on topics that require a synthesis of previous formal course work. Instructors: Sargent, Mould.

Ay 134. The Sun. *9 units (3-1-5); first term.* The physical state of the sun as derived from observations from the ground and from space. The solar wind and other solar-terrestrial effects. Students will have the opportunity to do a small research topic with materials from the Big Bear Solar Observatory. Given in alternate years; not offered in 1986–87.

Ay 141 abc. Research Conference in Astronomy. *2 units (1-0-1); first, second, third terms.* These conferences consist of reports on investigations in progress at the Mount Wilson, Las Campanas, Palomar, and Big Bear observatories and the Owens Valley Radio Observatory, and on other research that is of current interest. Graded pass/fail.

Ay 142. Research in Astronomy and Astrophysics. *Units in accordance with work accomplished.* The student should consult a member of the department and have a definite program of research outlined. Approval of the student's adviser must be obtained before registering. 36 units of Ay 142 or Ay 143 required for candidacy. Graded pass/fail.

Ay 143. Reading and Independent Study. *Units in accordance with work accomplished.* The student should consult a member of the department and have a definite program of reading and independent study outlined. Approval of the student's adviser must be obtained before registering. 36 units of Ay 142 or Ay 143 required for candidacy. Graded pass/fail.

Ay 151. Stellar Atmospheres and Radiative Transfer. *9 units (3-0-6); first term. Prerequisites: Ay 101 (undergraduates); Ph 98 or equivalent.* A basic course on radiative transfer in stellar atmospheres. Stellar spectra, radiation theory, sources of opacity, line formation, abundance analysis, non-LTE atmospheres. Instructor: Mould.

Ay 152. Stellar Interiors and Evolution. *9 units (3-0-6); second term. Prerequisites: Ay 101 (undergraduates); Ph 98 or equivalent.* A basic course on stellar structure and evolution, polytropes, radiative transport, convection, nuclear energy generation, main sequence, Hayashi track, advanced stages of evolution, pulsations, rotation, binary systems, white dwarfs, neutron stars, black holes. Instructor: Zirin.

Ay 153. Astronomical Measurements. *9 units (3-0-6); first term. Prerequisite: Ph 106 or equivalent.* A basic course on measurement and signal analysis techniques throughout the electromagnetic spectrum. Telescopes and interferometers; detectors and receivers; photometry and radiometry; imaging devices and image processing; spectrometers; space telescopes. Instructors: Lo, J. Cohen.

Ay 154. Galactic and Extragalactic Astronomy. *9 units (3-0-6); second term. Prerequisites: Ay 21 (undergraduates); Ph 106 or equivalent.* A basic course on the structure and properties of galaxies; kinematics and dynamics of our galaxy; spiral arms; stellar composition, masses and rotation of external galaxies; star clusters; galactic evolution; binaries, groups, and clusters of galaxies. Instructor: Sargent.

Ay 155. High Energy Astrophysics and Cosmology. *9 units (3-0-6); third term. Prerequisites: Ay 21 and Ph 106 (or equivalent).* A basic course on high energy astrophysics and cosmology; synchrotron radiation; inverse Compton scattering; pulsars; extragalactic radio sources; active galactic nuclei; black holes; extragalactic distance scale; cosmological models; galaxy formation; thermal history of the universe; nucleosynthesis. Instructor: Readhead.

Ay 156. Interstellar Medium. *9 units (3-0-6); third term. Prerequisite: Ay 102 (undergraduates).* A basic course on physical processes in the interstellar medium. Atomic and molecular spectroscopy, thermal and dynamic balance of interstellar medium, molecular clouds, magnetic fields, H II regions, supernova remnants, star formation, global structure of interstellar medium. Instructor: Scoville.

Ay 211. Extragalactic Astronomy. *9 units (3-0-6); third term.* A course for graduate students in astronomy, including a discussion of recent research in extragalactic astronomy and cosmology. Given in alternate years; not offered in 1986–87.

Ay 212. Topics in Astronomy. *9 units (3-0-6); second term.* A course for graduate students in astronomy. Topic for 1986–87 will be early stages of stellar evolution. Instructor: Boesgaard.

Ay 215. Seminar in Theoretical Astrophysics. *9 units (3-0-6); third term. Prerequisite: instructor's permission.* Seminar for advanced students on recent developments in astrophysics. The current theoretical literature will be discussed by the students. Given in alternate years; offered in 1986–87. Instructor: Goldreich.

Ay 218. High-Energy Astrophysics. *9 units (3-0-6); first term. Prerequisites: Ay 155, Ph 106, and Ph 125 or equivalent.* Topics will be chosen from the following: Equation of state and physical processes at high densities and high temperatures; hydrodynamics; shock waves; magnetohydrodynamics; radiation processes; relativistic gravity. Given in alternate years; offered in 1986–87. Instructors: Blandford, Phinney.

Ay 234. Seminar in Radio Astronomy. *6 units (2-0-4); second term. Prerequisite: Ay 155.* Recent developments in radio astronomy for the advanced student. Current publications and research in progress will be discussed by students and staff. Given in alternate years; not offered in 1986–87.

BIOLOGY

Bi 1. Introduction to Molecular Biology. *12 units (3-3-6); second term.* This course and its sequel, Bi 9, cover biology at the cellular level. After introducing basic concepts that are necessary for understanding biological systems at the molecular level, Bi 1 emphasizes the cellular processes that are involved in the organization and expression of genetic information, including what is commonly called molecular biology, and an introduction to topics in developmental biology and immunology. Graded pass/fail. Instructors: Abelson, Wold.

Bi 3. Introductory Topics in Biology. *6 units (2-0-4); first term.* An elective course designed for freshmen, dealing with topics in biology basic to understanding our world. Areas such as the origin of life, life in the Universe, evolution, man and his environment, ethical problems in biology and a broad perspective of the research interests of the faculty will be presented. Reading from a wide selection of sources will be required. Instructors: Revel and staff.

Bi 7. Organismic Biology. *9 units (3-3-3); first term. Prerequisite: Bi 1.* A survey of the principal kinds of organisms and the problems they have solved in adapting to various environments. Instructors: Brokaw and staff.

Bi 9. Cell Biology. *9 units (3-0-6); third term.* Bi 9 continues the coverage of biology at the cellular level, begun in Bi 1. Topics covered include cytoplasmic structure, membrane structure and function, cell motility, and cell-cell recognition. Emphasis is placed on both the ultrastructural and biochemical approaches to understanding these topics. Instructors: Lazarides and staff.

Bi 10. Cell Biology Laboratory. *6 units (0-4-2); third term. Prerequisite: Bi 1; designed to be taken concurrently with Bi 9.* An introduction to basic methods in cell biological research, including subcellular fractionation, practical enzymology and immunochemistry, use of radioisotopes, gel electrophoresis of proteins and nucleic acids, and light and electron microscopy. Instructors: Kennedy and staff.

Bi 22. Undergraduate Research. *Units to be arranged; first, second, third terms.* Special problems involving laboratory research in biology; to be arranged with instructors before registration. Graded pass/fail. Instructors: Staff.

Bi 23. Biology Tutorial. *Units to be arranged; first, second, third terms.* Study and discussion of special problems in biology, usually involving regular tutorial sessions with instructors. To be arranged through the undergraduate adviser before registration. Graded pass/fail. Instructors: Strauss and staff.

Bi/Ph 50. Introduction to Biophysics of the Nervous System. *9 units (3-0-6); second term. Prerequisites: Ph 2 a or Ph 12 a, and an introductory biology course in high school or at Caltech.* Selected topics illustrating areas where physics plays a key part in the function of the nervous system or in our attempts to understand it. Subject matter will include movement of ions across cell membranes, the action potential, the synapse, sensory transduction in the visual system, visual information processing, and psychophysics. (Will not be offered in 1987–88.) Instructor: Pine.

Bi 90 abc. Undergraduate Thesis. *12 or more units per term; first, second, third terms. Prerequisites: 18 units of Bi 22 or equivalent research experience in the research area proposed for the thesis, and instructor's permission.* This course is intended to extend the opportunities for research provided by Bi 22 into a coherent individual research project, carried out under the supervision of a member of the biology faculty. It normally involves three or more consecutive terms of work in the junior and senior years. The student will formulate a research problem based in part on work the student has already carried out, evaluate previously published work in the field, and present new results, in a thesis format. First two terms graded pass/fail; final term graded by letter on the basis of the completed thesis. Instructors: Revel and staff.

Bi 106. Developmental Biology of Animals. *6 units (2-0-4); second term. Recommended prerequisite: Bi/Ch 110.* Lectures and discussions dealing with various aspects of embryological development; cytoplasmic localization and cell interaction in early development, gene function and oogenesis, the role of accessory cells, gene regulation, the evolution of developmental processes and patterns of macromolecular syntheses in early embryological life. Given in alternate years; not offered in 1986–87. Instructor: E. Davidson.

Bi/Ch 110 abc. Biochemistry. *12 units (4-0-8); first, second, and third terms. Prerequisite: Ch 41 or instructor's permission. Instructors recommend Bi 1 as background for Bi/Ch 110 b and c.* Lectures and discussions on the molecular basis of biological structure and function. Emphasizes macromolecular structure and the metabolic processes involved in energy storage and utilization; storage, transmission, and expression of genetic information in prokaryotes and eukaryotes. Other topics in biochemistry of higher organisms: molecular regulatory mechanisms and the biochemistry of cell membranes. Instructors: Campbell, Parker, Raftery, Richards.

Bi 114. Immunology. *12 units (4-0-8); first term. Prerequisite: Bi 122 or equivalent.* The principles and methods of immunology and their application to various biological problems. Instructors: Rothenberg and staff.

Bi 115. Virology. *6 units (2-0-4); third term. Prerequisites: Bi 1, Bi 9.* An introduction to the chemistry and biology of viruses. Emphasis on the replication strategies of the animal viruses, with consideration also given to the epidemiology of viruses, the nature and control of virus diseases, the evolution of viruses, and some aspects of bacterial and plant virus replication. Given in alternate years; not offered in 1986–87. Instructor: Strauss.

Bi 122. Genetics. *9 units (3-0-6); second term. Prerequisite: Bi 1 or Bi 9, or instructor's permission.* A lecture and discussion course covering the basic principles of genetics. Instructor: Meyerowitz.

Bi 123. Genetics Laboratory. *3 units (0-3-0); second term. Prerequisite: Bi 122 (may be taken concurrently).* Laboratory exercises illustrating genetic principles and techniques, designed to accompany Bi 122. Instructor: Lewis.

Bi 125. Principles and Methods of Gene Transfer and Gene Manipulation in Eukaryotic Cells. *9 units (3-0-6); second term. Prerequisite: Bi/Ch 110.* A lecture and discussion course dealing with modern approaches to "genetic intervention" in eukaryotic cells. Topics: mutagenesis of cultured animal cells and selection schemes, gene transfer into cultured cells mediated by naked DNA, chromosomes and viruses, transformation of yeast by chromosomal DNA and plasmids, neoplastic transformation of plant cells by *Agrobacteria* plasmids, nuclear transplantation and gene injection into amphibian eggs and oocytes, selective drug-induced gene amplification in cultured animal cells, somatic cell hybridization. Given in alternate years; not offered in 1986–87. Instructor: Attardi.

Bi/Ch 132 ab. Biophysics of Macromolecules. *9 units (3-0-6); second, third terms. Prerequisite: Ch 21 ab or Ch 24 a or equivalent.* Biophysical chemistry of nucleic acids, including helix-random coil equilibria; reassociation kinetics; polymer statistics and conformations; sedimentation; gel electrophoresis; and other methods of separating nucleic acids. Bi/Ch 132 b is taught jointly with Ch 24 b. Not offered in 1986–87.

Bi 135. Optical Methods in Biology. *6 units (2-0-4); first term. Prerequisite: Ph 1 or instructor's permission.* Principles and practice of the operation of various types of light and electron microscopes, including phase contrast and interference microscopes as well as transmission electron microscopes and scanning electron microscopes of various types. Specimen preparation will be discussed and the interpretation of electron micrographs analyzed. Students interested in learning to use the electron microscope are also encouraged to undertake laboratory projects under Bi 22. Given in alternate years; not offered in 1986–87. Instructor: Revel.

Bi 137. Multicellular Assemblies. *9 units (3-0-6); third term. Prerequisite: Bi 9 or consent of instructor.* Aspects of the cellular interactions involved in the formation and maintenance of the hierarchy of tissues and organs in multicellular organisms. Topics covered will include cell membranes, cell movements and aggregation, cellular adhesion, intercellular communication, the organization of epithelial and connective tissues, and the histophysiology of a few typical organs. Given in alternate years; offered in 1986–87. Instructor: Revel.

Bi 150. Neurobiology. *10 units (4-0-6); first term.* Lectures and discussions on general principles of the organization and function of nervous systems, providing both an overview of the subject and a foundation for advanced courses. Topics include neurocytology and gross neuroanatomy; developmental neurobiology; the biophysical basis for action potentials, synaptic transmission, and sensory transduction; and the integration of these processes in sensory and motor pathways of the central nervous system. Laboratory demonstrations offer experience with the experimental preparations discussed in the course. Instructors: Van Essen, Tanouye.

Bi/Ph 151. Topics in Nervous System Biophysics. *6 units (2-0-4); third term. Prerequisite: Bi/Ph 50 or Bi 150.* A reading and discussion course. Topics will include membrane biophysics, neural modeling, theories of higher brain function, and methods for studying whole brain activity. Graded pass/fail. (Will not be offered in 1987–88.) Instructor: Pine.

Bi 152. Behavioral Biology. *6 units (2-0-4); second term.* Introduction to ethology and behavioral genetics. Topics include causation, development, evolution, and genetic analysis of animal behavior, with examples from both invertebrates and vertebrates. Instructors: Konishi and Benzer.

Bi 154. Topics in Experimental Psychology. *6 units (2-0-4); second term.* Lectures and discussions on sensory perception (visual and auditory), memory, and higher brain function in humans. Lectures will include displays and demonstrations of major perceptual phenomena. Graded pass/fail. Instructor: Julesz.

Bi 156 Neurochemistry. *9 units (3-0-6); third term. Prerequisite: Bi 150 or instructor's permission.* A lecture and discussion course covering the chemistry of neurotransmission at synapses, the molecular properties of neurons and glia, and the cellular interactions involved in the development of the nervous system. Neurochemical aspects of learning and mental illness will also be considered. Given in alternate years; not offered in 1986–87. Instructor: Patterson.

Bi 157. Comparative Nervous Systems. *9 units (2-3-4); third term.* An introduction to the comparative study of the gross and microscopic structure of nervous systems. Emphasis on the vertebrate nervous system; also the highly developed central nervous systems found in arthropods and cephalopods. Variation in nervous system structure with function and with behavioral and ecological specializations and the evolution of the vertebrate brain. Given in alternate years; offered in 1986–87. Instructor: Allman.

Bi 158. Primatology. *9 units (3-1-5); third term.* Evolutionary and behavioral biology of primates. Topics will include fossil primates, comparative anatomy, physiology and ethology of primates, and tool invention and symbolic communication in primates. Given in alternate years; not offered in 1986–87. Instructor: Allman.

Bi 161. Cellular Neurobiology Laboratory. *6 units (0-4-2); second term. Prerequisite: Bi 150 or Bi/Ph 50, or instructor's permission.* The principles of cellular neurobiology and membrane biophysics are illustrated using favorable preparations, such as the frog nerve-muscle synapse and cultured nerve and muscle tissue. Students conduct all aspects of the experiments, including dissection, fabrication of microelectrodes, intracellular stimulation and recording, and patch recording of single membrane channels. Graded pass/fail. Given in alternate years; offered in 1986–87. Instructor: Lester.

Bi 162. Central Nervous System Laboratory. *6 units (0-4-2); second term. Prerequisite: Bi 150 or Bi/Ph 50, or instructor's permission.* Physiological properties of individual neurons and multi-neural circuits will be explored in the mammalian cerebral and cerebellar cortices. Both *in vitro* and *in vivo* experimental techniques will be used. Students will be instructed in all aspects of the experimental procedures, including surgery, microelectrode fabrication, intra- and extra-cellular neural recording, and computer-based data analysis. Graded pass/fail. Given in alternate years; not offered in 1986–87. Instructor: Bower.

Bi 180. Methods in Molecular Genetics. *12 units (2-8-2); first term. Prerequisites: Bi 122 and instructor's permission.* An introduction to the current research tools of molecular genetics. Students will perform a series of structured experiments to familiarize them with basic genetic approaches, including mutant selection, genetic mapping, gene cloning and gene product analysis. The students will then confront an unresolved research problem in biology that they will address by both designing and executing their own experiments. Graded pass/fail. Instructors: Emr, Simon.

Bi/CS/Ph 185. Collective Computation. *9 units (2-4-3).* For course description, see Computer Science.

Bi/Ch 202 abc. Biochemistry Seminar. *1 unit; all terms.* A seminar on selected topics and on recent advances in the field. Instructors: Parker, Abelson, staff.

Bi 204. Genetics Seminar. *2 units; all terms.* Reports and discussion on special topics. Instructors: Meyerowitz, Emr, Simon.

Bi 211. Topics in Membrane and Synaptic Physiology. *6 units (3-0-3); first term.* Graduate seminar discussing the original literature on the biophysics and biochemistry of processes mediated by the neuronal cell membrane. Particular emphasis on current aspects of synaptic transmission. Given in alternate years; not offered in 1986–87. Instructor: Lester.

Bi 212. Topics in Ethology and Behavioral Genetics. *6 units (2-0-4); second term.* Reading and discussions of original papers related to animal behavior and its analysis by ethological and genetic methods. Given in alternate years; not offered in 1986–87. Instructors: Benzer and Konishi.

Bi 217. Central Mechanisms in Perception. *6 units (2-0-4); first term.* Reading and discussions of behavioral and electrophysiological studies of the systems for the processing of sensory information in the brain. Given in alternate years; offered in 1986–87. Instructor: Allman.

Bi 218. The Physiological Basis of Behavior. *6 units (2-0-4); third term.* Reading and discussions of original papers dealing with the problem of how nerve cells act to generate behavior. Several simple reflex, rhythmic, and learning behaviors are considered. The individual cellular elements and synaptic interactions responsible for generating each behavior are examined in detail. Other topics include the modulation of motor output by sensory input and experience. Given in alternate years; not offered in 1986–87. Instructor: Tanouye.

Bi 219. Developmental Neurobiology. *9 units (2-0-7); third term.* Advanced discussion course involving extensive reading of current papers and student presentations. Topics: the proliferation, migration, differentiation, and death of neurons, as well as the role of trophic factors, cell surface molecules, and hormones. Emphasis on the generation of specific synaptic connections and the molecular basis underlying it. Given in alternate years; offered in 1986–87. Instructor: Patterson.

Bi 220. Advanced Seminar in the Molecular Biology of Development. *6 units (2-0-4); second term.* Discussion of current papers on various pertinent topics including nucleic acid renaturation and hybridization studies; transcription level regulation of gene function; evolutionary change in developmental processes; molecular aspects of differentiation in certain more intensively studied systems, etc. Given in alternate years; offered in 1986–87. Instructor: E. Davidson.

Bi 222. Biochemistry of the Nervous System. *6 units (2-0-4); second term. Prerequisites: Bi/Ch 110 and Bi 150 or equivalent, or consent of instructor.* Reading and discussion illustrating recent applications of biochemical techniques to the study of the nervous system. Topics will include the characterization and function of peptide neurotransmitters, structural studies of neurotransmitter receptors, the biochemistry of ion channels, and structural and functional studies of synapses. The course will emphasize reading and evaluation of current research papers. Given in alternate years; offered in 1986–87. Instructor: Kennedy.

Bi 225. Topics in Cellular and Molecular Genetics. *6 units (2-0-4); second term.* Reading and discussion of current papers on the theory and practice of "genetic intervention" in higher eukaryotic cells. Approaches will include DNA and chromosome-mediated transformation of cells in culture, gene amplification, cell fusion, gene injection into eggs, and use of somatic cell genetics techniques for gene cloning. Emphasis on the use of these approaches to study problems in areas such as cell differentiation, cell cycle control, cell compartmentation, membrane physiology and assembly. Given in alternate years; not offered in 1986–87. Instructor: Attardi.

Bi 241. Advanced Topics in Molecular Biology. *6 units (2-0-4); third term. Prerequisite: instructor's permission.* Reading and discussion of new areas in molecular biology. Instructor: Dreyer.

Bi 270. Special Topics in Biology. *Units to be arranged; first, second, third terms.* Students may register with permission of the responsible faculty member.

Bi 299. Graduate Research. *Units to be arranged; first, second, and third terms.* Students may register for research units after consultation with their adviser.

BUSINESS ECONOMICS AND MANAGEMENT

BEM 100 ab. Business Economics and Management. *9 units (3-0-6); first, second terms. Open to graduate students.* This course endeavors to bridge the gap between engineering and business. The principal divisions are: 1) managerial accounting and information flows; 2) business finance; 3) quantitative technique and business decisions; 4) economic applications to business; and 5) systems analysis. Instructors: Staff, visiting lecturers.

BEM 102. Topics in Management Science. *9 units (3-0-6). Prerequisite: Ec/SS 11.* Various management and industrial organization topics, including queuing, inventory and reliability theory, optimal stopping with applications to job search and R&D. The underlying theory of simple stochastic processes will be developed as needed. Not offered in 1986–87. Instructor: Staff.

CAMPUS COMPUTING ORGANIZATION

CCO 1 abc: Computing Fundamentals. *6 units (2-0-4); first, second, third terms.* An introductory course covering the basics of computers and their use, designed for students who have no computing experience. Lectures cover the basic principles of computer hardware, operating systems and the representation and storage of information in the computer. Each term will teach the use of a single language using well documented examples; students will be expected to write several programs. CCO 1 a will cover PASCAL; CCO 1 b will cover C; and CCO 1 c will cover FORTRAN. Only one term can be taken for credit. With permission of the instructor, students may audit additional terms to broaden language experience. Instructor: C. Ray, staff.

CHEMICAL ENGINEERING

ChE 10. Introduction to Chemical Engineering Systems. *9 units (3-3-3); third term.* Basic concepts in transport phenomena and chemical kinetics are discussed with respect to a variety of problems of current interest to society. Instructor: Shair.

ChE 63 abc. Chemical Engineering Thermodynamics. *9 units (3-0-6); first, second, third terms.* Basic thermodynamic laws and relations for one-component closed systems and for simple steady-flow systems; the treatment includes imperfect substances and frictional processes. In the third quarter, chemical reaction equilibria and phase equilibria with practical applications. Instructor: Gavalas.

ChE 80. Undergraduate Research. *Units by arrangement.* Research in chemical engineering offered as an elective in any term. If ChE 80 units are to be used to fulfill elective requirements in the chemical engineering option, a thesis approved by the research director must be submitted in duplicate before May 10 of the year of graduation. The thesis must contain a statement of the problem, appropriate background material, a description of the research work, a discussion of the results, conclusions, and an abstract. The thesis need describe only the significant portion of the research. Graded pass/fail.

ChE 81. Special Topics in Chemical Engineering. *Units by arrangement. Prerequisite: instructor's permission.* Occasional advanced work involving reading assignments and a report of special topics. No more than 12 units in ChE 81 may be used to fulfill elective requirements in the chemical engineering option. Graded pass/fail.

ChE 90. Chemical Engineering Systems. *9 units (3-3-3); third term. (Not open to freshmen.)* Same as ChE 10 but with projects selected to suit the needs and interests of upperclass students. Instructor: Shair.

ChE 101. Chemical Kinetics and Reactor Design. *9 units (3-0-6); third term. Prerequisites: Ch 21 ab, ChE 103 ab.* Chemical kinetics. Ideal chemical reactors. Temperature effects in chemical reactors. Residence time distribution theory. Noncatalytic fluid-solid reactions. Fluid-fluid heterogeneous reactions. Heterogeneous reactors, with emphasis on simultaneous transport and chemical reaction. The packed bed reactor. Instructors: Staff.

ChE 103 abc. Transport Phenomena. *9 units (3-0-6); first, second, third terms. Prerequisites: AMa 95 or AM 113 ab, or concurrent registration in either.* A rigorous development of the basic differential equations of conservation of momentum, energy, and mass in fluid systems. Solution of problems involving fluid flow, heat transfer, and convective diffusion. Instructors: Brady (a, c), Shair (b).

ChE 104. Separation Processes. *9 units (3-0-6); first term. Prerequisites: ChE 63 abc, ChE 103 abc, or equivalent.* Application of the principles of mass transfer rates and phase equilibrium to the analysis of staged and continuous separation processes. Topics include absorption, extraction, binary and multicomponent distillation, adsorption, and ion exchange. Instructor: Shair.

ChE 105. Process Control. *9 units (3-0-6); second term. Prerequisite: AMa 95 abc or AM 113 abc, or concurrent registration in either.* Feedback control of linear systems. Frequency response. Sampled-data systems. Introduction to multivariable control. Instructor: Bailey.

ChE 110 ab. Optimal Design of Chemical Systems. *12 units (3-0-9); second, third terms. Prerequisites: ChE 63, ChE 101, ChE 103 and ChE 104, or equivalents.* Introduction to process design. Flowsheets for chemical processes. Synthesis of multicomponent separation sequences and reaction paths. Synthesis of heat exchange networks. Optimization. Process economics. Simulation of chemical processes. Design of a major process. Instructors: Seinfeld (a), Prater (b).

ChE 126 ab. Chemical Engineering Laboratory. *9 units (1-6-2); second, third terms.* Projects illustrative of problems in transport phenomena, unit operations, chemical kinetics, process control, and reactor design are performed. Instructor: Morari.

Ch/ChE 140. Special Topics in Chemistry and Chemical Engineering. Growth, Processing and Characterization of Semiconductors and Semiconductor Interfaces. *6 units (2-0-4).* For course description, see Chemistry.

ChE/Env 157 abc. Fundamentals of Air Pollution Engineering. *9 units (3-0-6); first, second, third terms. Open to graduate students and seniors with instructor's permission.* Principles necessary to understanding the sources, atmospheric behavior, and control of air pollutants. Air quality and emission standards, air pollution sources, generation of pollutants in combustion systems. Fundamentals of particulate air pollutants, aerosol physics and chemistry, gas-to-particle conversion processes, control techniques for particulate pollutants, pollutant effects on visibility. Atmospheric chemistry, atmospheric diffusion, control techniques for gaseous pollutants. Instructors: Cass, Flagan, Seinfeld. Only two terms will be offered in 1986–87.

ChE 161. Advanced Chemical Kinetics and Reactor Design. *9 units (3-0-6); first term. Prerequisites: ChE 101 or equivalent.* Theories of reaction rates. Heterogeneous catalysis, including physical structure and characterization of catalysts. Catalyst poisoning. Combustion. Fluidized bed reactors. Statistical estimation of kinetic parameters. Stability of chemical reactors. Instructor: Bailey.

ChE 162. Catalysis and Surface Chemistry. *9 units (3-0-6); third term. Prerequisite: Ch 21 abc or the equivalent.* Thermodynamics of two-dimensional systems. Physical adsorption and the BET theory. Chemical adsorption and the Langmuir isotherm. Localized and nonlocalized adsorption. General theories of heterogeneous catalysis by metals, semiconductors and insulators. Instructor: Weinberg.

ChE 163. Fundamentals of Biochemical Engineering. *9 units (3-0-6); second term. Prerequisites: ChE 101 or instructor's permission.* A first course in microbial and enzyme processes, natural or artificial, with applications to industrial fermentations, enzyme utilization, and wastewater treatment. Topics: Rudiments of microbiology; isolation and utilization of enzymes; kinetics of enzyme catalyzed reactions; substrate utilization and kinetics of microbial growth; microbial interactions of mixed cultures; transport phenomena in microbial systems; design and analysis of biological reactors; applications in industrial operations and natural systems. Instructor: Bailey.

ChE/Ch 164. Introduction to Statistical Thermodynamics. *9 units (3-0-6); second term. Prerequisite: Ch 21 abc or the equivalent.* Ensembles and a statistical mechanical formulation of the second and third laws of thermodynamics. Classical statistical mechanics and an introduction to quantum statistics. The ideal monatomic, diatomic and polyatomic gas. Translational, rotational, vibrational and electronic partition functions. Chemical equilibria. Real gases and distribution functions. The ideal crystal lattice. Instructor: Marcus.

ChE 165. Applied Chemical Thermodynamics. *9 units (3-0-6); first term. Prerequisite: ChE 63 abc or equivalent.* Thermodynamic states and the First Law. Entropy and the Second Law. Thermodynamic functions and generalized stability criteria for equilibrium. Phase and chemical equilibria. Instructor: Weinberg.

ChE 166 ab. Engineering Properties of Polymeric Materials. *9 units (3-0-6); first, second terms. Prerequisite: AMa 95 or equivalent.* Basic engineering properties of polymeric materials for the materials scientist and the chemical, mechanical, aeronautical, electrical, and civil engineer. Not offered in 1986–87.

ChE 167. Advanced Polymer Science. *9 units (3-0-6); second term. Prerequisite: ChE 166 ab or equivalent.* A course in the science of synthetic macromolecules: their characterization and properties. The emphasis is on an understanding of polymer properties in terms of molecular structure. Not offered in 1986–87.

ChE 168. Polymer Science Laboratory. *9 units (0-7-2); third term. Prerequisite: ChE 166 ab or equivalent.* An introduction to some of the basic techniques employed in the synthesis and characterization of synthetic polymers. Not offered in 1986–87.

ChE 169. Theoretical Thermodynamics. *9 units (3-0-6); third term. Prerequisite: ChE 63 ab or equivalent.* A postulatory exposition of the structure of equilibrium and steady-state (irreversible) thermodynamics. Not offered in 1986–87.

EE/ChE 170 abc. Introduction to Systems and Control. *9 units (3-0-6).* For course description, see Electrical Engineering.

EE/ChE 171 ab. Advanced Topics in Systems and Control. *9 units (3-0-6).* For course description, see Electrical Engineering.

ChE 173 ab. Advanced Transport Phenomena. *9 units (3-0-6); first, second terms. Prerequisite: AM 113 or AMa 95, or concurrent registration in either, or instructor's permission.* Foundations of heat, mass, and momentum transfer. Governing differential equations; unidirectional flows; laminar flow of incompressible fluids at high and low Reynolds number; bubbles, drops and other small particles; forced and free convection heat and mass transfer. Selected topics from: transport processes in suspensions, packed beds or porous media, and mixing processes, such as Taylor diffusion. Instructor: Leal.

ChE 174. Special Topics in Transport Phenomena. *9 units (3-0-6); third term. Prerequisite: AM 113 or AMa 95, or concurrent registration in either, or instructor's permission.* Advanced problems in heat, mass and momentum transfer. Introduction to the mechanics of non-Newtonian liquids; selected topics in hydrodynamic stability theory; and transport processes in turbulent flows. Other topics may be discussed, depending upon the needs and interests of the class. Instructor: Leal.

ChE 280. Chemical Engineering Research. *Offered to Ph.D. candidates in Chemical Engineering.* Main lines of research now in progress are covered in detail in Section 2.

CHEMISTRY

Ch 1 abc. General Chemistry. *6 units (3-0-3); first, second, third terms.* Lectures and recitations dealing with the principles of chemistry. First term: stoichiometry, states of matter; chemical equilibrium and factors influencing a system at equilibrium; the elements of chemical thermodynamics; relations between molecular properties and properties of matter in bulk; rates of reactions and reaction mechanisms. Second term: concepts of electronic structure, chemical bonding and intermolecular forces; modern theories relating to the electronic structure of atoms and chemical bonding in molecules, solids and surfaces. Third term: carbon chemistry, stereochemistry; chemical reactivity of organic and inorganic chemical systems; physical methods for the identification and characterization of molecules. Graded pass/fail. Instructors: Chan, Bercaw, Gray.

Ch 2 ab. Advanced Placement in Chemistry. *9 units (3-0-6); first, second terms. Prerequisite: instructor's permission.* The structure of molecules with an introduction to the structure of condensed phases. Algebraic methods are used to quantify the symmetry of molecular geometrical, vibrational, and electronic structure. Both quantum mechanical and modern experimental techniques of structural determination will be covered. Graded pass/fail. Instructors: Zewail, Richards.

Ch 3 a. Fundamental Techniques of Experimental Chemistry. *6 units (0-6-0); first, second, third terms.* Introduces the basic principle and techniques of synthesis and analysis and develops the laboratory skills and precision that are fundamental to experimental chemistry. Enrollment first term will be limited to students who have gained advanced placement into Ch 41, Ch 2, or Ch 21, or by permission of the instructor. Instructors: Bercaw and staff.

Ch 3 b. Experimental Procedures of Synthetic Chemistry. *8 units (1-6-1); third term. Prerequisites: Ch 1 a, Ch 1 b and Ch 3 a.* Provides instruction in fundamental synthesis, separation and characterization procedures used in chemical research. Graded pass/fail. Instructors: Bercaw and staff.

Ch 4 ab. Synthesis and Analysis of Organic and Inorganic Compounds. *9 units (1-6-2); Prerequisite: Ch 1 abc (or the equivalent) and Ch 3 a.* Previous or concurrent enrollment in Ch 41 is strongly recommended. Introduction to methods of synthesis, separation, purification, and characterization used routinely in chemical research laboratories. Ch 4 a: emphasis on spectroscopic methods of analysis. Ch 4 b: stress on applications of chromatography in addition to more classical separation techniques. Ch 4 a, first and second terms; Ch 4 b, third term only. Instructors: Bercaw and staff.

Ch 5 ab. Advanced Techniques of Synthesis and Analysis. *9 units (1-6-2); first, second terms. Prerequisite: Ch 4 ab.* Modern synthetic chemistry. Specific experiments may change from year to year. Multistep syntheses of natural products, coordination complexes, and organometallic complexes will be included. Experiments to illustrate the fundamental principles of inorganic and organometallic chemistry. Methodology will include advanced techniques of synthesis and instrumental characterization. Instructors: Collins, Myers.

Ch 6 ab. Application of Physical Methods to Chemical Problems. *10 units (0-6-4); second, third terms. Prerequisites: Ch 1abc, Ch 4 ab, and Ch 21 or equivalents (may be taken concurrently).* Introduction to the application of modern physical methods to chemical problems, with emphasis in the area of molecular spectroscopy. Techniques including laser Raman spectroscopy, ultraviolet photoelectron spectroscopy, and ion cyclotron resonance spectroscopy are used to examine the structure, properties, and reaction dynamics of molecules in the gas phase, in solution, and at surfaces. Instructor: Beauchamp.

Ch 10. Computing for Chemists. *5 units (2-0-3); second term.* An introduction to use of computers in scientific calculations, commonly available computers and operating systems, use of prepared programs, editors, elements of programming in BASIC, FORTRAN, Pascal and C, modems and intercomputer communications, and simple graphics programming. Not offered in 1986–87. Instructor: Roberts.

Ch 14. Chemical Equilibrium and Analysis. *6 units (2-0-4); first term.* A systematic treatment of ionic equilibria in solution. Topics covered include acid-base equilibria in aqueous and nonaqueous solutions, complex ion formation, chelation, oxidation-reduction reactions, and some aspects of reaction mechanisms. Instructor: Richards.

Ch 15. Chemical Equilibrium and Analysis Laboratory. *10 units (0-6-4); first term. Prerequisites: Ch 1 abc, Ch 3 a, Ch 14 (may be taken concurrently).* Laboratory experiments are used to illustrate modern instrumental techniques that are currently employed in industrial and academic research. Emphasis on determinations of chemical composition, measurement of equilibrium constants, and trace-metal analysis. Instructors: Anson, Schaefer, Raftery.

Ch 21 abc. The Physical Description of Chemical Systems. *9 units (3-0-6); first, second, third terms. Prerequisites: Ch 1 abc, Ph 2 abc, Ma 2 abc.* Atomic and molecular quantum mechanics, spectroscopy, thermodynamics, statistical mechanics, and chemical kinetics. Instructors: McKoy, Weitekamp, Baldeschwieler.

Ch 24 ab. Introduction to Biophysical Chemistry. *9 units (3-0-6); second, third terms. Prerequisites: Ma 1 abc, Ph 1 abc, Ch 21 a or Ph 2 abc.* Fundamental physical chemistry, with an emphasis on those topics most important in biology. Thermodynamics and its applications to aqueous solutions and living systems, membrane potentials and the thermodynamics of transport, reaction kinetics and mechanisms, transport properties, applications of molecular spectroscopy in biology, and statistical mechanics with applications to biological polymers. Ch 24 b is taught jointly with Bi/Ch 132 b. Not offered in 1986–87.

Ch 41 abc. Chemistry of Covalent Compounds. *9 units (3-0-6); first, second, third terms. Prerequisite: Ch 1 abc or instructor's permission.* The synthesis, structure, and mechanisms of reactions of covalent compounds. Emphasis will be on the study of molecules formed from carbon and other first- and second-row elements. Instructors: Grubbs, Dougherty, Dervan.

Ch 80. Chemical Research. *Offered to B.S. candidates in chemistry. Prerequisite: consent of research supervisor.* Experimental and theoretical research experiment requiring a report containing an appropriate description of the research work. Graded pass/fail.

Ch 81. Independent Reading in Chemistry. *Units by arrangement. Prerequisite: instructor's permission.* Occasional advanced work involving reading assignments and a report on special topics. No more than 12 units in Ch 81 may be used as electives in the chemistry option. Graded pass/fail.

Ch 90. Oral Presentation. *2 units (1-0-1); second term.* Training in the techniques of oral presentation of chemical topics. Practice in the effective organization and delivery of reports before groups. Open only to students with junior standing or higher. Graded pass/fail. Instructor: Zewail.

Ch 91. Scientific Writing. *3 units (1-0-2); third term.* Practical training in the writing of technical reports, reviews, and research papers on chemical topics. Open to undergraduates only. Graded pass/fail. Instructor: Schaefer.

Bi/Ch 110 abc. Biochemistry. *12 units (4-0-8).* For course description, see Biology.

Ch 112. Inorganic Chemistry. *9 units (3-0-6); first term. Prerequisite: Ch 41 abc or equivalent.* Introduction to group theory, ligand field theory, and bonding in coordination complexes and organotransition metal compounds. Systematics of synthesis, bonding, and reactivities of commonly encountered classes of transition metal compounds. Instructor: Collins.

Ch 117. Introduction to Electrochemistry. *6 units (2-0-4); third term.* A discussion of the structure of the electrode-electrolyte interface, the mechanism by which charge is transferred across it, and of the experimental techniques used to study electrode reactions. The topics covered change from year to year but usually include diffusion currents, polarography, coulometry, irreversible electrode reactions, the electrical double layer, and the kinetics of electrode processes. Instructors: Staff.

Ch 118 ab. Experimental Electrochemistry. *Units by arrangement; third term.* Laboratory practice in the use of selected electrochemical instruments and techniques. The student may pursue a set of expository experiments or elect to carry out a research project in electrochemistry. Instructors: Staff.

Ch 120 abc. Nature of the Chemical Bond. *Part a, 9 units (3-0-6) first term; part b, 6 units (2-0-4) second term; part c, 6 units (1-1-4) third term. Prerequisite: Ch 21 a or an equivalent introduction to quantum mechanics.* Modern ideas of chemical bonding, with emphasis on qualitative concepts and how they are used to make predictions of geometries, energies, excited states, and rules for chemical reactions. Applications will emphasize molecules involving both main-group and transition metals and will include some discussion of impurity states in solids, and the bonding and reactions at surfaces of solids. Part c is a lab in which the student uses modern computer programs to calculate wavefunctions and properties of molecules. Part b is not a prerequisite for part c. Instructor: Goddard.

Ch 122 ab. Methods for the Determination of the Structure of Molecules. *9 units (3-0-6); first, second terms. Prerequisite: Ch 21 abc or instructor's permission.* Modern methods used in the determination of the structure of molecules, including x-ray, electron, and neutron diffraction; mass spectrometry; optical, infrared, Raman, microwave, Mössbauer, nuclear magnetic, and electron spin resonance spectroscopy. The emphasis will be on diffraction methods (first term) and nuclear magnetic resonance (second term). Instructors: Marsh, Baldeschwieler.

Ch 125 abc. The Elements of Quantum Chemistry. *9 units (3-0-6); first, second, third terms. Prerequisite: Ch 21 abc or an equivalent brief introduction to quantum mechanics.* A first course in molecular quantum mechanics consisting of a quantitative treatment of quantum mechanics with applications to systems of interest to chemists. The basic elements of quantum mechanics, the electronic structure of atoms and molecules, the interactions of radiation fields and matter, scattering theory, and reaction rate theory. Instructors: Kuppermann, McKoy.

Ch 127. Nuclear Chemistry. *9 units (3-0-6); first term. Prerequisite: Consent of instructor.* A survey course in the properties of nuclei and in atomic phenomena associated with nuclear particle detection. Topics include rates of production and decay of radioactive nuclei; interaction of radiation with matter; nuclear masses, shapes, spins and moments; modes of radioactive decay; nuclear fission and energy generation. Offered in 1987–88 and alternate years. Instructor: Burnett.

Ch 130. Spectroscopy. *9 units (3-0-6); second term.* Discussion of various topics in modern spectroscopy. Group theory with applications to molecular structure and spectroscopy. Not offered in 1986–87. Instructors: Marcus, Zewail.

Ch 131. The Chemistry of Amino Acids, Peptides, and Proteins. *9 units (3-0-6); third term. Prerequisite: Ch 41 abc.* A discussion of the chemical reactions, structures, and functions of amino acids, peptides, and proteins. Given in alternate years; not offered in 1986–87.

Bi/Ch 132 ab. Biophysics of Macromolecules. *9 units (3-0-6).* For course description, see Biology. Not offered in 1986–87.

Ch 135. Chemical Dynamics. *9 units (3-0-6); third term. Prerequisites: Ch 21 abc and Ch 41 abc or equivalent, or with consent of instructor.* Detailed considerations of the cross sections, rates, energetics, and mechanisms of chemical reactions. Emphasis is on theoretical models used to interpret gas-phase reactions studied with molecular beam and laser techniques. Not offered in 1986–87. Instructor: Beauchamp.

Ch/ChE 140. Special Topics in Chemistry and Chemical Engineering. Growth, Processing and Characterization of Semiconductors and Semiconductor Interfaces. *6 units (2-0-4); third term.* The growth of different classes of semiconductors, including Group IV elements and both III-V and II-VI compound semiconductors. Emphasis will be on current techniques, such as Molecular Beam Epitaxy, Chemical Vapor Deposition, Metal-Organic Chemical Vapor Deposition, Liquid Phase Epitaxy and Vapor Phase Epitaxy and how they can be used to grow multilayer structures. Electrical, physical and chemical characterization of materials grown via these processes will be examined, with emphasis on surface sensitive techniques. Factors influencing semiconductor interface properties will be explored in detail. Other topics include laser-assisted processes, metallization, and etching techniques. Instructor: P. M. George.

Ch 142. Frontiers in Chemical Biology. *4 units (2-0-2); second term. Prerequisite: Bi/Ch 110 abc or instructor's permission.* A discussion of enzyme structure and function, and ligand-protein-nucleic acid interactions. Not offered in 1986–87. Instructors: Parker, Raftery.

Ch 144 abc. Advanced Organic Chemistry. *9 units (3-0-6); first, second, third terms. Prerequisite: Ch 41 abc or equivalent.* An advanced survey of modern organic chemistry. First term: structural and theoretical organic chemistry; kinetic, thermochemical, and orbital symmetry concepts; second term: organic reaction chemistry emphasizing modern studies of reactive intermediates; third term: organic polymeric substances: structure, properties, synthesis and uses. Ch 144 bc not offered in 1986–87. Instructor: Dougherty.

Ch 146. Bio-Organic Chemistry. *6 units (2-0-4); second term. Prerequisite: Ch 41 abc or equivalent.* Lectures will cover the application of the principles and the tools of organic chemistry to the understanding of biological processes. Instructor: Dervan.

Ch 147 ab. Polymer Chemistry. *9 units (3-0-6); second, third term. Prerequisites: Ch 41 abc or equivalent.* An introduction to polymers and polymer composites, with emphasis in Ch 147 a on how the molecular structures and stereochemistry of polymers can be related to physical properties such as thermal stability, elasticity, brittleness, ease of fabrication, etc., which are important in practical applications; use of NMR to determine the regularity of polymer structures. In Ch 147 b, synthetic methods, especially the catalytic procedures of polyolefin and copolymer preparation, will be emphasized. Applications of such systems in the preparation of materials for optical and electrical devices will be discussed. Instructors: Roberts, Grubbs.

Ch 154. Organometallic Chemistry. *9 units (3-0-6); second term. Prerequisite: Ch 112 or equivalent.* A general discussion of the reaction mechanisms, synthetic and catalytic uses of transition metal organometallic compounds. Instructors: Bercaw, Grubbs.

Ch 155. Oxidation Chemistry. *9 units (3-0-6); third term. Prerequisite: Ch 112 or equivalent.* A general treatment of the principles of homogeneous oxidation chemistry, fundamental classes of oxidizing agents and oxidation reactions, mechanisms of oxidation reactions, metal-catalyzed oxidation reactions, especially those involving molecular oxygen and its peroxy derivatives, biochemical enzymatic oxidations, structure and reactivity of metal-oxo compounds, ozone and singlet oxygen. Not offered in 1986–87. Instructor: Collins.

ChE/Ch 164. Introduction to Statistical Thermodynamics. *9 units (3-0-6).* For course description, see Chemical Engineering.

Ch 165. Nonequilibrium Statistical Mechanics. *9 units (3-0-6); third term. Prerequisite: Ch 164 or equivalent.* Transport processes in dilute gases. Boltzmann equation. Theory of Brownian Motion. Langevin and Fokker-Planck equations. Time-correlation functions and applications. Instructor: Marcus.

Ch 180. Chemical Research. *Units by arrangement. Offered to M.S. candidates in chemistry.* Graded pass/fail.

Bi/Ch 202 abc. Biochemistry Seminar. *1 unit.* For course description, see Biology.

Ch 212. Advanced Inorganic Chemistry. *9 units (2-0-7); third term. Prerequisites: Ch 112 and Ch 21 abc or concurrent registration.* A series of topics in modern inorganic chemistry. Instructor: Gray.

Ch 213 abc. Advanced Ligand Field Theory. *12 units (1-0-11); first, second, third terms. Prerequisite: Ch 21 abc or concurrent registration.* A tutorial course of problem solving in the more advanced aspects of ligand field theory. Recommended only for students interested in detailed theoretical work in the inorganic field. Instructors: Gray and staff.

Ch 224. Advanced Topics in Magnetic Resonance. *9 units (2-0-7); third term. Prerequisites: Ch 125 abc or Ph 125 abc or concurrent registration or equivalent, Ch 122 b or equivalent.* A detailed presentation of some of the important concepts in magnetic resonance unified by the spin density operator formalism. Topics will include both classic phenomena and recent developments, especially in solid-state and two-dimensional NMR. Instructor: Weitekamp.

Ch 227 ab. Advanced Topics in Chemical Physics. *9 units (3-0-6); second, third terms. Prerequisite: Ch 125 abc or Ph 125 abc or equivalent.* The general quantum mechanical theory of molecular collisions will be presented in detail. Quasi-classical, semi-classical, and other approximations. Applications to inelastic and reactive molecule-molecule and inelastic electron-molecule collisions. Not offered in 1986–87. Instructor: Kuppermann.

Ch 229 abc. Experimental Basics of X-Ray Diffraction. *6 units (2-0-4); first, second, third terms.* First term: production, collimation, and monochromatization of x-rays, including total reflection, refraction, and polarization; second term: detection, energy analysis and intensity measurements of x-rays, including theory and practice of diverse counting techniques; third term: basics of x-ray instrumentation, including metrology of complex multi-axis systems and the pertinent principles of heat-transfer as applied to very accurate cryogenic x-ray analysis of single crystals. Not offered in 1986–87. Instructor: Samson.

Ch 241 a. Topics in Advanced Organic Chemistry. *6 units (2-0-4); second term. Prerequisite: Ch 144 ab.* Topics of current interest in advanced organic chemistry will be presented in depth, in four- to six-week intervals. Areas covered: physical organic chemistry, synthetic methodology and design, organometallic and bio-organic chemistry. Not offered in 1986–87.

Ch 242 a. Chemical Synthesis. *4 units (2-0-2); second term. Prerequisite: Ch 41 abc.* The concepts of synthetic planning will be developed through the analysis of recorded syntheses. The methodology of the organization of a complex set of reactions so as to accomplish a chosen goal will be examined with the aid of examples of bio-organic, organic, and organometallic interest. Not offered in 1986–87.

Ch 244 a. Topics in Chemical Biology. *6 units (3-0-3); first term.* A discussion of biological membrane biogenesis, structure, and function. Topics range from membrane-bound enzymes to receptors for neurotransmitters, hormones, light, proteins or peptides and will include current work on models of simple behavior. Not offered in 1986–87. Instructor: Raftery.

Ch 247 a. Organic Reaction Mechanisms. *6 units (2-0-4); third term.* A mechanistic view of free radical reactions, using examples from biological systems will be developed. Topics: initiation, termination, and propagation of radical reactions *in vivo*, mechanisms of lipid damage, spin labeling, photosynthesis, oxygen radicals and oxygen toxicity, and radical reactions in proteins and nucleic acids. Not offered in 1986–87.

Ch 280. Chemical Research. *Hours and units by arrangement.* By arrangement with members of the faculty, properly qualified graduate students are directed in research in chemistry.

CIVIL ENGINEERING

CE 10 abc. Structural Analysis and Design. *9 units (3-0-6); first, second, third terms. Prerequisite: AM 97 abc.* Study and design of selected structures such as a reinforced concrete building, arch bridge, gravity dam, or engineering facility. Each project considers initial conception, cost-benefit, and optimum design, and concludes with actual design of a structure or portion of a structure. Instructor: Staff.

CE 17. Civil Engineering. *9 units (3-0-6); third term. Prerequisite: senior standing.* Selected comprehensive problems of civil engineering systems involving a wide variety of interrelated factors. Instructors: Staff.

CE 105. Introduction to Soil Mechanics. *9 units (2-3-4); first term. Prerequisite: AM 97.* A general introduction to the physical and engineering properties of soil, including origin, classification and identification methods, permeability, seepage, consolidation, settlement, slope stability, lateral pressures and bearing capacity of footings. Standard laboratory soil tests will be performed. Instructor: Scott.

CE 115 ab. Soil Mechanics. *9 units (3-0-6); first term. 9 units (2-3-4); second term. Prerequisite: CE 105 or equivalent; may be taken concurrently.* Study of the engineering behavior of soil through the examination of its chemical, physical, and mechanical properties. Classification and identification of soils, surface chemistry of clays, interparticle reactions, and soil structure. Linear constitutive relations for soils, including steady state and transient water flow. In the second term, attention is given to nonlinear soil behavior, theories of yielding, plasticity, constitutive models, and problems of plastic stability. Failure modes of footings, walls, and slopes. Instructor: Scott.

CE 124. Special Problems in Structures. *9 units (3-0-6); any term.* Selected topics in structural mechanics and advanced strength of materials to meet the needs of first-year graduate students. Instructors: Staff.

CE 130 abc. Civil Engineering Seminar. *1 unit (1-0-0); each term.* All candidates for the M.S. degree in civil engineering are required to attend a graduate seminar, in any division, each week of each term. Graded pass/fail. Instructor: Staff.

CE 150. Foundation Engineering. *9 units (3-0-6); third term. Prerequisite: CE 115 ab.* Methods of subsoil exploration. Study of types and methods of design and construction of foundations for structures, including single and combined footings, mats, piles, caissons, retaining walls, cofferdams, and methods of underpinning. Text: *Foundation Analysis*, Scott. Instructor: Scott.

CE 160 abc. Structural Engineering. *9 units (3-0-6); first, second, third terms. Prerequisite: CE 10 or equivalent.* Topics that form the foundation for structural analysis and design are covered. Examples are techniques for linear and nonlinear, static and dynamic analysis, including analysis of structure-foundation and structure-fluid systems, the nature of loadings due to wind and earthquake, and concepts in design. Special consideration is given to the behavior and design of specific structural systems such as buildings, bridges, concrete dams, liquid storage tanks, tunnels and pipelines, cable structures, and offshore structures. Special emphasis is placed on engineering for earthquakes. Not offered in 1986–87.

CE 180. Experimental Methods in Earthquake Engineering. *9 units (1-5-3); third term. Prerequisite: AM 151 abc or equivalent.* Laboratory work involving calibration and performance of basic transducers suitable for the measurement of strong earthquake ground motion, and of structural response to such motion. Study of principal methods of dynamic tests of structures, including generation of forces and measurement of structural response. Instructors: Staff.

CE 181. Principles of Earthquake Engineering. *9 units (3-0-6); first term.* Characteristics of potentially destructive earthquakes from the engineering point of view. Determination of location and size of earthquakes; earthquake magnitude and intensity and frequency of occurrence; engineering implications of geological phenomena, including earthquake mechanisms, faulting, fault slippage, and the effects of local geology on earthquake ground motion. Not offered in 1986–87.

CE 182. Structural Dynamics of Earthquake Engineering. *9 units (3-0-6); second term. Prerequisite: AM 151 ab.* Response of structures to earthquake ground motion; nature of building code requirements and their relation to actual behavior of structures such as long-span suspension bridges, and fluids in tanks and reservoirs; earthquake design criteria. Not offered in 1986–87.

CE 200. Advanced Work in Civil Engineering. *6 or more units as arranged; any term.* Members of the staff will arrange special courses on advanced topics in civil engineering for properly qualified graduate students. The following numbers may be used to indicate a particular area of study.

CE 201. Advanced Work in Structural Engineering.

CE 202. Advanced Work in Soil Mechanics.

CE 300. Civil Engineering Research.

For courses in environmental engineering science and hydraulics, see separate sections.

COMPUTER SCIENCE

CS/EE 4. Introduction to Digital Electronics. *6 units (2-0-4); second term.* An introduction to the significant concepts and techniques of modern digital integrated circuitry. The formulation of logical equations; their realization in hardware; binary arithmetic; its implementation with logical functions. Design and construction of a simple computer. Graded pass/fail. Instructor: Goodman.

CS/Ma 6 abc. Introduction to Discrete Mathematics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 1 abc.* Set theory, the Peano axiom system and elementary number theory, graph theory, paths and trees, generating functions. Algebraic structures, semigroups, permutation groups, automata, lattices and Boolean algebras. Finite fields and coding theory. Linear programming. Mathematical logic, propositional calculus and predicate calculus, models and Godel's completeness and incompleteness theorem. Natural deduction. Instructors: Wales, Velickovic.

CS 10. Introduction to Computing. *6 units (0-3-3); first and second terms.* Stored program machines, control structures, modular program design, symbolic control and data manipulation, data structures, recursion, and high-level programming. Laboratory involves programming on personal computers in PASCAL. Students will be expected to become familiar with PASCAL and structured programming methodology. Instructors: Staff.

CS/EE 11. Digital Electronics Laboratory. *6 units (0-3-3); third term. Prerequisites: CS/EE 4. 6 units credit allowed toward freshman laboratory requirement.* An introductory laboratory designed to provide practical hardware experience of theory covered in CS/EE 4. The student is expected to design, build, and test a wide variety of commonly used digital circuits using modern integrated circuits. Graded pass/fail. Instructor: Goodman.

CS 51. Principles of Microprocessor Systems. *9 units (3-3-3); first term.* The principles and design of microprocessor-based computers. Subjects include switching theory, minimization of switching functions, computer arithmetic, machine models, and assembly language programming. Instructor: Ray.

CS 52. Microprocessor Systems. *12 units (3-6-3); second term. Prerequisite: CS 51 or equivalent.* Emphasis on student solutions to real problems using both assembly and high-level programming languages. Use of microprocessor development aids and interactive computing in developing microprocessor-based systems are presented and demonstrated via homework assignments. Instructor: Ray.

CS/EE 53. Microprocessor Project Laboratory. *9 units (0-9-0) or 12 units (0-12-0) as arranged with the instructor; third term. Prerequisite: CS 52 or equivalent.* A project laboratory to permit the student to design and build a microprocessor system. Instructor: Ray.

CS/EE 54. Advanced Microprocessor Projects Laboratory. *9 units (0-9-0) or 12 units (0-12-0) as arranged with the instructor; first term. Prerequisite: Permission of instructor.* A project laboratory to permit the student to design and build a microprocessor-based system. This laboratory is for the experienced student who can work independently and who has taken or has had experience equivalent to CS/EE 53. Instructor: Ray.

CS 80 abc. Undergraduate Research in Computer Science. *Units in accordance with work accomplished. Consent of both research adviser and course supervisor required before registering.* This course provides supervised research in computer science by undergraduates. Topic must be approved by the supervisor, and a formal final report must be presented at the completion of the research. Graded pass/fail. Instructors: Staff.

CS/Ma 117 abc. Computability Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 5 abc or equivalent.* Various approaches to computability theory, e.g., Turing machines, recursive functions, Markov algorithms; proof of their equivalence. Church's thesis. Theory of computable functions and effectively enumerable sets. Decision problems. Undecidable problems: word problems for groups, solvability of diophantine equations (Hilbert's 10th problem). Relations with mathematical logic and the Gödel Incompleteness Theorems. Decidable problems, from number theory, algebra, combinatorics, and logic. Complexity of decision procedures. Inherently complex problems of exponential and superexponential difficulty. Feasible (polynomial time) computations. Polynomial deterministic vs. nondeterministic algorithms, NP complete problems and the P = NP question. Given in alternate years; not offered in 1986–87. Instructors: Kechris, Woodin.

CS/EE/Ma 129 abc. Information and Complexity. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 2 c and CS/EE 4 or equivalent.* A basic course in information theory and computational complexity with emphasis on fundamental concepts and tools that equip the student for research in these areas. Topics include Shannon's theory, Turing machines and computability, Kolmogorov complexity, information flow in computation, time and circuit complexity, VLSI complexity, and collective computation. A unified analytic approach will be followed throughout, and the theory will be interpreted through practical applications. Instructor: Abu-Mostafa.

CS 136. Functional Programming. *9 units (3-3-3); first term.* An introduction to the design and implementation of functional Lisp-like programs. Topics: side-effect-free recursive functions, lambda calculus, combinators, normal order reduction and lazy evaluation, programming with infinite objects, garbage collection. Aspects of sequential and concurrent implementation. Not offered in 1986–87. Instructor: Martin.

CS 137. Systematic Programming. *9 units (3-0-6); first term. Prerequisites: CS 10 or equivalent, and Ma/CS 6.* The design and verification of sequential programs. Topics: a short review of propositional and predicate calculus, axiomatic semantics, predicate transformers, fixed-point theorems, procedures, recursion, and abstract data types. Classical programming examples illustrate the different techniques for defining pre- and post-condition, finding invariant relations, deriving programs, and proving termination. Not offered in 1986–87. Instructor: Martin.

AMa/CS 138 ab. Computer Algorithms. *9 units (3-0-6).* For course description, see Applied Mathematics.

CS 139 ab. Concurrency in Computation. *9 units (3-0-6); second, third terms. Prerequisite: CS 137 or equivalent.* Design and verification of concurrent algorithms. Topics: different models of concurrent computations; process synchronization by shared variables and synchronization primitives; distributed processes communicating by message exchange; the concepts of synchronization, indivisible actions, deadlock and fairness; semantics and correctness proofs; implementation issues; and application to VLSI algorithm design. Parallel machine architecture issues include mapping a parallel algorithm on a network of processors, and classical parallel algorithms and their complexity. Instructor: Martin.

CS 142 abc. Computer Modeling and Data Analysis. *9 units (3-3-3); first, second, third terms.* The building of conceptual models as an expression of the patterns perceived in the analysis of data. Data base systems, discrete simulation, decision support systems, and expert systems. Small group projects and extensive use of the computer. Given in alternate years; offered in 1987–88. Instructor: F. Thompson.

CS 144 abc. Artificial Intelligence. *9 units (3-3-3); first, second, third terms. Prerequisite: consent of instructor.* Current areas of research in artificial intelligence, including knowledge representation, expert systems, natural language understanding, inference and reasoning, and theorem proving. In the first two terms, individual or small group projects will be required; a class project will be a major part of the third term. Given in alternate years; offered in 1986–87. Instructor: F. Thompson.

CS 170 abc. Computer Aided Design. *9 units (3-0-6); first, second, third terms.* An overall view of computer subsystem design flow in practice, and of required computer design aids: design languages and representations; design data bases and data structures; topological, geometrical and electrical models; algorithmic and analytic techniques for partitioning; design verification, simulation, testing, checking, and layout. Incorporation of programs into computer aided design systems. A principal goal of the course is the specification, design, carrying out, and documentation of portions of an actual design system, with the student working as a member of a design team. Instructor: Ayres.

CS 174 abc. Computer Graphics Laboratory. *9 units (3-6-0); first, second, third terms. Prerequisites: Ma 2, CS 10, and extensive programming experience.* The art of making pictures by computer. Hardware and algorithms will be described. Topics: graphics input and output, three-dimensional transformations and modeling, interactive modeling and design, hidden line elimination, surface rendering, and lighting models. Students will implement several medium-scale projects including a 3-D line drawing system, polygon and surface editors, and a 3-D hidden surface rendering package. There will be an opportunity for independent projects third term. Not offered in 1986–87. Instructor: Blinn.

CS 180. Masters Thesis Research. *Units (total of 45) are determined in accordance with work accomplished.*

CS/EE 181 abc. VLSI Design Laboratory. *12 units (3-6-3); first, second, third terms. Prerequisites: CS/EE 4 and CS 10, or equivalent.* Digital integrated system design, with project laboratory designing, verifying, and testing high complexity MOS microcircuits. First term lecture and homework topics emphasize disciplined design, and include MOS logic, layout, and timing; computer-aided design and analysis tools; electrical and performance considerations. Each student is required by the end of first term to complete the design, layout, and verification of an integrated circuit project of modest complexity. Projects are fabricated. Advanced topics second and third terms vary year to year. Projects are large-scale designs done by teams, computer-aided design tools, and testing. Instructor: Seitz.

EE/CS 182 abc. Analog Integrated Circuit Design. *9 units (3-3-3).* For course description, see Electrical Engineering.

EE/CS 183 ab. Integrated Digital Communication. *9 units (3-0-6).* For course description, see Electrical Engineering.

Bi/CS/Ph 185. Collective Computation. *9 units (2-4-3); second term. Prerequisite: Completion of undergraduate requirements for CS, physics or applied physics, or equivalent quantitative background.* New physical problems arise with large-scale parallel systems such as the meaning of time order or simultaneity; new logistical/physical problems dominate the design, and new collective phenomena emerge. The course describes the computation in a context ranging from device physics to biology, and from elementary logic devices to concepts in complexity. It will build toward the modeling, design, and fabrication of circuits relevant to extensive parallel and collective computation. Each student must undertake a design or other project and participate in discussions. Instructors: Mead, Hopfield.

CS/Ph 186 ab. Experimental Projects in Collective Computation. *9 units (0-9-0); second, third terms. Prerequisite: Bi/CS/Ph 185.* Projects course dealing with various aspects of collective computation as covered in Bi/CS/Ph 185. A completed project and report are required. Instructors: Mead, Hopfield.

CS/Ph 187 abc. Potentialities and Limitations of Computing Machines. *9 units (3-0-6); first, second, third terms.* An overview of the theory and practice of computers. Turing machines and computability, error correction methods, reversible machines, thermodynamic and quantum theoretical limitations on speed, reliability, and energy requirements. Discussion of present practice in design and operation of silicon technology. Other possibilities using superconductivity, light. Parallel programming, nearest neighbor concurrent processors, cellular automata, brain analogues. Robots, artificial intelligence. Problems of wire profusion in large systems and design of large software systems. Graded pass/fail. Instructor: Feynman.

CS 237 abc. Design and Implementation of Programming Languages. *9 units (3-3-3); first, second, third terms. Prerequisite: Advanced programming background.* Current practice and research in programming languages. Syntactic and semantic issues with emphasis on the latter. Syntactic topics: finite automata, regular expressions, and lexical analysis; push- down automata and context free grammars; top down and bottom up parsing techniques; syntax-directed translation. Semantic topics: code generation, optimization, binding mechanisms, storage management, and execution environments. Language design topics: abstraction mechanisms, advanced control regimes, very high level languages, functional languages, object oriented languages, logic programming languages. Further topics: interpreter and compiler construction issues, the impact of languages on hardware design. Extensive laboratory work will be required. Given in alternate years; offered in 1986–87. Instructor: Kajiya.

CS 257 abc. Simulation. *9 units (3-3-3) first, (3-5-1) second, (3-5-1) third term.* Mathematical and computational modeling methods. First term: the mathematical foundations of simulation, such as Eulerian equations of motion, tensor analysis, applied 3-D geometry, and the mathematics of continuum dynamics. Second term: the numerical methods of simulation, such as the numerical solution of differential equations, the finite element method and Monte Carlo techniques. Third term: case studies applying these techniques to selected three-dimensional problems in the physical sciences. Term projects for the third term will involve implementing a case study or other computational application of the methods. Some experience with vector and raster graphics would be helpful. Instructor: Barr.

CS 280. Research in Computer Science. *Units in accordance with work accomplished. Approval of student's research adviser and his or her option adviser must be obtained before registering.*

CS 282 abc. Reading in Computer Science. *6 units or more by arrangement; first, second, third terms. Permission of the instructor required.*

CS 284 abc. Special Topics in Computer Science. *9 units (3-0-6). Permission of the instructor required.* Instructors: Staff.

CS 286 abc. Seminar in Computer Science. *9 units (3-0-6). Permission of the instructor required.* Instructors: Staff.

ECONOMICS

Ec/SS 11. Introduction to Economics. *9 units (3-0-6); first, second terms.* An introduction to economic methodology, models and institutions. Includes both basic microeconomics and an introduction to modern approaches to macroeconomic issues. Instructor: Staff.

Ec 13. Readings in Economics. *Units to be determined for the individual by the department.* Not available for credit toward humanities-social science requirement. Graded pass/fail.

Ec 15. Introduction to Macroeconomics: Principles and Problems. *9 units (3-0-6); first, third terms.* Problems of inflation and depression and the tools of monetary and fiscal policy. Instructor: Oliver.

Ec 98 abc. Senior Research and Thesis. *Prerequisite: instructor's permission.* Senior economics majors wishing to undertake research may elect a variable number of units, not to exceed 12 in any one term, for such work under the direction of a member of the economics faculty.

HSS 99. See page 224 for description.

Ec 101. Selected Topics in Economics. *9 units (3-0-6).* Instructors: Staff, visiting lecturers.

Ec/SS 112. History of Economic Analysis. *9 units (3-0-6). Prerequisite: Ec/SS 11 or SS 13.* The development of economic analysis and doctrine, particularly during the 19th century. Specific concentration on the work of Smith, Marx, and the utilitarians. Instructors: Border, Hoffman.

Ec 115. Population and Environment. *9 units (3-0-6); second term.* The causes and consequences of rapid population growth and the problem of reducing the rate of growth through control of fertility. Instructors: Staff.

Ec 116. Contemporary Socioeconomic Problems. *9 units (3-0-6); first term. Prerequisites: Ec/SS 11 and PS/SS 12 or equivalents.* An analytical investigation of the economic aspects of certain current social issues. Topics: the economics of education, medical care systems, urban affairs, and the welfare system. Instructors: Staff.

Ec 118. Environmental Economics. *9 units (3-0-6); third term. Prerequisite: Ec/SS 11 or equivalent.* The methods of price and welfare theory are used to analyze the causes of air, water, and other environmental pollution, to examine their impact on economic welfare, and to evaluate selected policy alternatives for managing our environment. Instructors: Staff.

Ec 119. Financial Aspects of Monetary Theory and Macroeconomics. *9 units (3-0-6); first term. Prerequisite: Ec 15.* The interaction of financial markets with the macro-economy. Topics: ISLM Model, review and extensions; supply of money; long-term interest rates and the term structure; efficient-markets theory and evidence; determination of the short-term interest rate; asset market theory. Instructor: Dubin.

Ec 120. International Economic Theory. *9 units (3-0-6); third term.* Factors affecting the exchange of goods and services and the flow of capital between markets. Theory is stressed. Instructor: Oliver.

Ec 121 ab. Intermediate Microeconomics. *9 units (3-0-6); first, second terms. Prerequisites: Ec/SS 11 and PS/SS 12 or equivalents.* A study of consumer preference, the structure and conduct of markets, factor pricing, measures of economic efficiency, and the interdependence of markets in reaching a general equilibrium. Instructors: Dubin, Gilligan, Reinganum.

Ec 122. Econometrics. *9 units (3-0-6); second term. Prerequisite: Ma 112 a.* The application of statistical techniques to the analysis of economic data. Instructors: Dubin, McKelvey, Rivers.

Ec 123. Forecasting Economic Time Series. *9 units (3-0-6); third term. Prerequisite: Ec 122.* Various forecasting techniques and their application to business and economics. Instructor: Vuong.

Ec 124 abc. Mathematical Methods of Economics. *9 units (3-0-6). Prerequisites: Ma 108 a and Ec 121 ab (can be taken concurrently).* Mathematical tools of modern economic theory and their applications to consumer theory, general equilibrium, and welfare economics. Emphasis on developing rigorous exposition by the students. Instructors: Staff.

Ec 125 ab. The Economics of International Relations. *9 units (3-0-6); first, second terms.* The economic and political factors that influence relations among nations. Topics: foreign exchange markets, international banking and business, the pattern of international trade and payments, the International Monetary Fund and the World Bank, the European Common Market and the American Foreign Aid Program. The foreign economic policy of the United States is analyzed in some detail. This course emphasizes theory less than does Ec 120. Instructor: Oliver.

Ec 126 ab. Money, Income, and Growth. *9 units (3-0-6); first, second terms. Prerequisite: Ec/SS 11 or equivalent, or instructor's permission.* An intensive study of Keynes's *General Theory of Employment* and post-Keynesian developments in the theory of income, consumption, investment, and growth. Instructors: Dubin, Vuong.

Ec 127. Problems in Economic Theory (Seminar). *Units by arrangement; first, second, third terms. Prerequisite: Ec 126 or its equivalent.* Consideration of selected topics in economic theory. Instructors: Staff and guest lecturers.

Ec 128. The Elements of Dynamic Economics. *9 units (3-0-6); first term. Prerequisite: Ec/SS 11 or equivalent.* The role of competition as a determinant of the rate of progress, and the relationship between microbehavior and macroperformance. Instructors: Staff.

Ec/SS 129. Economic History of the United States. *9 units (3-0-6); first term. Prerequisite: Ec/SS 11 or SS 13.* An examination of certain analytical and quantitative tools and their application to American economic development. Instructor: Davis.

Ec 131. Labor Economics. *9 units (3-0-6). Prerequisite: Ec/SS 11 or equivalent.* The modern theory of labor markets. Empirical evidence will supplement theoretical results. Instructor: Wilde.

Ec/PS 134. The Political Economy of Urban Areas. *9 units (3-0-6); second term. Prerequisite: PS/SS 12 or equivalent.* Development of a theory of urban government, using analytic concepts from microeconomics and political science. Instructor: Kiewiet.

Ec 138. Introduction to Welfare Economics. *9 units (3-0-6). Prerequisite: Ec/SS 11.* Economic efficiency of various market arrangements; modern developments in the theories of decentralization and informational efficiency. Instructors: Border, Vuong.

Ec 139. Microfoundations of Macroeconomics. *9 units (3-0-6); third term. Prerequisite: Ec/SS 11 or equivalent.* Aspects of microeconomic theory especially relevant to understanding aggregate economic performance. Topics: models of market disequilibrium with quantity rationing. Instructor: Vuong.

Ec 140. Economics of Energy Policy. *9 units (3-0-6); third term. Prerequisite: Ec 121 ab or equivalent.* Issues in contemporary resource/energy policies with particular emphasis on federal energy independence policy. After a brief survey in theory of resource economics, major issues are identified and their current solutions are contrasted to other alternatives in terms of feasibility and optimality. Instructor: Dubin.

Ec 143. Resource Economics. *9 units (3-0-6); first term. Prerequisite: Ec/SS 11.* Topics in the allocation of natural resources. Problems of extraction, exploitation, exploration, etc. for renewable and nonrenewable resources, e.g., fisheries, fresh water, fossil fuels. Instructors: Staff.

Ec/SS 145. Public Finance. *9 units (3-0-6). Prerequisite: Ec/SS 11 or consent of instructor.* An examination of major issues in tax and expenditure policy at the intermediate level. An introduction to the theory of tax and expenditure policy is followed by intensive examination of two or three major policy issues. The issues will vary from year to year but some examples are: the choice between income and consumption taxes, the role of taxes on wealth, the economics of social security. Instructor: Strnad.

Ec 150. Independent Study on Population Problems. *Units to be arranged. Prerequisite: Ec 115 or equivalent.* This course covers a broad range of problems, including the technological, economic, demographic, sociological, political, and biological aspects of population growth, movement, and density. Graded pass/fail. Instructors: Staff.

ELECTRICAL ENGINEERING

CS/EE 4. Introduction to Digital Electronics. *6 units (2-0-4); second term.* For course description, see Computer Science.

EE 5. Introduction to Linear Electronics. *6 units (2-0-4); third term.* An introduction to the significant concepts of modern linear electronic circuitry. A.C. circuit analysis; networks; their characterization in frequency and time domain. Amplifier gain, frequency response. Power, dynamic range, design of power amplifiers. Design and construction of a typical electronic device such as a tape recorder or hi-fi amplifier. Graded pass/fail. Not offered in 1986–87.

CS/EE 11. Digital Electronics Laboratory. *6 units (0-3-3).* For course description, see Computer Science.

EE 14 abc. Introduction to Electronic Engineering. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 1 abc, Ph 1 abc.* Linear circuit analysis, Kirchoff's laws, transient and steady-state network solutions, phasor notation, Thevenin and Norton theorems, piece-wise linear analysis, power considerations, introduction to Laplace transform and the pole-zero description of network characteristics. Principles of silicon diodes, FET's and transistors, temperature effects and device characteristics and limitations, models. Active circuit analysis, distortion, frequency response and multistage amplifiers, oscillators, stability and Nyquist's Theorem, operational amplifiers. Instructor: Mullin.

EE 32 ab. Introduction to Linear Systems. *9 units (3-0-6); first, second terms. Prerequisites: Ma 1 and Ma 2.* An introduction to the analysis and synthesis of analog and digital electronic circuits, signals, and systems. Sampling, modulation, and filtering of signals represented as continuous or discrete functions of time. Input-output relations of linear time-invariant systems. Special emphasis will be placed on transform techniques (Fourier, Laplace, and Z-Transforms). Instructor: McEliece.

EE 40. Fundamentals of Energy Processing Systems. *9 units (3-0-6); first term. Prerequisites: Ma 2 abc, Ph 2 abc, EE 14 abc, EE 90 abc.* Introduction to electrical energy processing systems as distinct from information processing systems. Elementary magnetic devices: generators, motors, and transformers. The special problems of electronic power processing. Instructor: Cuk.

CS/EE 53. Microprocessor Project Laboratory. *9 units (0-9-0) or 12 units (0-12-0) as arranged with the instructor.* For course description, see Computer Science.

CS/EE 54. Advanced Microprocessor Projects Laboratory. *9 units (0-9-0) or 12 units (0-12-0) as arranged with the instructor.* For course description, see Computer Science.

EE 78 abc. Senior Thesis, Experimental. *9 units; first, second, third terms. Prerequisite: instructor's permission.* Supervised experimental research experience, open only to senior electrical engineering majors. Requirements, set by individual faculty members, will include a written report based upon actual laboratory experience. The selection of topic and the final report must be approved by the Electrical Engineering Undergraduate Committee. Not offered on a pass/fail basis. Instructor: Martel (in charge).

EE 79 abc. Senior Thesis, Theoretical. *9 units; first, second, third terms. Prerequisite: instructor's permission.* Supervised theoretical research experience, open only to senior electrical engineering majors. Requirements, set by individual faculty members, will include a written report based upon the work performed. The selection of topic and the final report must be approved by the Electrical Engineering Undergraduate Committee. Not offered on pass/fail basis. Cannot be used to satisfy the laboratory requirement in EE. Instructor: Martel (in charge).

EE 90 ab. Laboratory in Electronics. *Units by arrangement in multiples of 4 units (0-3-1); second, third terms.* An introductory laboratory normally taken in the sophomore and/or junior year. Experiments acquaint the student with the characteristics of linear and passive electronic circuits and devices and the behavior of simple linear and nonlinear active elements. Individual projects may be performed. Text: *Electronics: BJT's, FET's, and Microcircuits,* Angelo; or *Basic Electronics for Scientists,* Brophy. Graded pass/fail. Instructor: Martel.

EE 91 abc. Experimental Projects in Electronic Circuits. *Units by arrangement; 6 units minimum each term. Prerequisites: EE 14 abc and EE 90 or equivalents. Recommended: EE 114 abc or CS 112, 114, 116 (may be taken concurrently). Open to seniors; others only with consent of instructor.* An opportunity to do original projects in electronics and electronic circuits. Selection of significant projects, the engineering approach, demonstration of a finished product through the use of modern electronic techniques. The use of integrated circuit elements, digital and analogue, is encouraged. Printed circuit board facilities are available. Text: Literature references. Instructor: Goodman.

EE/Mu 107 abc. Projects in Music and Science. *Units to be individually arranged, up to a maximum of 9.* Students will carry out, singly or in groups, projects of study or research exploring the connections of music with the sciences. EE/Mu 107 a will be devoted to Analytic Listening to Live and Reproduced Sound; it may be taken by itself and has no prerequisites. *EE/Mu 107 b and c, devoted to the projects, require instructor's permission and 107 a as prerequisites.* Credit in music or EE but not in both. Instructor: Boyk.

EE 112 abc. Digital Signal Processing Principles. *9 units (3-2-4); first, second, third terms. Prerequisites: EE 32 ab, AMa 95 abc, or equivalents.* Signal sampling, transform techniques, fast-transform algorithms, linear systems, stability test procedures, classical filter approximations, FIR and IIR digital filters, allpass functions, structural passivity, low-noise and low-sensitivity digital filters, linear-prediction and lattice-algorithms, multirate signal processing and decimation-interpolation filter banks for sub-band coding applications. Instructor: Vaidyanathan.

EE 114 abc. Electronic Circuit Design. *9 units (3-0-6); first, second, third terms. Prerequisite: EE 14 abc or equivalent.* Applications of solid-state electronic devices in circuits and systems. Emphasis on methods of engineering analysis and design. Recommended for seniors and graduate students. Instructor: Middlebrook.

EE 117 ab. Power Electronics. *9 units (3-1-5) second term; (3-2-4) third term. Prerequisite: EE 14 abc or equivalent.* Introduction to repetitively switched power circuits for ac-to-dc, dc-to-ac, and dc-to-dc conversion and/or regulation of voltage or current in high-power applications: power supplies, motor controls, power amplifiers. Components, control techniques, analysis, and design. Laboratory part of the course includes the design of a switching dc-to-dc converter (part a), closed loop regulator (part b), and verification of the analysis technique and measurement methods through the laboratory assignments (part b). Instructor: Cuk.

EE 124. Pattern Recognition. *9 units (3-6-0); first term. Prerequisite: Ma 2.* The course will cover classic results from pattern recognition and will discuss within this context associative memories and related neural network models of computation. Discriminant functions, the capacity of linear discriminant functions, perceptron and related teaching algorithms, parametric (statistical) training techniques, unsupervised learning; nonlinear discriminant functions, associative memories, learning algorithms for layers of discriminant functions. Instructor: Psaltis

EE/Ma 126. Information Theory. *9 units (3-0-6); first term. Prerequisite: Ma 2 abc.* Shannon's mathematical theory of communication. Entropy and mutual information for discrete and continuous random variables; mathematical models for communication channels; Shannon's noisy-channel coding theorem; calculation of channel capacity. Discussion of the implications of the theory for real communication systems. This course, when followed by EE/Ma 127 ab (for which, however, it is not a prerequisite), should prepare the student for research in information and coding theory. Instructor: Posner.

EE/Ma 127 ab. Error-Correcting Codes. *9 units (3-0-6); second, third terms. Prerequisite: Ma 2 abc.* This course, which is a sequel to EE/Ma 126, but which may be taken independently, will cover the most important techniques for combating errors that occur in the transmission or storage of data. Topics: algebraic block codes, e.g., Hamming, Golay, BCH, Reed-Solomon, Goppa, Fire; convolutional codes; concatenated codes; and the associated encoding and decoding algorithms. Self-contained introduction to the theory of finite fields. Instructors: Swanson (a), McEliece (b).

CS/EE/Ma 129 abc. Information and Complexity. *9 units (3-0-6).* For course description, see Computer Science.

APh/EE 130. Introduction to Optoelectronics. *9 units (3-0-6).* For course description, see Applied Physics.

EE 150. Topics in Electrical Engineering. *Units and terms to be arranged.* Content will vary from year to year, at a level suitable for advanced undergraduate or beginning graduate students. Topics will be chosen according to the interests of students and staff. Visiting faculty may present all or portions of this course from time to time. Instructors: Staff.

EE 151 ab. Engineering Electromagnetics. *9 units (3-0-6); second, third terms. Prerequisites: Ph 2, EE 14; and AMa 95 (may be taken concurrently) or consent of the instructor.* Transmission lines and distributed circuits, methods of solution for electro- and magneto-static problems, Maxwell's equations, plane wave propagation in lossy and dispersive media, guided waves, introduction to microwave circuit elements and techniques. Instructor: Gould.

EE 152. Guided Wave Circuits. *9 units (3-0-6); first term. Prerequisite: EE 151 ab or equivalent.* Planar and cylindrical dielectric waveguides; optical fibers and integrated circuits. Network formulation of distributed systems; scattering matrix; discontinuities in waveguides. Selections from periodic propagating structures, coupled mode devices, electronic waveguide. Not offered in 1986–87.

EE 153. Computer Aided Design of Microwave Integrated Circuits. *9 units (2-2-5); first term. Prerequisites: EE 14 abc and EE 151 ab, or equivalent.* The goal is to design, build, and test microwave integrated circuits. Students lay out the circuits on computers and use photolithography to etch the substrates. The lectures cover networks, noise, planar transmission lines, planar antennas, Schottky diodes, mixers, multipliers, gallium-arsenide field-effect transistors, and microwave transistor amplifiers. Students build a coupler, a microstrip antenna, a mixer, and a low-noise amplifier. Instructor: Rutledge.

EE 155 abc. Electromagnetic Fields. *9 units (3-0-6); first, second, third terms. Prerequisite: APh 106 abc or equivalent.* Advanced course in electromagnetic theory and its application to the theory of electromagnetic fields in matter, the theory of electric and magnetic properties of matter, and the theory of electromagnetic wave propagation. Instructor: Papas.

EE/Ge 157 abc. Introduction to the Physics of Remote Sensing. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 2 abc or equivalent.* Introduction to the interaction of electromagnetic waves with natural surfaces and atmospheres. Scattering of microwaves by surfaces and volume scatterers. Microwave and thermal emission from atmospheres and surfaces. Spectral reflection of natural surfaces and atmospheres in the near infrared and visible regions of the spectrum. Review of modern spaceborne sensors and associated technology and data analysis. Emphasis on sensor design, new techniques, ongoing developments, and data interpretation. Examples of applications in geology, planetology, oceanography, astronomy and atmospheric research. Instructor: Elachi.

EE/Ge 158. Application of Remote Sensing in the Field. *6 units (0-5-1); third term. Prerequisite EE/Ge 157 ab.* Application of remote sensing techniques learned in EE/Ge 157 ab to field situations. During spring break students will visit areas in eastern California and western Nevada that have been used as test areas for visible and near-infrared, thermal infrared, and microwave scattering methods. Satellite, aircraft, and ground spectrometer data will be compared with surface observation by the student. A brief introduction to image processing procedures in the third term. Instructor: Albee.

EE 160. Communication System Fundamentals. *9 units (3-0-6); third term. Prerequisite: EE 32 ab.* Laws of radio and guided transmission, noise as a limiting factor, AM and FM signals and signal-to-noise ratio, sampling and digital transmission, errors, information theory, error correction. Emphasis will be on fundamental laws and equations and their use in communication system designs, including voice, video, data, and radar. Instructor: Goodman.

EE 162. Random Processes in Communication and Control. *9 units (3-0-6); first term. Prerequisite: AMa 95 abc.* Introduction to single parameter random processes: stationarity; correlation functions; power spectral density; Gaussian processes. Response of linear systems to random processes. Least mean square error linear filtering and prediction. Instructor: Simon.

EE 163 ab. Introduction to Communication Theory. *9 units (3-0-6); second, third terms. Prerequisite: EE 162 or equivalent.* Mathematical models of communication processes; signals and noise as random processes; sampling and quantization; modulation and spectral occupancy; signal-to-noise ratio and error probability; information theoretic considerations; demodulation and detection in analog and digital communication systems. Instructor: Simon.

EE 165. Topics in Telecommunication System Engineering. *9 units (3-0-6); second term. Prerequisite: at least one term of communications or signal processing. For students having some familiarity with telecommunication elements and models.* Approaches to the design of overall telecommunication systems based on specifications, constraints, and demand. Topics will be chosen from terrestrial, satellite, and deep space communication, radar and radio navigation, and switched voice and data networks ranging in size from the office to the world. Topics and examples depend on instructor's and students' interests. Instructors: Staff.

EE/ChE 170 abc. Introduction to Systems and Control. *9 units (3-0-6); first, second, third terms. Prerequisites: E 13, E 101 or equivalents.* Analysis of linear multivariable systems, using state space, frequency domain, stochastic, and optimal techniques. Unified treatment using linear operator theory. Extensions of classical control techniques to multivariable systems, stressing singular value analysis and the Linear Quadratic Gaussian problem. Estimation and Kalman filtering. Sampled-data control theory. Examples from electrical, chemical, mechanical, and aerospace systems. Instructors: Sideris, Morari.

EE/ChE 171 ab. Advanced Topics in Systems and Control. *9 units (3-0-6); second and third terms. Prerequisite: EE/ChE 170 or instructor's permission.* Advanced problems in linear and nonlinear control system design with emphasis on practical aspects, including robustness, constraints, computer implementation, effects of the plant design on performance, and comparative evaluation of alternate design techniques. Applications to electrical, chemical, mechanical, and aerospace systems. Current topics from the literature will be discussed, depending on student interests. Instructors: Morari, Staff.

CS/EE 181 abc. VLSI Design Laboratory. *12 units (3-6-3).* For course description, see Computer Science.

EE/CS 182 abc. Analog Integrated Circuit Design. *9 units (3-3-3); first, second, third terms. Prerequisites: EE 14, EE 90, APh 3, CS 10 or their equivalents.* Device, circuit and system techniques for the design of large-scale CMOS analog systems. The MOS transistor above and below threshold. Current mirrors. The differential transconductance amplifier. Analog addition, subtraction, multiplication, absolute value, interpolation, division. Circuits with time constants: Linear filters of first and second order, monostable and astable relaxation oscillators. Automatic gain control. System examples from feedback control, vision, and auditory processing. In addition to doing laboratory work on elementary circuits, each student is required to design a modest system-level project and submit it for fabrication. Third term laboratory is reserved for testing and evaluating these projects. Instructor: Mead.

EE/CS 183 ab. Integrated Digital Communication. *9 units (3-0-6); second, third terms. Prerequisite: At least one term of communications or signal processing.* Concepts and systems used in transmitting and switching voice and data digitally in communication networks, with emphasis on common-carrier and computer communication. Traffic theory, queueing theory, circuit switching, protocol hierarchy, packet switching, local area networks, integrated services, cellular radio, and analysis and design of large-scale switched digital networks. Emphasis is on the changes in communication concepts being wrought by the digital revolution. Instructor: Posner.

EE 191. Advanced Work in Electrical Engineering. *Units to be arranged.* Special problems relating to electrical engineering will be arranged. Primarily for undergraduates; students should consult with their advisers. Graded pass/fail.

EE 194. Microwave Laboratory. *9 units (1-4-4); third term. Prerequisite: EE 51 ab or equivalent.* Selected laboratory experiments and related theory on microwave generation and amplification; measurements of impedance, frequency and power; properties of microwave cavities, waveguides, networks, periodic structures, antennas. Not offered in 1986–87. Instructors: Staff.

EE 243 abc. Quantum Electronics Seminar. *6 units (3-0-3); first, second, third terms.* Advanced treatment of topics in the field of quantum electronics. Each weekly seminar consists of a review and discussion of results in the areas of quantum electronics and optoelectronics. Instructor: Yariv.

EE 255 abc. Problems in Electromagnetic Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: EE 155 abc or equivalent.* Advanced mathematical methods of electromagnetic theory and gravitational electrodynamics. Text: Course notes. Instructor: Papas.

EE 291. Advanced Work in Electrical Engineering. *Units to be arranged.* Special problems relating to electrical engineering. Primarily for graduate students; students should consult with their advisers.

ENGINEERING (GENERAL)

E 1 ab. Microcomputers in Engineering. *3 units (0-3-0); E 1 a offered first and second terms; E 1 b offered third term.* A problem-oriented introduction to the microcomputer, its operating system, and computer programming using BASIC. Problems drawn from several engineering disciplines will demonstrate elementary numerical analysis, algorithms, and graphics. In E 1 b other programming languages such as FORTRAN will be introduced in addition to more advanced methods and applications. Students will be expected to complete projects based on the examples provided. Graded pass/fail. Instructors: Staff.

E 5. Laboratory Research Methods in Engineering and Applied Science. *6 units (1-3-2); second term. 6 units credit allowed toward freshman laboratory requirement.* An introduction to experimental methods and problems typical of a variety of engineering fields. Staff members representing various areas of interest within engineering and applied science will supervise experiments related to their specialty. As the situation permits, students are given some choice in selecting experiments. Instructors: Staff.

E 10. Technical Seminar Presentations. *3 units (1-0-2); second, third terms. (Only graduating students required to take E 10 are permitted to preregister. Others wishing to take the course should come to the organizational meeting and will be admitted if there is room. NOTE: Those who neither preregister nor attend the O.M. may not be permitted to enroll.)* This course provides guidance and practice in organizing and preparing topics for presentation and in speaking with the help of visual aids, including the blackboard, the overhead projector, and the slide projector. Instructors: McDonough, staff.

E 13. System Dynamics. *12 units (3-0-9); first term. Prerequisites: Ma 1 abc, Ph 1 abc, or instructor's permission.* Predicting the behavior of systems of physical members from their mathematical models—mechanical, electrical, fluid, thermal, and others. Natural dynamic characteristics and stability: s-plane analysis and Routh's method. Dynamic coupling and natural modes. Forced response using Fourier, impulse, and Laplace techniques. Not offered in 1986–87. Instructors: Staff.

E 101. Introduction to Automatic Control. *9 units (3-0-6); third term. Prerequisite: E 13 or equivalent.* Design of linear feedback control systems for error, stability, and dynamic response specifications. Analysis by the root-locus technique of Evans and the frequency-response techniques of Nyquist, Bode, and Nichols. Introduction to the state-space approach. Examples from aeronautics, electronics, and civil engineering. Instructor: Staff.

E 102 abc. Introduction to Systems Analysis and Control. *9 units (3-0-6); first, second, third terms. Prerequisites: E 13, E 101 or equivalent.* Analysis of linear and nonlinear systems, stability and control of dynamical systems. Noise and stochastic processes, filtering and estimation theory, nonlinear system identification theory.

E 150 abc. Engineering Seminar. *1 unit (1-0-0); each term.* All candidates for the M.S. degree in applied mechanics, electrical engineering, materials science, and mechanical engineering are required to attend any graduate seminar in any division each week of each term. Graded pass/fail. Instructors: Staff.

ENGINEERING GRAPHICS

Gr 1. Basic Graphics. *3 units (1-2-0); first term.* This course deals with the fundamental aspects of projective geometry and graphical techniques used by the scientist and engineer as an aid in spatial visualization, communication and in creative design. Emphasis on the effective use of freehand sketching, orthographic projection, and basic descriptive geometry solutions helpful in computer-augmented design or graphics systems. Instructor: Welch.

ENGINEERING SCIENCE

ES 200 abc. Topics in Bioengineering. *9 units (3-0-6); first, second, third terms.* First two terms: the foundation of low-Reynolds-number fluid physics, the motion of a rigid or flexible body, flows of suspensions, and transfer processes. Third term: various applications to rheology, blood flow in living systems, chemical flow problems, motility of micro-organisms, and bioconvection. Instructors: Staff.

ES 250 abc. Research in Engineering Science. By arrangement with members of the staff, properly qualified graduate students are directed in research in Engineering Science. Hours and units by arrangement.

ENGLISH

En 1 ab. English as a Second Language. *9 units (3-0-6 or 4-0-5); first, second terms.* A program in the fundamentals of English composition for non-native speakers of English, required for foreign students in need of supplementary instruction before entering Freshman Humanities courses. Students will be assigned to either En 1 b or the two-quarter sequence of En 1 ab on the basis of a diagnostic examination. *Not available for credit toward the humanities-social science requirement.* Instructors: Fonseca, Linden-Martin.

En 2. Basic English Composition. *9 units (2-2-5); first, second terms.* A course in the fundamentals of English composition for native speakers of English, required for students in need of supplementary instruction before entering Freshman Humanities courses. Students will be assigned to En 2 on the basis of a diagnostic examination. *Not available for credit toward the humanities-social science requirement.* Instructor: Giuliano.

ENVIRONMENTAL ENGINEERING SCIENCE

Env 1. Engineering Problems of Man's Environment. *9 units (3-0-6); third term. Prerequisites: Ph 1 ab, Ch 1 ab, and Ma 1 ab. Registration limited to freshmen and sophomores or with the permission of the instructor.* An introduction to the engineering design of measures to limit man's impact on the environment. Global and local cycles in the hydrosphere, atmosphere, and biosphere; energy and materials balance in environmental problems; source control of pollutants. The process of establishing environmental goals is discussed. Instructor: Cass.

Env 90. Undergraduate Research in Environmental Engineering Science. *Units by arrangement; any term. Approval of research supervisor required prior to registration.* Independent research on current environmental problems; laboratory or field work is encouraged. A written report is required for each term of registration. Seniors may prepare a thesis with approval of the EES faculty at the beginning of the senior year; in this case, registration should be for at least three consecutive terms. Graded pass/fail. Instructors: Staff.

Env 100. Special Topics in Environmental Engineering Science. *6 or more units as arranged. Prerequisite: instructor's permission.* Special courses of reading, problems, or research for graduate students working for the M.S. degree or qualified undergraduates. Graded pass/fail. Instructors: Staff.

Env 112 abc. Hydrologic Transport Processes. *9 units (3-1-5), first term; 9 units (3-0-6), second, third terms. Prerequisites: AMa 95 abc or AM 113 abc (may be taken concurrently); ME 19 abc; and some knowledge of elements of hydrology (may be satisfied by special reading assignments).* The hydrologic cycle and analysis of hydrologic data; dynamic similitude; turbulent shear flow in rivers and estuaries; stratified flow, turbulent plumes and buoyant jets; hydraulic models. Transport and dispersion of solutes, sediments and heat; evaporation and density stratification in natural waters. Engineering of outfalls. Flow through porous media, wells, groundwater recharge, and seawater intrusion in aquifers. Instructor: Brooks.

Env 116. Experimental Methods in Air Pollution. *9 units (1-4-4); first term (1986–87), third term thereafter. Prerequisite: ChE/Env 157 abc (may be taken concurrently) or permission of instructor.* Methods of sampling and measurement of particulate and gaseous pollutants. Projects illustrative of problems in aerosol size distribution measurements, instrument calibration, particle characterization, and sampling systems are performed. Instructor: Flagan.

Env 142 ab. Chemistry of Natural Water Systems. *9 units (3-0-6); first, second terms. Prerequisite: Ch 1 abc, Ch 14, or equivalent.* Chemistry of electrolyte solutions, heterogeneous processes, and redox reactions applied to quantitative description of natural waters. Chemical characteristics of lakes, streams, and seawater; comparison of real systems with stoichiometric, equilibrium, and steady-state models; properties of colloids in natural water systems; coagulation-flocculation processes; adsorption phenomena. Instructor: Morgan.

Env 143. Water Chemistry Laboratory. *6-9 units as arranged with instructor; third term. Prerequisite: Env 142 ab.* Laboratory experiments and measurements dealing with the major and minor constituents of natural waters. Topics include seawater chemistry, heterogeneous equilibria, rates of precipitation, redox processes, adsorption, and particle coagulation. Measurement techniques include electrometry, spectrophotometry, liquid and gas chromatography, light scattering, and atomic absorption spectrophotometry. Instructors: Hoffmann, Morgan.

Env 144. Ecology. *6 units (2-1-3); second term.* Basic principles of ecology and ways in which human activities can influence natural populations. (May be taught in conjunction with parts of Env 145 a.) Instructor: North.

Env 145 ab. Environmental Biology. *10 units (2-4-4), second term; 9 units (3-0-6), third term.* An exposition of basic biological principles concerning interrelations between organisms, particularly those directly affecting man and his environment. Extensive reading is required, covering a broad scope of biological literature. Instructor: North.

Env 146. Chemical Reaction Engineering for Water Quality Control. *9 units (3-0-6); first term. Prerequisite: Env 142 a or equivalent (may be taken simultaneously).* Basic principles of reaction engineering applied specifically to unit operations used in water and wastewater engineering. Emphasis on the underlying chemical principles. Topics: adsorption, catalysis, chlorination, coagulation and flocculation, gas transfer, ion exchange, nitrogen and phosphorus removal, oxidation-reduction, ozonation, precipitation, reverse osmosis, and ultrafiltration. Not offered in 1986–87. Instructor: Hoffmann.

Env 147. Biochemical Reaction Engineering for Water Quality Control. *9 units. (3-0-6); second term. Prerequisite: Env 146 or permission of instructor.* Fundamental principles of biochemical engineering as applied to wastewater treatment. Design concepts will be emphasized. Topics: elementary microbiology, fundamentals of microbial metabolism, substrate utilization and kinetics of microbial growth, mixed culture interactions, design and analysis of biological reactors, activated sludge process design, trickling filter design, nitrification, denitrification, anaerobic digestion, microbiology of the sulfur cycle, and microbiology of metals. Not offered in 1986–87. Instructor: Hoffmann.

Env 150 abc. Seminar in Environmental Engineering Science. *1 unit (1-0-0); each term.* Seminar on current developments and research within the field of environmental engineering science, with special consideration to work at the Institute. Graded pass/fail.

ChE/Env 157 abc. Fundamentals of Air Pollution Engineering. *9 units (3-0-6).* For course description, see Chemical Engineering.

Env 170. Design of Strategies for Environmental Control. *9 units (3-0-6); second term. Prerequisite: instructor's permission.* Principles which underlie the design of efficient and effective solutions to large-scale regional environmental control problems. Environmental data set analysis, mathematical modeling, model verification, and optimization of emission control strategies. Instructor: Cass.

Env 200. Advanced Topics in Environmental Engineering Science. *Units by arrangement, any term.* Course to explore new approaches to environmental problems. The topics covered vary from year to year, depending on the interests of the students and staff.

Env 206. Special Problems in Biological Engineering Science. *Units by arrangement, any term. Prerequisite: AMa 95 abc.* Special topics in the application of engineering principles to biological and medical problems can be explored on mutual agreement between advanced students and one or more of the participating faculty. Instructors: Leal, Wu.

Env 214 abc. Advanced Environmental Fluid Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisites: Hy 101 or Ae/APh 101, AMa 101 or AM 125.* A study of the transport and dispersing properties of fluid motions in the air, oceans, estuaries, rivers, lakes, and groundwater. Emphasis is given to the processes and scales of motion that are important to engineering problems of pollution control. Offered in 1987–88. Instructor: List.

Env 242 abc. Applied Chemical Kinetics. *9 units (3-0-6); first, second, third terms. Prerequisite: Env 142 ab or permission of instructor.* Fundamental concepts of chemical kinetics as applied to problems in aquatic chemistry, atmospheric chemistry, geochemistry, and water and wastewater treatment. Topics include basic principles, enzyme kinetics, experimental methods, kinetic theories, extrathermodynamic relationships, gas phase kinetics, heterogeneous kinetics, mechanisms, mathematical techniques, microbial kinetics, multiphase systems, and oscillating chemical reactions, solution phase kinetics. Instructor: Hoffmann.

Env 250. Advanced Environmental Seminar. *4 units (2-0-2); each term. Prerequisite: instructor's permission.* A seminar course for advanced graduate students and staff to discuss current research and technical literature on environmental problems. As the subject matter changes from term to term, it may be taken any number of times. Instructors: Staff.

Env. 300. Thesis Research.

Other closely related courses (listed elsewhere) are ChE 103, ChE 173, Ec 118, EE/ChE 170, Ge 103, Hy 101, Hy 111, Hy 113, Hy 121, Hy 210, Hy 211, and Hy 213.

Graduate students may also enroll in graduate courses offered by Scripps Institution of Oceanography under an exchange program. Graduate students majoring in environmental engineering science, who may take a subject minor in oceanography for the Ph.D. degree, should consult the executive officer for more information.

FRENCH *(See Languages)*

GEOLOGICAL AND PLANETARY SCIENCES
GEOLOGY, GEOBIOLOGY, GEOCHEMISTRY, GEOPHYSICS, PLANETARY SCIENCE

Ge 1. Introductory Geology. *9 units (3-3-3); first, third terms.* A broad and up-to-date view of the earth, focusing upon major geological items currently of interest, such as paleomagnetism, mid-oceanic rises, sea-floor spreading, plate tectonics, continental drift, evolution of continental plates, the earth's interior, and environmental geology. Topics of consideration vary with the individual instructor and with class interests. Classes are limited in size and individually handled by full-time faculty members. All registrants must be prepared to devote six weekend days to field trips. Instructors: Wyllie, Allen, Burnett.

Ge 4. Introduction to the Solar System. *6 units (3-0-3); third term.* An introductory survey of the bodies in our solar system. Meteoritic data and astrophysical observations on young stars provide information on the processes and materials of the early solar system. Interplanetary dust, asteroids, and comets are discussed in relation to the known types of meteorites. The post-Apollo view of the Moon is used as a basis for comparison with other small planets such as the Jovian satellites. Venus and Mars are considered in the light of recent planetary missions; Jupiter and Saturn as examples of outer planets. Instructor: Stevenson.

Ge 5. Geobiology. *9 units (3-0-6); second term. Prerequisites: consult instructor.* Biologically related processes and environments in the crust throughout the span of earth history. The environmental influence that the change from a reducing to an oxidizing atmosphere had upon the evolution of life processes and the subsequent progression of organisms and organic activity throughout the oxidizing era. Organic progression and differentiation in time and space in terms of environment. Instructor: Kirschvink.

Ge 40. Special Problems for Undergraduates. *Units to be arranged; any term.* This course provides a mechanism for undergraduates to undertake honors-type work in geologic sciences. By arrangement with individual members of the staff. Graded pass/fail.

Ge 41 abc. Undergraduate Research and Bachelor's Thesis. *Units to be arranged; first, second, third terms.* Guidance in seeking research opportunities and in formulating a research plan leading to preparation of a bachelor's thesis is available from the division undergraduate research counselor, Professor Epstein. Graded pass/fail.

The following courses may, at the discretion of the instructor, not be offered if the enrollment is less than five.

Ge 100. Geology Club. *1 unit (1-0-0); first, second, third terms.* Presentation of papers on research in geological and planetary sciences by guest speakers. Graded pass/fail. Instructor: Kirschvink.

Ge 101 abc. Introduction to the Earth and Planets. *Prerequisites: Ma 2, Ph 2.* The three terms may be taken independently, and are recommended for upper division electives in the geological and planetary sciences.

101 a. Planetary Science. *9 units (3-0-6); first term.* The planets; their probable composition, physical state, and dynamical behavior. Ground-based observations, spectroscopy, photometry, radio interferometry, radar mapping, observations from spacecraft. Theories of atmospheric structure, surface processes, internal history. Speculations on the origin and evolution of bodies in the solar system. Instructor: Yung.

101 b. Geophysics. *9 units (2-1-6); second term.* An introduction to the physics of the earth. The present internal structure of the earth, theories of the origin and evolution of the earth, the earth's gravity and magnetic field, and fundamentals of wave propagation in earth materials. The contributions that heat flow, gravity, paleomagnetic, and earthquake mechanism data have made to our understanding of geodynamics. Instructors: Hager, Ahrens.

101 c. Geology. *9 units (3-3-3); third term.* The constitution of the solid earth and the history of its development in time based on the record preserved in the rocks and on observation of ongoing earth processes. Igneous, sedimentary, and metamorphic processes and products. Geochemistry and geochronology. Evolution of land masses and oceans and their biota through geologic time. Deformation of the earth in plate tectonics; orogenesis. Surface processes and land forms. Glaciation and climatic history. Current state of research in these subjects. Field trips. Instructor: Kamb.

Ge 102. Oral Presentation. *2 units (1-0-1); third term.* Practice in the effective organization and delivery of reports before groups. Successful completion of this course is required of all candidates for degrees in the division. Instructor: Ahrens.

Ge 103 abc. Atmospheres and Oceans. *9 units (3-0-6); first, second, third terms.* Physical and chemical processes in atmospheric fluid envelopes. First term: weather and climate, dynamics of large-scale motions in atmospheres and oceans. Second term: atmospheric radiative transfer and remote sensing, atmospheric temperatures and radiative equilibrium. Third term: atmospheric chemistry and photochemistry. Instructors: Ingersoll (first term), Muhleman (second term), Yung (third term).

Ge 104 ab. Advanced General Geology. *9 units (3-4-2). Prerequisites: Ch 1 or 2, Ma 1, Ph 1.*

104 a. Minerals as Physical, Chemical, and Geological Systems. *First term.* Atomic structure and physical properties of the solid state, with emphasis on the important minerals. Relations between bonding forces, structure, composition, properties, and conditions of formation of minerals. The occurrence and properties of the major mineral groups that are important at the earth's surface and in the interior will be studied in the laboratory. Instructor: Rossman.

104 b. Rocks and Their Geological Settings. *Second term.* A study of igneous, metamorphic, and sedimentary rocks with emphasis on their common geologic settings, and the basic chemical and physical processes affecting their origin. Genesis of igneous rocks and silicate crystal-melt-vapor equilibria. Metamorphic processes, rocks, and structures. Introduction to sedimentary rocks from the perspective of igneous and metamorphic source terranes and associations, and compositional controls on metamorphic derivatives. An overview of the relations between petrogenetic processes and global tectonics. Instructor: Saleeby.

Ge 105. The Geologic Record. *9 units (3-3-3); first term.* Introduction to historical geology, including basic principles of biostratigraphy, physical stratigraphy, magnetostratigraphy, geochronology, and tectonics, focused on the interpretation and understanding of biological, geochemical, and tectonic processes and events which have influenced earth history, with particular emphasis on the evolution of the biosphere. One or two weekend field trips to fossiliferous strata and paleoenvironments in the southern California region. Instructor: Kirschvink.

Ge 106. Structural Geology. *9 units (3-3-3); second term.* Mechanics of rock deformation. Interpretation of the record of deformation of the earth's crust from rock structures on the megascopic (faults, folds), mesoscopic (foliation, lineation), and microscopic (crystal fabric, dislocations) scales. Structural analysis by geometrical and graphical techniques and with use of subsurface data (well logs, seismic sections). Structure of major regional tectonic elements of the earth's crust. Field trips for study of structural features. Instructor: Kamb.

Ge 107. Geologic Field Mapping. *9 units (0-9-0); third term. Prerequisite: Ge 106.* Introduction to the rationale and techniques of geologic field mapping. Emphasis is on the construction of a geologic map in a terrane of moderately deformed, stratified rocks. Synthesis and interpretation of field data in the laboratory, including the construction of cross-sections and stratigraphic columns. Two- or three-day field trips. Instructor: Taylor.

Ge 108. Applications of Physics to the Earth Sciences. *9 units (3-0-6); third term. Prerequisites: Ph 2 and Ma 2 or equivalent.* An intermediate course in the application of the basic principles of classical physics to the earth sciences. Topics will be selected from two groups such that independent courses will be offered in alternate years and the course may be taken twice for credit. Topics: the mechanics of rotating bodies, the two-body problem, tidal theory, oscillations and normal modes, diffusion and heat transfer, wave propagation, electro- and magneto-statics, Maxwell's equations, and elements of statistical and fluid mechanics. Instructor: Muhleman.

Ge 110. Sedimentary Geology. *9 units (3-3-3); third term. Prerequisites: Ge 104 ab, Ge 105.* Origin and evolution of sedimentary rocks. 1) Sedimentary materials, processes, and environments; 2) Description and classification of sedimentary rocks; 3) Interpretation of paleoenvironments and stratigraphic history from field and subsurface observations. Instructor: Murray.

Ge 111 ab. Invertebrate Paleontology. *9 units (2-5-2); first, second terms.* Morphology and geologic history of the common groups of the lower invertebrates, with emphasis on their evolution and adaptive modifications; consideration of the higher invertebrate groups; preparation of fossils and problems of invertebrate paleontology. Not offered in 1986–87.

Ge 113. Heterogeneous Phase Equilibrium in Mineral Systems. *9 units (3-0-6); second term.* Principles of phase relationships in mineral-liquid-vapor systems through a range of pressures and temperatures. Unary, binary, ternary, and quaternary systems with examples drawn from systems with components such as silicates, carbonates, salts, H_2O and CO_2. Instructor: Wyllie.

Ge 114. Optical and X-Ray Mineralogy. *12 units (3-6-3); first term. Prerequisite: Ge 104.* Methods of optical crystallography. Measurement of optical constants with the polarizing microscope. X-ray determination of lattice parameters. Characterization and identification of minerals by optical and X-ray methods. Systematic application of these methods to the study of important mineral groups. Instructor: Rossman.

Ge 115 ab. Petrology and Petrography. Systematic study of rocks and rock-forming minerals with emphasis both upon the use of the petrographic microscope and megascopic identification; interpretation of mineral assemblages, textures, and structures; problems of genesis.

115 a. Igneous Petrology and Petrography. *12 units (3-6-3) or 6 units (3-0-3) with consent of instructor; second term. Prerequisites: Ge 114, Ch 21 a.* The mineralogical and chemical composition, origin, occurrence, and classification of igneous rocks considered mainly in the light of chemical equilibrium and of experimental studies. Detailed consideration of the structures, phase relations, and identification of the major igneous minerals. Instructor: Albee.

115 b. Metamorphic Petrology and Petrography. *12 units (3-6-3) or 6 units (3-0-3) with consent of instructor; third term. Prerequisite: Ge 115 a.* The mineralogic and chemical composition, occurrence, and classification of metamorphic rocks; interpretation of mineral assemblages in light of chemical equilibrium and experimental studies. Detailed consideration of structure, phase relations, composition, and determination of the major metamorphic minerals. Instructor: Stolper.

Ge 121 abc. Advanced Field and Structural Geology. *12 units (0-9-3). Prerequisites: Ge 104 b, Ge 123 a.* Letter sequence may vary from year to year.

121 a. Field mapping investigations of igneous and metamorphic problems in various tectonic settings in southern California and adjacent regions. Instructor: Saleeby.

121 b. Field mapping investigations in various areas of predominantly sedimentary rocks in southern California, with emphasis on sedimentary processes and Quaternary geology. Instructor: Allen.

121 c. Field and supporting laboratory studies in the geometries and mechanisms of several rock deformational regimes. Subjects include metamorphic tectonites, thrust and wrench faults, and melanges. Instructor: Silver.

Ge 123 ab. Summer Field Geology. *15 units (3 weeks). Prerequisites: Ge 104 ab, Ge 107.*

123 a. Intensive field study of an area in western North America with emphasis on stratigraphic and structural interpretation by the construction of geologic maps and cross-sections. The course is designed to complement the field training in southern California afforded by Ge 107 and Ge 121. Sessions are arranged at the beginning or end of the respective summer break. Instructor: Saleeby.

123 b. Advanced topics in geologic field mapping which may be offered as a direct extension of Ge 123 a, or taken individually from a consenting faculty member. Highly recommended for geology majors. Instructors: Staff.

Ge 124 ab. Paleomagnetism and Magnetostratigraphy. Application of paleomagnetism to the solution of problems in stratigraphic correlation and to the construction of a high-precision geological time scale. Given in alternate years; offered in 1986–87. Instructor: Kirschvink.

124 a. *9 units (3-3-3); second term. Prerequisites: Ge 104 abc, Ge 105 ab.* The principles of rock magnetism and physical stratigraphy; emphasis on the detailed application of paleomagnetic techniques to determination of the history of the geomagnetic field.

124 b. *6 units (0-0-6); spring recess. Prerequisite: Ge 124 a.* An eight-day field trip to the Colorado Plateau to study the physical stratigraphy and magnetic zonation.

Ge 126. Introduction to Quaternary Geology. *12 units (3-3-6); first term.* An introduction to study of the evolution of the earth's surface during the past million years. Sedimentary, erosional, and tectonic processes involved in the development of landscapes; Pleistocene and Holocene stratigraphy; the use of soils, weathering rates, radiocarbon dating, palynology, and other tools in deciphering recent geological history. The laboratory will involve the use of aerial photographs and an individual research project. Given in alternate years; offered in 1986–87. Instructor: Sieh.

Ge 131. Origin of the Solar System. *9 units (3-0-6); second term. Prerequisite: instructor's permission.* A critical assessment of the physical processes responsible for the formation of the Sun and planets, including astrophysical constraints, gravitational instabilities and accretion discs, formation and early evolution of the giant planets and their satellite systems, terrestrial planetary accretion, primary differentiation, outgassing, and thermal evolution of solid bodies. Given in alternate years; offered in 1986–87. Instructor: Stevenson.

Ge 135. Regional Geology of Southern California (Seminar). *6 units (3-0-3); second term. Prerequisites: Ge 104 abc, Ge 105 ab or equivalent.* Reading and discussion of selected topics in the geology of southern California and adjacent areas, with emphasis on outlining the important regional research problems. Instructor: Silver.

Ge 136. Regional Field Geology of Southwestern United States. *9 units (1-0-8); third term. Prerequisites: Ge 104 or Ge 105, or instructor's permission.* Includes at least nine days of weekend field trips into areas of southwestern United States displaying highly varied geology. Each student is assigned the major responsibility of being the resident expert on a pertinent subject for each trip. Graded pass/fail. Instructors: Sieh, Allen.

Ge 140 ab. Introduction to Isotope Geochemistry. *6 units (2-0-4); second term. Prerequisite: instructor's permission.* An introduction to the physics and chemistry of isotopes and a broad overview of the principles and conceptual techniques used in stable and radiogenic isotope geochemistry will be illustrated by examples of geologic or planetary processes.

140 a. The processes responsible for natural variations in the isotopic composition of the lighter elements (H, C, O, N, Si, S), with applications to geochemical problems. Isotopic fractionation mechanisms. Use of oxygen and hydrogen isotopic data to study the origin and history of various types of rocks and to determine the climatic records in cherts, carbonate fossils, ancient woods, and ice cores. Significance of $^{34}S/^{32}S$ and $^{13}C/^{12}C$ variations in the sulfur and carbon cycles, with applications to problems in geobiology. Use of stable isotopes in the study of meteorites and lunar materials. Instructor: Epstein.

140 b. The origin and evolution of radiogenic parent-daughter systems in nature, with application to the determination of the ages of rocks and minerals, and of the earth, meteorites, and the moon, mainly utilizing the U-Th-Pb-He, Rb-Sr, Sm-Nd, K-Ar and ^{14}C systems. Applications to problems of igneous petrology and metamorphism, and to the large-scale differentiation of the planets. Instructor: Wasserburg.

Ge 150. The Nature and Evolution of the Earth. *Units to be arranged. Offered by announcement only.* Discussions at an advanced level of problems of current interest in the earth sciences. Students may enroll for any or all terms of this course without regard to sequence. Instructors: Staff and visitors.

Ge 151. Planetary Surfaces. *9 units (3-0-6); third term.* A review of the processes responsible for formation and modification of the surfaces of the terrestrial planets, icy satellites, and small bodies, and the surface histories so recorded. Topics: exogenic surface processes, especially those associated with impact, gravitational degradation, atmospheric modification of surfaces by wind and water, and the direct interaction of surfaces with plasmas; endogenic modification of surfaces by tectonics and volcanism. Given in alternate years; offered 1987–88. Instructors: Staff.

Ge 153. Planetary Radio Astronomy. *9 units (3-0-6); second term. Prerequisite: instructor's permission.* The interpretation of radio astronomy observations of the Moon, Mercury, Venus, Mars, and Jupiter in terms of the planets' surface properties and atmospheric characteristics. Thermal and non-thermal emission mechanisms in planetary atmospheres and surfaces, with emphasis on the construction of mathematical planetary models that can be tested by all possible observational techniques including radio interferometry, planetary occultation, and radar astronomy. Given in alternate years; offered in 1987–88. Instructor: Muhleman.

Ge 154. Planetary Atmospheres. *9 units (3-0-6); third term. Prerequisites: Ma 2, Ph 2, Ge 103, or Ay 151 highly desirable.* Current problems in fluid dynamics, radiative transfer, and atmospheric chemistry as suggested by recent ground-based and spacecraft-related data on the planets and their satellites. Instructors: Yung, Ingersoll.

EE/Ge 157 abc. Introduction to the Physics of Remote Sensing. *9 units (3-0-6).* For course description, see Electrical Engineering.

EE/Ge 158. Application of Remote Sensing in the Field. *6 units (0-5-1).* For course description, see Electrical Engineering.

Ge 160 abc. Seismological Laboratory Seminar. *1 unit (1-0-0); first, second, third terms.* Presentation of current research in geophysics by students, staff, and visitors. Graded pass/fail. Instructor: Anderson.

Ge 166. Physics of the Earth's Interior. *9 units (3-0-6); second term.* Interpretation of the observed geophysical data describing the earth's interior in terms of the earth's evolution, ongoing geodynamic processes, and composition and thermal state of the mantle and core. Instructor: Anderson.

Ge 167. Planetary Physics. *9 units (3-0-6); first term. Prerequisites: Ph 106 abc, AMa 95 abc, or AM 113 abc.* Solar system dynamics, with emphasis on slow changes in the orbit and rotation rates of planets and satellites. Topics: tidal friction, resonant orbits and rotation rates, gravitational fields of planets and satellites, dynamics of polar wandering, continental drift, and planetary rings. Instructor: Goldreich.

Ge 170. Tectonics. *9 units (4-0-5); second term. Prerequisites: Ge 104 b, Ge 105, Ge 106.* Kinematics of plate tectonics and the geological complexities of plate margins; history of the ocean basins, the nature of ocean-continent transitions and a survey of orogenic belts around the world; the application of neotectonic and petrogenetic processes to the interpretation of the geologic record and the application of geophysical theory and data to tectonic analysis. Given every three years; offered 1987–88. Instructors: Saleeby, Kamb.

Ge 176. Physics of Earthquakes. *9 units (3-0-6); first term. Prerequisites: AMa 95 abc or instructor's permission.* Study of earth structure and earthquake phenomena by application of physical principles. Emphasis on understanding complex earthquake phenomena in the light of fundamental physical and mathematical concepts. Topics: structure of the earth in relation to propagation of earthquake waves, static and dynamic models of earthquakes, interpretation of far- and near-field phenomena, significance of earthquakes in plate tectonics, and problems pertaining to earthquake prediction. Instructor: Kanamori.

Ge 177. Quaternary Tectonics and Seismotectonics. *9 units (3-0-6); first term. Prerequisites: Ge 104, 105, and 106 or equivalents.* Geologic manifestations of recent crustal deformation. Geomorphology, stratigraphy, and structural geology applied to the study of active faults and folds in a variety of tectonic settings. Relation of seismicity and geodetic measurements to geologic structure and active tectonics processes, including case studies of selected earthquakes; offered in 1987–88. Instructors: Allen, Sieh.

Ge 181. Sedimentary Environments and Depositional Facies. *9 units (3-3-3); offered by announcement only.* Modern depositional settings, processes of sediment erosion, transport and deposition; stratigraphic principles; interpretation of ancient facies; basin analysis. Instructors: Staff.

Ge 203 ab. Advanced Atmospheres and Ocean. *9 units (3-0-6); second and third terms. Prerequisite: Ge 103 or equivalent.* Advanced topics pertaining to the dynamics, thermodynamics and chemistry of atmospheres and oceans. Course content varies from year to year.

Ge 212. Thermodynamics of Geological Systems. *9 units (3-0-6); first term. Prerequisite: Ch 21 abc, Ge 115 abc or equivalents.* Chemical thermodynamics, with emphasis on applications to geologic problems. Heat flow, diffusion, phase transformations, silicate phase equilibria, solid solutions, the effect of H_2O in silicate melts, and equilibrium in a gravitational field. Text: *Chemical Thermodynamics*, Prigogine and Defay. Given in alternate years; offered in 1986–87. Instructor: Taylor.

Ge 213. Advanced Seminar in the Earth and Planetary Sciences. *Units and prerequisites dependent upon topics. Offered by announcement only.* Seminar on special topics and problems of current interest.

Ge 214. Spectroscopy of Minerals. *9 units (3-0-6); third term. Prerequisite: Ge 114, Ch 21 or instructor's permission.* The origin of color, pleochroism, and luminescence in minerals, infrared absorption spectroscopy of mineral substances. The application of spectroscopic methods to mineralogical problems, including site populations and other optical properties. Given in alternate years; offered in 1986–87 Instructor: Rossman.

Ge 215 abc. Topics in Advanced Petrology. *12 units each term (3-6-3); first, second, third terms. Prerequisites: Ge 115, Ch 21.*

215 a. Chemical Petrology. *First term.* Lectures, seminars, and laboratory studies of the chemical reactions that occur in rocks. Emphasis on rock-water interactions, mineral deposition, hydrothermal alteration, and the formation of ore deposits. Given in alternate years; offered in 1987–88. Instructor: Taylor.

215 b. Advanced Igneous Petrology. *Second term.* Lectures, seminars, and laboratory studies on igneous petrogenesis and rocks, emphasizing experimental studies. Given in alternate years; offered in 1987–88. Instructor: Stolper.

215 c. Advanced Metamorphic Petrology. *Third term.* Lectures, seminars, and laboratory studies on metamorphic petrogenesis and rocks. Emphasis on the interpretation of natural assemblages and of mineral relations. Not offered in 1987–88.

Ge 223. Summer Field Seminar in Cordilleran Tectonics. *12 units (two weeks field work).* Preparatory reading and laboratory session followed by extended field trips in western North America examining and discussing key locations in the tectonic analysis of the North American Cordillera. Students are expected to make independent field observations and to integrate such observations into discussions of the pertinent literature. Given every three years; offered in 1986–87. Instructors: Saleeby, Silver.

Ge 225 abc. Planetary Sciences Seminar. *1 unit (1-0-0); first, second, third terms.* Required of all planetary science graduate students; others welcome. First term: current research by staff and students. Second and third terms: planetary research with spacecraft and current developments in planetary science. Instructors: Staff.

Ge 226. Observational Planetary Astronomy. *9 units (3-0-6); third term.* Optical and infrared radiation detectors, spectrometers, polarimeters, and photometers will be discussed in the context of the observational study of the planets. Other topics will include the design of observational programs and the assessment of the reliability of data by critical analysis of observational literature. Given in alternate years; offered in 1987–88. Instructor: Westphal.

Ge 229. Glaciology. *9 units (3-0-6); offered by announcement only.* Origin and behavior of the North American ice sheet, physical conditions and structures of existing glaciers, glacier flow, erosional and depositional processes and products. Instructor: Kamb.

Ge 232. Chemistry of the Solar System. *9 units (3-0-6); third term. Prerequisite: Ge 140 b or consent of instructor.* An advanced course using both chemical and isotopic data to evaluate the current state of knowledge concerning the composition of major segments of the solar system, viz. solar and meteoritic abundance data to infer the average solar system composition; the chemistry of meteorites as a clue to initial conditions in the solar nebula; the bulk composition of the earth and moon; constraints on the bulk composition of the other planets emphasizing data on atmospheric constituents. Given in alternate years; offered in 1987–88. Instructor: Burnett.

Ge 240. Advanced Isotope Geochemistry. *9 units (3-0-6); third term. Prerequisite: Ge 140 ab or permission of instructor.* Lectures and problems on the variations in the isotopic composition of elements in nature, with applications to studies of the origin of the solar system, planetary evolution, igneous and metamorphic petrology, hydrothermal alteration and ore deposits, and the origin and history of the earth's atmosphere and hydrosphere. Emphasis is placed on the integration of stable and radiogenic isotope studies in current research areas, utilizing problem sets and extensive reading of articles in scientific journals, including discussion of instrumentation and modern techniques of measurement of isotopic and chemical abundances. Given in alternate years; offered in 1986–87. Instructors: Taylor, Wasserburg.

Ge 242. Metal Pathways Through Terrestrial and Marine Ecosystems. *6 units (2-0-4); third term. Prerequisite: instructor's approval.* Sources of lead and some other trace metals in the atmosphere, their depositions on oceans and land plants, their cycling through ecosystems, modes of their introduction to and removal from the oceans, and anthropogenic perturbations of their natural cycles. Instructor: Patterson.

Ge 244 ab. Paleoecology Seminar. *5 units; second, third terms.* Critical review of classic investigations and current research in paleoecology and biogeochemistry. Instructor: Kirschvink.

Ge 247. Tectonics of the North American Cordillera. *9 units (3-0-6); second term. Prerequisite: Ge 121 abc or instructor's approval.* Major structural features of the North American Cordillera, and the present physical state of the crust and upper mantle; craton-ocean plate interactions; analysis of displaced crustal fragments; reactivation of cratonic crust; regional stratigraphic patterns; tectonic significance of igneous and metamorphic belts; relation of neotectonic patterns to paleotectonic records. Given every three years; offered in 1986–87. Instructors: Saleeby, Silver.

Ge 248. Geodynamics. *9 units (3-0-6); third term.* The application of continuum mechanics to geologic problems of mass and heat transfer with emphasis on problems of plate tectonics. Basic concepts include stress, infinitesimal and finite strain, brittle failure, elastic, plastic, viscous, power law and visco-elastic deformation. These concepts will be used to examine selected problems such as the mechanics of subduction, the rise of mantle diapirs and generation of oceanic crust, postglacial rebound, postseismic rebound, generation and effects of anisotropy, mantle convection, and the driving mechanism for plate motions. Given in alternate years; not offered in 1986–87. Instructor: Hager.

Ge 260. Solid-State Geophysics. *9 units (3-2-4); third term. Offered by announcement only. Prerequisite: familiarity with basic concepts of thermodynamics and mineralogy; see instructor.* The application of high-pressure physics to geologic problems. Topics: concepts of elastic and shock propagation in single and polycrystalline solids and in fluids, and their relation to various thermodynamic processes; phase changes, dynamic yielding, shock metamorphism, and high-pressure electrical properties of minerals and application of shock and ultrasonic equation-of-state data to earth and planetary interiors. Instructors: Ahrens, Stevenson.

Ge 261 abc. Advanced Seismology. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 or equivalent.* Essential material in modern seismology; elastic wave propagation, ray theory, normal mode theory, free oscillations, applications to determination of earth structure and earthquake source mechanism, interpretation of seismograms, geophysical time series analysis and synthesis. Instructors: Harkrider, Helmberger.

Ge 265. Geophysical Digital Signal Analysis. *9 units (3-0-6); first term. Prerequisites: Fourier transforms or permission of instructor.* Discrete data analysis with particular emphasis on geophysical problems. Topics: Z-transforms, discrete Fourier transforms, filtering, convolutional models, deconvolution, autoregressive-moving average models, spectral analysis, missing data, model fitting, and two-dimensional and multichannel analysis. Instructor: Clayton.

Ge 266. Analysis of Seismic Reflection Data. *9 units (3-0-6); third term. Prerequisites: partial differential equations and/or permission of instructor.* The analysis of densely recorded reflection data as it relates to exploration geophysics. Topics: review of acoustic wave theory, layered earth models, one-way extrapolations operators, migration methods, velocity estimation, multiple suppression, statics, slant stacks, and inversion methods. Instructor: Clayton.

Ge 268. Inverse Problems in Geophysics. *9 units (3-0-6); second term. Prerequisite: Linear algebra or permission of instructor.* Basic concepts in inverse theory: singular value decomposition, generalized inverse, resolving kernals and error estimation. The application to selected geophysical problems such as 1D and 3D seismic velocity and attenuation structures in the earth from body and surface waves, density structure from gravity and normal modes. Instructor: Tanimoto.

Ge 277. Quaternary Tectonics Seminar. *6 units (1-3-2); second term.* Detailed analysis of one or more active tectonic regions, including discussion of published literature and field examination. Participation in a one-week field excursion during spring break may be required. Instructors: Allen, Sieh.

Ge 282 abc. Geological Sciences Seminar. *1 unit; first, second, third terms.* Presentation of papers by invited investigators. In charge: Hager, Burnett.

Ge 297. Advanced Study. *Units to be arranged.*

Ge 299. Thesis Research. Original investigation, designed to give training in methods of research, to serve as theses for higher degrees, and to yield contributions to scientific knowledge.

GERMAN *(See Languages)*

GREEK *(See Languages)*

HISTORY

Courses above H 20 are open only to students who have fulfilled the freshman humanities requirement.

H 1 abc. Introduction to Europe. *9 units (3-0-6); first, second, third terms.* From the Middle Ages to the present day. Topics and reading vary with instructor, but will usually include feudalism, the Renaissance and Reformation, 17th-century England, the French Revolution and Napoleon, the Industrial Revolution, 19th-century liberalism and nationalism, Marx, overseas expansion, the Russian Revolution, fascism, the two World Wars, and the Cold War. Instructors: Staff.

H 2 ab. Revolution to Roosevelt. *9 units (3-0-6); first, second terms.* An examination of the major topics in American history. First term: topics from the period 1765 to 1877; second term: 1877 to the present. Instructors: Staff.

H 3 ab. Traditional Europe: Society, Material Life and Values before 1800. *9 units (3-0-6).* Introduction to patterns of life and thought in pre-industrial Europe, stressing the structure of economic, political, and cultural life. First term: 300AD–1400AD; second: 1300–1800. Terms may be taken independently. Instructors: Benton, Searle, Hoffman.

H 6 abc. American Life and Thought. *9 units (3-0-6); first, second, third terms.* Topics in the development of American culture, explored through selected social, political, and artistic materials, including essays, novels, and films. Instructor: Rosenstone.

H 8 abc. Introduction to Asia. *9 units (3-0-6).* "Asia" includes that civilizational expanse from Morocco to Japan. No textbook; instead, a variety of books including narrative histories, biographies, novels, and anthropological studies that illuminate aspects of the life, thought, religion, history, politics, and economic development of the area. Instructors: Dirks, Fay, Lee, Prakash.

H 40. Reading in History. *Units to be determined for the individual by the department. Elective, in any term.* Reading in history and related subjects, done either in connection with the regular courses or independently, but under the direction of members of the department. A brief written report will usually be required. Graded pass/fail. *Not available for credit toward humanities-social science requirement.*

H 97 ab. Junior Tutorial. *9 units (2-0-7); second, third terms. Prerequisite: instructor's permission.* Designed for students majoring in history, with frequent meetings between the instructor and student. The course subject matter will vary according to individual needs. Normally taken in the junior year. Instructors: Staff.

H 98 ab. Senior Tutorial. *9 units (2-0-7); first, second terms. Prerequisite: instructor's permission.* Designed for students majoring in history, with frequent meetings between the instructor and student. Normally taken in the senior year. Instructors: Staff.

H 99 abc. Research Tutorial. *9 units (1-0-8). Prerequisite: instructor's permission.* Students will work with the instructor in the preparation of a research paper which will form the basis of an oral examination. Instructors: Staff.

H 103 abc. Medieval and Renaissance Europe.* *9 units (3-0-6).* Cultural, political, and economic history: (a) from the end of the Roman Empire to the First Crusade; (b) from the First Crusade to the age of Dante, exploring relationships between artistic expressions and political, economic, and religious institutions; (c) the 14th and 15th centuries, treating the Black Death, war, the implications of demographic decline, and the culture of the early Renaissance. Terms are independent and may be taken separately. Instructors: Benton, Hoffman, Searle.

H 105. Love in the Western World.* *9 units (2-0-7); first term.* A history of love, marriage, and sexual relations, from antiquity to modern times. Reading in the works of such influential authors as Plato, Ovid, Andreas Capellanus, and Castiglione, with special attention to the growth of romantic love. Instructor: Benton.

H 106 abc. Topics in Medieval and Renaissance History.* *9 units (3-0-6); second term.* Seminar treatment of special topics, varying from term to term, including history of autobiography, economic development, love and marriage, political theory, and childhood. For schedule of anticipated topics, see instructors or Registrar. Instructors: Benton, Searle.

H 107 ab. Psychohistory.* *9 units (3-0-6).* The influence of psychological factors in the course of history and of historical forces in the shaping of groups and individuals. Students are encouraged to take both courses in sequence, though each is a self-contained unit and may be taken separately. H 107 a covers the premodern period and H 107 b the modern period. Instructor: Benton.

H 108. Europe and Asia.* *9 units (2-0-7).* Books both nonfiction and fiction that illuminate such topics in the interrelation of Europe and Asia as the fall of Constantinople, the voyages of discovery, the Opium War, and the British in India. Not offered in 1986–87. Instructor: Fay.

H 109. Protestant, Catholic, and Jew.* *9 units (2-0-7).* Books both nonfiction and fiction that illuminate such topics in the political and social history of religion in Europe as Joan of Arc, Luther, the Spanish Armada, Victorian conformity, and the "final solution." Instructor: Fay.

H 110. Early Modern Europe.* *9 units (3-0-6); third term.* Topics in social and economic history of Europe up to the 19th century, with special attention to quantitative analysis. Topics will include the crisis of the later Middle Ages, violence and religious change, and revolution and political stability. Instructor: Hoffman.

*Advanced courses with credit toward the 36-unit Humanities requirement. Other advanced courses receive credit toward the 36-unit H&SS requirement. See page 83.

H 111 ab. The Italian City-State.* *9 units (3-0-6); two terms; each can be taken separately.* H 111 a: the general political phenomenon of the city-state, and the reactions of Italian thinkers, such as Dante and Machiavelli, to the problems of such societies. H 111 b: Venice, unique among the city-states. Instructor: Searle.

H 112. Contemporary Europe.* *9 units (3-0-6); third term.* Public issues, social trends, and cultural developments that are of special interest in Europe today. While the setting will be historical, particular emphasis will be placed on what has been going on in the last 25 years. Instructors: Staff.

H 113. Germany. *9 units (3-0-6).* Principal historical developments in Germany from the Reformation to the present day. Emphasis on the evolution of social and political institutions and attitudes. Instructor: Ellersieck.

H 114. European Intellectual History.* *9 units (3-0-6); second term.* Topics in the history of European thought since the Enlightenment. Emphasis on philosophy and social theory, and their relations to political, economic, and social developments. Instructors: Staff.

H 115. Seminar on National Security in Historical Perspective.* *9 units (2-0-7); second term.* The process of policy formation within the government, the relationship of disarmament and arms control to defense policy, and the role of international organizations in the development of an orderly world society. Instructor: Staff.

H 116. Russia. *9 units (3-0-6); first term.* The major developments and characteristics of Russian history during the Muscovite and Imperial periods, from the 16th century to the Revolution of 1917. Instructor: Ellersieck.

H 117. The Soviet Union Since the Revolution. *9 units (3-0-6); second term.* Selected episodes of Soviet political, economic, and social history from the Revolution to the present. Emphasis on the continuity of Russian history. Instructor: Ellersieck.

H 118. Britain and Her Empire.* *9 units (2-0-7).* Books both nonfiction and fiction that illuminate such topics in British history after 1815 as the army, the aristocracy, the Reform Act of 1832, Marxism, the working class, and overseas expansion and contraction. Instructor: Fay.

H 119. The Middle East.* *9 units (2-0-7).* Books both nonfiction and fiction that illuminate the history of this area from Muhammad to the present, with particular attention to the relations between Arabs and Jews. Instructor: Fay.

H 121. South Asian Civilization.* *9 units (3-0-6); third term.* The development of religious, mythological, and philosophical traditions in South Asia and the implications of this development for contemporary society and polity. Particular attention will be paid to Hindu thought. Not offered in 1986–87. Instructor: Dirks.

H 122. Gandhi.* *9 units (3-0-6).* Readings will include Gandhi's *Autobiography,* biographies and memoirs, detailed studies of Gandhi's political role in the Indian nationalist movement and of the traditional roots of his charisma, and several conflicting assessments of the significance of Gandhi's political style and ideology for modern India and the world. Instructor: Dirks.

H 123. Caste, Village, and Peasant in South Asia.* *9 units (3-0-6).* Fundamental institutions in India's history and society. Readings will consist of anthropological studies and historical perspectives of kinship and hierarchy, village social structure and patterns of settlement, agriculture, religion, and the difference between peasant and tribal society. Instructor: Dirks.

*Advanced courses with credit toward the 36-unit Humanities requirement. Other advanced courses receive credit toward the 36-unit H&SS requirement. See page 83.

H 124 ab. Family History in Premodern Societies.* *9 units (3-0-6).* Four aspects of family history in China, India, and Europe. The first is demographic, establishing the parameters of birth, marriage, and death. The second is economic, treating the family as a unit of production as well as consumption. The third is social, analyzing the evolving structure of various kin groupings—lineage, clan, household, and family. The fourth is cultural, identifying and interpreting the symbolic forms and meanings of the "family." The main focus will be on Asia. Instructors: Dirks, Lee.

H 125. History and Anthropology.* *9 units (3-0-6); second term.* A study of works by anthropologists who write on historical topics and by historians who borrow from anthropology. Examples drawn from Asian and European history include religious ritual, family structure, village life, political organization, and revolution. Instructor: Dirks.

H 130. History of War. *9 units (3-0-6); first term.* Instructive episodes in the evolution of warfare. Emphasis upon the role of political, economic and social factors in influencing the choice of organization, armament, tactics and the timing of conflict. Instructor: Ellersieck.

H 131. History through Film.* *9 units (2-2-5).* An approach to historical problems in part through the medium of full-length, fictional motion pictures. Each term will focus on a specific theme. Instructor: Rosenstone.

H 132. Japan.* *9 units (3-0-6); third term.* An introduction to Japanese civilization, past and present. The interrelation between art, culture, philosophy, politics, and society. Instructor: Rosenstone.

H 133. History of Ancient China, 2000 B.C.–1200 A.D.* *9 units (3-0-6).* A systematic analysis of the growth and character of China from its early origins to the eve of the Mongol invasion. The characteristic development and unique features of pre-imperial and imperial China, including the periods of the first empire, disunion, and the second empire, will be examined in the context of how China developed into an enduring political and social entity. Instructor: Lee.

H 134. History of Late Imperial China, 1200–1800.* *9 units (3-0-6); first term.* An exploration of several major problems, including the growth of autocracy, population development, social mobility, and the Ming-Qing dynasty transition in the history of China, from the formation of the Mongol empire to the eve of the Opium War. Instructor: Lee.

H 135. History of Modern China, 1800–present.* *9 units (3-0-6).* The main events of 19th- and 20th-century China, with the various interpretations of their historical significance. Focus is on the modern roots of the Chinese revolution beginning with Sun Yat-Sen. Not offered in 1986–87. Instructors: Fay, Lee.

H 146. American Biography.* *9 units (3-0-6).* Leading Americans as seen through the best of their biographies, with an examination of the changing methods in the art of biography. Instructor: Ridge.

H 147. The Far West and the Great Plains.* *9 units (3-0-6).* The exploration and development of the great regions of western America. Special attention will be paid to the influence of the natural environment, and the exploitation of it by such industries as the fur trade, mining, cattle ranching, farming, and oil. Instructor: Ridge.

H 148. The Supreme Court in U.S. History.* *9 units (3-0-6); third term.* The development of the Supreme Court, its doctrines, and its role in U.S. history through analyses of selected cases. Not offered in 1986–87. Instructor: Kousser.

*Advanced courses with credit toward the 36-unit Humanities requirement. Other advanced courses receive credit toward the 36-unit H&SS requirement. See page 83.

H/SS 150. Problems in the History of English Law and Society.* *9 units (3-0-6); first term. Available for credit toward the 36-unit undergraduate humanities requirement or for option requirements in social science.* Aspects of the development of law and society in pre-industrial England. A particular problem, which may differ from one term to another, will consider the relationship between actions at common law, legal administration, legislation, social structure, and the economic basis of society. Can be used to satisfy advanced law requirement if SS 33 has been taken previously. Instructor: Searle.

H 151. The Shaping of Modern America, 1890–1917.* *9 units (3-0-6).* Selected social, economic, and political trends of the era, such as immigration, urbanization, and reform. Instructor: Kousser.

H 152. America in the Era of Roosevelt and Truman.* *9 units (3-0-6); second term.* Topics in the history of the Depression, World War II, and the origins of the Cold War. Instructors: Kevles, Rosenstone.

H 153 ab. America Since World War II.* *9 units (3-0-6); second, third terms.* Topics in the recent social, cultural, and political history of the United States. First term is not a prerequisite for second term. Instructor: Kevles.

H 156. The History of Modern Science.* *9 units (3-0-6).* Selected topics in the development of the physical and biological sciences since the 17th century, with emphasis on the evolution of scientific ideas as a problem in intellectual history. Instructor: Kevles.

H 157. Science in America, 1865–Present.* *9 units (3-0-6).* A study of the social and political history of American science, emphasizing the relationship of the research community to universities, industry, and government. Instructor: Kevles.

H 159. American Radicalism.* *9 units (3-0-6); second term.* The nature of dissident American social and political movements in the 19th and 20th centuries, with emphasis on their critiques of American life, their role in society, and their contributions. Not offered in 1986–87. Instructor: Rosenstone.

H 161. Selected Topics in History. *9 units (3-0-6). Advanced credit to be determined on a course-by-course basis by the instructor.* Instructors: Staff and visiting lecturers.

H 201. Reading and Research for Graduate Students. Units to be determined for the individual by the staff.

HUMANITIES

Introduction to Humanities. Practical courses in the basic disciplines of the humanities that emphasize reading, thinking, and writing.

Hum 1 ab. Introduction to Interpretation. *9 units (3-0-6); first and second terms, second and third terms. The initial term is a prerequisite for the next.* Introduction to methods for interpreting different types of cultural works, to develop skills that will allow the student to critically interpret these works. Given in two two-quarter sections. Instructors: Staff.

Hum 101. Historical Explanations. *9 units (3-0-6); first term.* The aims, methods, and objectives of different historical writings from the classical world to the present. A comparative study of certain fundamental forms and concepts: fact, event, explanatory program, form of textualization. Instructor: McGann.

*Advanced courses with credit toward the 36-unit Humanities requirement. Other advanced courses receive credit toward the 36-unit H&SS requirement. See page 83.

Hum 102. Critical Philosophy. *9 units (3-0-6); second term.* The course begins with an examination of ancient methods of dialectic and moves forward to the work of various modern critical thinkers, including Marx, Nietzsche, the Frankfurt School, and several contemporary European philosophers, including Baudrillard. Instructor: McGann.

Hum 103. An Introduction to Film.* *9 units (3-0-6).* A survey of filmmaking and the film industry with an examination of selected films. Instructor: Gaskell.

Hum 104. Plato.* *9 units (3-0-6).* The course will read the major dialogues. Studies the Socratic Myth *(Protagoras, Euthyphro, Apology, Crito)*, the Platonic Eros *(Phaedrus, Symposium)*, and the ***Republic*** and selections from the *Laws*. Class reports and final paper. Instructor: McGann.

*Advanced courses with credit toward the 36-unit Humanities requirement. Other advanced courses receive credit toward the 36-unit H&SS requirement. See page 83.

HUMANITIES AND SOCIAL SCIENCES

HSS 99. Humanities-Social Science Tutorial Program. Upon application and screening by the tutorial committee, which is composed of HSS faculty, a limited number of sophomores, juniors, and seniors will be admitted to a tutorial program. Once admitted, a student will work on a one-to-one basis with tutors drawn from the division's faculty, at the rate of 9 units per term, on subjects agreed upon between student, tutor, and the tutorial committee. Written work will be required, letter grades given, and a term's work and grade reported (through the tutorial committee) in the form shown by the following example:

HSS 99 Tutorial (World War I in fiction) 9 units.
Instructor: Tutorial Committee Staff.

The tutorial committee will review each student's work periodically, may require that a student take regular HSS courses along with or prior to a tutorial, and may ask a student to leave the program altogether.

The program is not designed for students in the four HSS options, and units earned in it do not take the place of course or tutorial instruction in those options, unless the option representatives approve. The program is nevertheless open to applicants from those options.

HYDRAULICS

Hy 100. Hydraulics Problems. *Units to be based upon work done, any term.* Special problems or courses arranged to meet the needs of first-year graduate students or qualified undergraduate students. Graded pass/fail.

Hy 101 abc. Fluid Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisites: ME 19 abc and Hy 111 or equivalents.* General equations of fluid motion; two- and three-dimensional steady and non-steady potential motion; cavity and wake flow; surface waves, linear and nonlinear shallow-water waves, flow in stratified fluids, stability; acoustic fields, sound radiation and scattering, acoustic energy transport; one-dimensional steady and non-steady gas-dynamics, expansion fans, shock waves; two- and three-dimensional flow fields; laminar flow, Stokes and Oseen problems, laminar boundary layer; laminar instability, turbulent shear flow; introduction to problems in heterogeneous flow, chemically reacting flow, sediment transport, flow through porous media. Instructor: Marble.

Hy 105. Analysis and Design of Hydraulic Projects. *6 or more units as arranged; any term.* The detailed analysis or design of a complex hydraulic structure or water resources project emphasizing interrelationships of various components, with applications of fluid mechanics and/or hydrology. Students generally work on a single problem for the entire term, with frequent consultations with their instructor. Instructors: Staff.

Hy 111. Fluid Mechanics Laboratory. *6–9 units as arranged with instructor; third term. Prerequisite: ME 19 ab.* A laboratory course in the basic mechanics of incompressible fluid flow, complementing lecture course ME 19 abc. Students usually select approximately three regular experiments, but they may propose special investigations of brief research projects of their own. Students also gain experience in making engineering reports. Although the course is primarily for seniors, it is also open to first-year graduate students who have not had an equivalent course. Instructors: Staff.

Hy 113 ab. Coastal Engineering. *9 units (3-0-6); first, second terms. Prerequisites: ME 19 abc and Hy 111 or equivalents; AMa 95 abc.* Engineering applications of the theory of small and finite amplitude water waves; diffraction, reflection, refraction; wind-generated waves and wave prediction procedures; tides and their interaction with the coastline; effect of waves on coastal structures such as breakwaters and pile-supported structures; coastal processes. Not offered every year. Instructor: Raichlen.

Hy 121. Advanced Hydraulics Laboratory. *6 or more units as arranged; any term. Prerequisite: instructor's permission.* A laboratory course, primarily for first-year graduate students, dealing with flow in open channels, sedimentation, waves, hydraulic structures, hydraulic machinery, or other phases of hydraulics of special interest. Students may perform one comprehensive experiment or several shorter ones. Instructors: Staff.

Hy 200. Advanced Work in Hydrodynamics or Hydraulic Engineering. *Units to be based upon work done; any term.* Special course to meet the needs of advanced graduate students.

Hy 201 abc. Turbomachines. *6 units (2-0-4); first, second, third terms. Prerequisite: Hy 101 or instructor's permission.* The theory and operation of hydraulic fluid machines, principally pumps, and turbines. Recent two- and three-dimensional inviscid flow design theories. Special consideration to the effects of cavitation in methods of design and behavior of large systems. Not offered every year. Instructor: Acosta.

Hy 204 abc. Hydrodynamics of Free Surface Flows. *9 units (3-0-6); first, second, third terms. Prerequisites: Hy 101 abc, AM 113 abc and AM 125 abc, or equivalent.* Theory of surface waves in a dispersive medium. Infinitesimal waves and wave resistance of floating or submerged bodies. Ship hydrodynamics. Theory of planing surface and hydrofoil. Scattering and diffraction of surface waves. Geometrical wave approximation. Hydrodynamic stability. Nonlinear waves and existence theorems. Shallow-water waves. Open-channel flows and river waves. Flows with shear and stratification of density and entropy. Free streamline theory for jets, wakes, and cavities. General theory for curved obstacles; existence and uniqueness. Unsteady flows with jets and cavities. The course material in the third term may vary, depending upon the needs and interests of the class. Not offered in 1986-87. Instructor: Wu.

Hy 210 ab. Hydrodynamics of Sediment Transportation. *9 units (3-0-6); second, third terms. Prerequisites: AMa 95 abc, Env 112 abc, and Hy 101 abc.* The mechanics of the entrainment, transportation, and deposition of solid particles by turbulent fluids, including discussion and interpretation of results of laboratory and field studies of alluvial streams, and wind erosion. Not offered every year. Instructor: Brooks.

Hy 211. Advanced Hydraulics Seminar. *4 units (2-0-2); every term.* A seminar course for advanced graduate students to discuss and review the recent technical literature in hydraulics and fluid mechanics. Civil and environmental engineering topics that are not available in courses offered by the Division of Engineering and Applied Science. Subject will vary depending upon the needs and interests of the students. May be taken any number of times with the permission of the instructor. Instructors: Staff.

Hy 213. Advanced Coastal Engineering. *9 units (3-0-6); third term. Prerequisites: Hy 101 abc and Hy 113 ab.* Selected topics in coastal engineering such as harbor resonance, mooring and berthing of ships, structural forces due to waves, tsunamis and other impulsive wave systems. Not offered every year. Instructor: Raichlen.

Hy 300. Thesis Research.

INDEPENDENT STUDIES PROGRAM

Students who have chosen to enter the Independent Studies Program (ISP) instead of a formulated undergraduate option may enroll in special ISP courses. These courses are designed to accommodate individual programs of study or special research that fall outside ordinary course offerings. The student and the instructor first prepare a written course contract specifying the work to be accomplished and the time schedule for reports on progress and for work completed. The units of credit and form of grading are decided by mutual agreement between the instructor, the student, and his or her advisory committee. See page 106 for complete details.

JET PROPULSION

JP 121 abc. Jet Propulsion Systems and Trajectories. *9 units (3-0-6); each term. Open to all graduate students and to seniors with permission of the instructor.* Modern aspects of rocket, turbine, electrical, and nuclear propulsion systems and the principles of their application to lifting, ballistic, and space flight trajectories. Combustion and burning characteristics of solid and liquid propellants, liquid propellant fuel systems, combustion instability. Subsonic and supersonic compressors and turbines, basic gas turbine propulsion cycle and its variations, inlets and diffusers. Nuclear rockets, nuclear air breathing cycles. Instructors: Marble, Zukoski.

JP 131. Combustion Technology. *9 units (3-0-6); third term. Prerequisites: APh/ME 17 and ME 19.* Application of fluid dynamic and chemical principles to the study of combustion processes, including the theoretical and experimental treatment of laminar and turbulent flames; the combustion of liquid droplets and solid particles; and technical aspects of gas, oil, and coal combustion. Instructor: Zukoski.

JP 170. Jet Propulsion Laboratory. *9 units (0-9-0); third term.* Laboratory experiments related to propulsion problems. Instructor: Zukoski.

JP 213. Dynamics of Reacting Gases. *9 units (3-0-6); each term. Prerequisites: Ae/APh 101 abc or Hy 101 abc, or equivalent.* Application of gas dynamic and chemical principles to the study of combustion processes, including the theoretical and experimental treatment of laminar and turbulent flames; acoustic and detonation waves; the volatilization and combustion of liquid droplets and solid particles; combustion problems of air-breathing engines and of liquid and solid propellant rockets; flame stability; and aspects of gas, oil, and coal combustion. Not offered in 1986–87. Instructor: Marble.

JP 270. Special Topics in Propulsion. *6 units (2-0-4); each term.* The topics covered will vary from year to year. Instructors: Staff.

JP 280. Research in Jet Propulsion. *Units to be arranged.* Theoretical and experimental investigations of problems associated with propulsion and related fields. Instructors: Staff.

JP 290 abc. Advanced Seminar in Jet Propulsion. *1 unit (1-0-0); each term.* Seminar on current research problems in propulsion and related fields. Instructors: Staff.

LANGUAGES

L 39. Reading in French, German, or Russian. *Units to be determined for the individual by the department.* Reading in scientific or literary French, German, or Russian under the direction of the department. Graded pass/fail. *Not available for credit toward humanities-social science requirement.*

HSS 99. See page 224 for description.

L 101. Selected Topics in Language. *Units to be determined by arrangement with the instructor.* Graded pass/fail. Instructors: Staff and visiting lecturers.

L 102 abc. Elementary French. *10 units (3-1-6); first, second, third terms.* The course aims at providing a superior reading knowledge plus competence in general conversation. Students who have had French in secondary school or college must consult with the instructor before registering. Not open to students with more than one previous year of French. Instructors: Staff.

L 103 abc. Intermediate French. *9 units (3-0-6); first, second, third terms. Prerequisite: L 102 abc or equivalent.* Grammar review, conversation practice, introduction to French history, literature, and politics, and exposure to basic scientific and technical reading and communicating. Instructors: Staff.

L 105 abc. French Literature. *9 units (3-0-6); first, second, third terms. Prerequisite: L 103 abc or equivalent. Courses need not be taken in sequence.* Each term treats a body of French literature from the standpoint of a dominant theme. Conducted in French. Instructor: A. Smith.

L 110 abc. Elementary Greek. *9 units (3-0-6); first, second, third terms.* Course objective is to learn to read ancient Greek with speed and accuracy. First and second terms will not count towards 108-unit requirement unless third term is completed. Instructor: Pigman.

L 130 abc. Elementary German. *10 units (3-1-6); first, second, third terms.* Grammar fundamentals and their use in aural comprehension, speaking, reading, and writing. Students who have had German in secondary school or college must consult with the instructor before registering. Instructors: Aebi, Washburn.

L 132 abc. Intermediate German. *9 units (3-0-6); first, second, third terms. Prerequisite: L 130 abc or equivalent.* Reading of short stories and plays, grammar review, and aural and oral drill. Students who have studied German elsewhere must consult with the instructor before registering. Instructor: Aebi.

L 139. Independent Reading in French, German, or Russian Literature. For graduate students who have completed at least one year of literature in the foreign language. Units to be determined for the individual by the department. Graded pass/fail. Instructors: Staff.

L 140 abc. German Literature. *9 units (3-0-6); first, second, third terms. Prerequisite: L 132 abc or equivalent.* The reading and discussion of works by selected 19th- and 20th-century authors. Conducted in German. Instructors: Staff.

L 141 abc. Elementary Russian. *10 units (3-1-6); first, second, third terms.* The course covers grammar and builds toward the capacity to understand, speak, read, and write Russian. Students who have had Russian in secondary school or college must consult with the instructor before registering. Instructor: Lindholm.

L/Lit 151. Literature and the Natural Sciences in Translation. *9 units (3-0-6); first term.* Discussion of 18th- and 19th-century authors, focusing on their response to the natural sciences of their time. The reading will be largely French (e.g., Diderot, Balzac, Stendahl, Gobineau, Zola), but may include Anglo-American works. (Note: this course will also be given in French under the listing of L 105.) Instructor: A. Smith.

L/Lit 152 ab. French Literature in Translation: Classical and Modern. *9 units (3-0-6).* First term: French "classical" literature of the 17th and 18th centuries; second term: from 1939 to the present, and with literary responses to "the Absurd." Readings are in English, but students may read French originals. Instructor: A. Smith.

L 153 abc. Intermediate Russian. *9 units (3-0-6); first, second, third terms. Prerequisite: L 141 abc or equivalent.* Grammar review, readings, discussion, and reports on material from Russian science, culture, and history. Instructors: Staff.

L/Lit 154. French Literature in Translation: The French Novel. *9 units (3-0-6); second term.* Famous novels of the 16th to the 20th century are read against the historical, sociological, and philosophical background. Readings are in English, but students may read the French originals. Not offered in 1986–87. Instructor: A. Smith.

L/Lit 160 ab. German Literature in Translation.* *9 units (3-0-6).* First term: from the Middle Ages through the Romantic Age. Second term: literature of the 20th century, stressing Kafka, Hesse, T. Mann, Frisch, Duerrenmatt, and Grass. Instructors: Staff.

L/Lit 165 abc. Russian Literature in Translation.* *9 units (3-0-6); first, second, third terms.* The development of Russian literature in its socio-historical context from the Classical period to contemporary Soviet texts. Authors will range from Pushkin to Solzhenitsyn. All readings in English. Instructor: Cheron.

L 166 abc. Russian Literature. *9 units (3-0-6); first, second, third terms. Prerequisite: L 153 or equivalent and by special arrangement with the instructors.* Reading and discussion of representative works of selected 19th- and 20th-century Russian authors. Conducted in Russian. Students are advised to take these courses in sequence. Instructors: Staff.

L/Lit 167 abc. Latin Literature.* *9 units (3-0-6); first, second, third terms. Prerequisite: three years of high school Latin or equivalent.* Intensive study of such writers as Catullus, Horace, Lucretius, Ovid, Patronius, Plautus, Terence, and Virgil. The reading may vary from year to year; student may repeat the course with permission of the instructor. Instructor: Pigman.

*Advanced courses with credit toward the 36-unit Humanities requirement. Other advanced courses receive credit toward the 36-unit H&SS requirement. See page 83.

LINGUISTICS

Lin 101 a. Introductory Linguistics. *9 units (3-0-6); first term.* Language is a system that carries meaning to sound. Phonology is the study of sound; semantics is the study of meaning. Syntax is about the ways we go from phonology to semantics. Phonetics, phonemic theory, morphology, phrase structure grammar, transformational grammar. Extensive reading required. Instructor: B. Thompson.

Lin 101 b. Linguistic Theory. *9 units (2-1-6); second term.* Current models of language structure, especially in syntax and semantics. Transformational generative grammar, case grammar, generative semantics, semantic theories. A research project is required. Instructor: B. Thompson.

Lin/SS 103. Psycholinguistics. *9 units (2-1-6); third term.* A seminar-type course on language behavior as a reflection of conceptual processes. Language acquisition, aphasia and other language disturbances, linguistic memory and grammar organization, language and the brain, multilingualism. A research project is required. Instructor: B. Thompson.

Lin/SS 104. Sociolinguistics. *9 units (2-1-6).* Seminar and research on language in social interaction. Experiments required. Readings in language variation (dialects, slang, jargon, scientific, and other). Given in alternate years; offered in 1986–87. Instructor: B. Thompson.

Lin/SS 105. Computational Linguistics. *9 units (2-1-6); first term. Prerequisite: Lin 101 a or Lin 101 b or equivalent.* English as a language for communication with computers. Problems in parsing and semantic data base analysis. Review through readings of natural language processing systems, including speech recognition and other AI (artificial intelligence) applications. Research required. Given in alternate years; not offered in 1986–87. Instructors: B. Thompson, F. Thompson.

LITERATURE

Courses above Lit 20 are open only to students who have fulfilled the Freshman Humanities requirements.

Lit 1 abc. Literature Past and Present. *9 units (3-0-6); first, second, third terms.* A critical exploration of literature, primarily English, from the Middle Ages or the Renaissance to the present. Instructors: Staff. *Students may not receive credit for both Lit 1 and Lit 2 a.*

Lit 2 a. Tragedy. *9 units (3-0-6); first term.* Readings in the theory and practice of tragedy, in an effort to understand the nature of the genre, the sources from which it springs, and the different forms it may take. Not offered in 1986–87. Instructors: Staff.

Lit 2 b. Comedy. *9 units (3-0-6); second term.* Readings in the theory and practice of comedy and satire, as above (in Lit 2 a). Not offered in 1986–87. Instructors: Staff.

Lit 4. Introduction to Poetry. *9 units (3-0-6); second, third terms.* What is poetry? Why does it exist? Why and how should one read it? Working from basic concepts in aesthetics, students will read and discuss a substantial range of poems, from simple to complex. Instructors: Staff.

Lit 5. Literature of Initiation. *9 units (3-0-6); second term.* A study of the experience of initiation, the passage in an individual's life from innocence into experience, and the consequent emergence of a new identity during a critical period of confrontation, testing, and conversion. The reading will vary from year to year, but will include selected readings in anthropology and psychology as well as novels, short stories, and plays. Instructor: D. Smith.

Lit 6. The Hero and Society. *9 units (3-0-6); third term.* A study of the development of the hero from his role as a model of society's ideals through his emergence into the "anti-hero" of much contemporary literature. Reading matter will vary, chosen from ancient, medieval, and modern literatures. Instructors: Staff.

Lit 7. Literature and Myth. *9 units (3-0-6); third term.* A study of significant myths and of ways in which they have influenced the literature of Western civilization—particularly the literature of Britain and America. Instructor: Ende.

Lit 8. The Self in Literature. *9 units (3-0-6).* Students investigate the problem of the "self"—in its relation to other people and to the world at large—through literary works ranging from overt autobiographies to complex fictions on the nature of human identity. Not offered in 1986–87. Instructors: Staff.

Lit 9 abc. Special Topics in Literature. *9 units (3-0-6).* Topics ranging from classical myth to modern poetry. When offered, specific course content is announced prior to preregistration. Instructors: Staff.

Lit 10. Sexual Identity in Literature. *9 units (3-0-6).* A study of male/female roles, relations, and conflicts as a literary theme and problem. Not offered in 1986–87. Instructors: Staff.

Lit 11. Shakespeare through Film. *9 units (3-0-6); second term.* A study of three or four of Shakespeare's major plays (the selection will vary from year to year). Starting with several film versions of each play, the course will consider the problem of dramatic interpretation as a way of approaching the larger problem of interpreting literary works. Instructors: Bush, Sutherland.

Lit 30. Reading in English. *Units to be determined for the individual by the department.* Collateral reading in literature and related subjects, done in connection with regular courses in literature or history, or independently of any course, but under the direction of members of the department. Graded pass/fail. Instructors: Staff. *Not available for credit toward humanities-social science requirement.*

Lit 31. Summer Reading. *Units to be determined for the individual by the department. Maximum 9 units.* Reading in literature, history, and other fields during summer vacation; books to be selected from a recommended reading list, or in consultation with a member of the staff. Critical essays on reading will be required. Graded pass/fail.

Lit 98. Tutorial for Literature Majors. *9 units (2-0-7). Prerequisite: written permission of instructor and convener.* An individual program of directed reading and research for literature majors to undertake the study of an area not covered by regular courses. Instructors: Staff.

HSS 99. See page 224 for description.

Lit 102 ab. The Classical Heritage.* *9 units (3-0-6); first, second terms.* A study of the major texts of Greco-Roman civilization and their background. No knowledge of Greek or Latin is required. Instructor: Pigman.

Lit 103 ab. The Epic of Return.* *9 units (3-0-6); second, third terms.* The *Odyssey* and its transformations. First term: *Odyssey,* the *Aeneid,* Augustine's *Confessions* and Dante's *Divine Comedy;* second term: *Paradise Lost* and *Ulysses.* The first term is a prerequisite for the second. Instructor: Bush.

Lit 106 ab. English and Continental Medieval Literature.* *9 units (3-0-6); second, third terms.* Major medieval literary works and their relationship to the philosophical and social context of the time. First term: English texts, from *Beowulf* to Malory; second term: other European literature in translation, especially Dante's *Divine Comedy.* Instructors: Staff.

Lit 108 abc. Seminar in Creative Writing. *9 units (3-0-6).* An introduction to some of the techniques of writing prose and poetry. Students' writing periodically will be reviewed by the instructor. Instructors: Staff.

Lit 109 abc. Science Writing for Television. *3 units (1-0-2).* Students will write original television scripts, based on materials being prepared for the Caltech television course in physics, "The Mechanical Universe." Both student and professional scripts for this series will be read, edited, and discussed critically with the television staff. Not offered in 1986–87. Instructor: Hutchings.

Lit 112 ab. English Renaissance Literature.* *9 units (3-0-6); first, second terms.* The major genres and themes of English Renaissance literature from the Reformation of the early 16th century through the metaphysical poets of the 17th century. First term: Skelton, More, Spenser, Marston, Wyatt, Marlowe, Shakespeare (sonnets), Jonson. Second term: Middleton, Webster, Donne, Herbert, Vaughan, Crashaw, Marvell. Instructor: Pigman.

Lit 114 ab. Shakespeare.* *9 units (3-0-6); first, third terms.* A close study of Shakespeare's plays with an emphasis on his language, dramatic structures, characters, and themes. Each term

*Advanced courses with credit toward the 36-unit Humanities requirement. Other advanced courses receive credit toward the 36-unit H&SS requirement. See page 83.

will concentrate on a detailed consideration of one of Shakespeare's major comedies or tragedies, followed by a survey of three or four other plays. The first term is not a prerequisite for the second. Instructor: La Belle.

Lit 116. Milton.* *9 units (3-0-6).* Milton's important short works, his epics, and selections from his prose will be read against the background of the major issues of the 17th century. Instructor: Pigman.

Lit 120. Satire and Common Sense in Restoration and 18th-Century Literature.* *9 units (3-0-6).* A seminar on the great writers, the prevailing genres, and the critical theories of the Restoration, Augustan, and mid-18th-century periods. Instructor: Staff.

Lit 122 abc. The English Novel.* *9 units (3-0-6); first term.* Development of the English novel from the 18th century to the present. First term: early novelists, through Scott; second term: the great Victorians; third term: modern British and Irish novelists. Instructor: Sutherland.

Lit 125. Romanticism.* *9 units (3-0-6).* The formations and transformations of European romanticism between its advent in the German *Sturm und Drang* to its late historical development in France in the 1830s. Focus is on representative works by German, English, French, and Russian romantics. Not offered in 1986–87. Instructor: McGann.

Lit 130 abc. The 19th- and 20th-Century Novel.* *9 units (3-0-6).* A three-term exploration of the late 19th- and 20th-century European, English, and American novel. No term is a prerequisite to the other terms. A study of the great seminal figures. Instructor: D. Smith.

Lit 131. Vision and Community in American Literature.* *9 units (3-0-6).* An examination of one of the central tensions in the American experience, from its beginnings in the Anne Hutchinson trial to its manifestation in the work of T.S. Eliot. Instructor: Bush.

Lit 132. American Naissance-Renaissance.* *9 units (3-0-6).* Major figures of an emerging national literature in the romantic period: Irving, Brown, Cooper, Poe, Emerson, Thoreau, Hawthorne, and Melville. Instructor: D. Smith.

Lit 136. 19th-Century American Poetry.* *9 units (3-0-6).* The works, lives, and backgrounds of Walt Whitman and Emily Dickinson, and other poets as late as 1914. Instructors: Staff.

Lit 138. The Gilded Age.* *9 units (3-0-6); third term.* Major figures from the post-Civil War period to the First World War, including Twain, James, Howell, Norris, Wharton, Dreiser, and Stephen Crane. Instructor: D. Smith.

Lit 145. James Joyce.* *9 units (3-0-6).* Through *Dubliners* to *Ulysses:* an introduction to one of the most challenging and rewarding of 20th-century novels. Instructor: Gaskell.

Lit 146 ab. 20th-Century American and British Poetry.* *9 units (3-0-6); second, third terms.* A two-term seminar on the major poets and poetic theories from the turn of the century to the present. First term: American poets; second term (may be taken independently of the first): British poets. Not offered in 1986–87. Instructor: Bush.

Lit 147. Contemporary American Poetry.* *9 units (3-0-6).* Works of the principal poets and poetic movements that developed in the United States after the Korean War. Various poets and poetic movements, including the Confessional Poets, the New York school, Beat poetry, Deep Image work, and the Language poets. Instructor: McGann.

Lit 148. The Poetry of Ideas.* *9 units (3-0-6).* Study of poets whose works are meant to be taken seriously for their ideas and their knowledge, whether systematic, positive, or both. The relation between poetry and philosophy. Writers to be studied are Lucretius, Shelley, Pound, and a group of contemporary American poets. Final paper. Instructor: McGann.

*Advanced courses with credit toward the 36-unit Humanities requirement. Other advanced courses receive credit toward the 36-unit H&SS requirement. See page 83.

Lit 149 ab. Contemporary Latin American Literature.* *9 units (3-0-6); second, third terms.* Analysis and discussion of major works of fiction in translation by such writers as García Márquez, Vargas Llosa, Cortázar, Borges, Puig, Amado, Donoso and Fuentes. Attention to social, historical, political, and literary background as well as to specific texts. Texts available in English translation or in original Spanish. Terms can be taken separately. Instructor: Berg.

Lit/Psy 150 ab. Psychoanalysis and Literature.* *9 units (3-0-6); first, second terms.* The ways in which both works of literature and contemporary psychoanalytic theory help to illuminate such basic and essential issues as literary interpretation and meaning, the structure of the unconscious, the relation of childhood to adulthood, and the nature of dreams. Authors covered will vary from term to term and may include Coleridge, Dostoevsky, Kafka, Thomas Mann and Wordsworth. Instructors: Breger, Ende. *May be taken to satisfy advanced humanities requirement or option elective requirements in economics or social science.*

L/Lit 151. Literature and the Natural Sciences in Translation. *9 units (3-0-6).* For course description, see Languages. Not offered in 1986–87.

L/Lit 152 ab. French Literature in Translation: Classical and Modern. *9 units (3-0-6).* For course description, see Languages.

L/Lit 154. French Literature in Translation: The French Novel. *9 units (3-0-6).* For course description, see Languages. Not offered in 1986–87.

L/Lit 160 ab. German Literature in Translation.* *9 units (3-0-6).* For course description, see Languages.

L/Lit 165 abc. Russian Literature in Translation.* *9 units (3-0-6).* For course description, see Languages.

L/Lit 167 abc. Latin Literature.* *9 units (3-0-6).* For course description, see Languages.

Lit 170 abc. From Mysteries to Absurdism: A Survey of Drama. *9 units (3-0-6).* First term: the origins of "modern" drama in the Middle Ages to the Classical Age in 17th-century France. Second term: the "Age of Elegance" in the late 17th century to the "Triumph of the Bourgeoisie" in the 19th century. Third term: theatre from Ibsen to the present. Not offered on a pass/fail basis. Instructor: Mandel.

Lit 171. The Divided Self in Literature and Psychology.* *9 units (3-0-6).* Reading from English and American psychoanalytic researchers as well as readings in 19th- and 20th-century literature exploring the differing views of the self in two disciplines. Representative authors Winnicott, R. D. Laing, Tennyson, Arnold, Yeats and others. Instructor: Ende.

Lit 172. Literary Creativity.* *9 units (3-0-6); second term.* Sources and products of the creative process as exemplified by the works of Milton, Coleridge, Tennyson, Yeats, and Plath. Both the biographies of the writers and the psychological roots of their creativity will be explored. Not offered in 1986–87. Instructor: Ende.

Lit 180. Special Topics in Literature. *9 units (3-0-6).* See Registrar's announcement for details. Advanced credit to be determined on a course-by-course basis by the instructor. Instructors: Staff.

Lit 199. The Literature of Excess.* *9 units (3-0-6); third term.* Several modern traditions of crisis and liminal fiction from their initial appearance in Gothic and Romantic forms. Novels of horror and terror, fantasy texts of various sorts, as well as science fiction and surrealist documents; many of the books will be 20th-century works. Includes some important contemporary authors such as Gabriel García Márquez and Stanislaw Lem. Given in alternate years; offered in 1986–87. Instructor: McGann.

*Advanced courses with credit toward the 36-unit Humanities requirement. Other advanced courses receive credit toward the 36-unit H&SS requirement. See page 83.

MATERIALS SCIENCE

APh/MS 4. Introduction to Materials Science. *6 units (2-0-4).* For course description, see Applied Physics.

MS 5 abc. Structure and Properties of Solids. *9 units (3-0-6); first, second, third terms. Prerequisites: Ch 1 abc, Ph 2 abc.* Application of basic principles of chemistry and physics for understanding the properties of solids. Electron states and the arrangement of atoms. Thermal, electric and magnetic properties. Phase tranformations and diffusion. Dislocations and mechanical properties. Instructor: Wood.

MS 15 abc. Principles of Materials. *9 units (3-0-6); first, second, third terms.* The principles involved in the selection, the thermal treatment, and the mechanical treatment of engineering materials. Metallic materials, with some consideration given to ceramics and polymers. Emphasis on the utilization of phase transformations and strengthening mechanisms to obtain desired properties. Instructor: Buffington.

MS 90. Materials Science Laboratory. *9 units (1-6-2); third term. Prerequisite: MS 15 or equivalent or may be taken concurrently.* An introductory laboratory in relationships between structure and properties of crystalline solids. Experiments involve structure determination by X-ray diffraction, mechanical property measurements, and crystal defect observation by chemical etching, X-ray topography, and transmission electron microscopy. Individual projects may be performed, depending upon the student's interests and abilities. Instructor: Vreeland.

MS 100. Advanced Work in Materials Science. The staff in materials science will arrange special courses or problems to meet the needs of students working toward the M.S. degree or of qualified undergraduate students. Graded pass/fail for research and reading.

MS 105. Mechanical Behavior of Metals. *9 units (3-0-6); second term. Prerequisites: AM 97 abc, MS 5 abc.* The mechanical behavior of metals for engineering applications. Elastic behavior of anisotropic materials and polycrystalline aggregates. Yielding, plastic flow, and strengthening mechanisms, the influence of temperature and rate of loading on plastic deformation. Fracture of metals by ductile flow, brittle cracking, fatigue, and creep. Behavior under impact loading. Instructor: Wood.

MS 120. Kinetics of Crystal Imperfections. *9 units (3-0-6); first term.* Treatment of crystal imperfections, their interactions, and their influence on some physical and mechanical properties; taught at the level of Friedel, *Dislocations*. Instructor: Vreeland.

MS 121. Solid State Diffusion. *9 units (3-0-6); second term.* Fundamentals of diffusion in the solid state; taught at the level of Manning, *Diffusion Kinetics for Atoms in Crystals*, and Shewmon, *Diffusion in Solids*. Instructors: Staff.

MS 130. Metallography and Pyrometry. *9 units (0-6-3); first term. Prerequisite: MS 15 or equivalent.* Metallurgical studies of materials of current technological interest, utilizing optical metallography and photomicrography, temperature measurements, and cooling curves to study phase transformations. Instructor: Wood.

MS 131. Crystal Defects. *9 units (1-6-2); second term. Prerequisite: MS 120.* Techniques used in the study of crystal defects and their influence on physical and mechanical properties; relationship between crystal structure and properties studied in experiments that utilize optical microscopy, electron microscopy, and X-ray topography. Instructor: Vreeland.

MS 132. X-Ray Metallography Laboratory. *9 units (0-6-3); third term. Prerequisite: MS 5 a.* Experiments on X-ray emission spectra and absorption edges. Determination of crystal structures by the Von Laue and Debye-Scherrer methods. Use of the X-ray spectrometer. Study of preferred orientation in cold worked metals. Application of X-ray diffraction methods to the study of the phase diagrams. Instructors: Staff.

MS 200. Advanced Work in Materials Science. The staff in materials science will arrange special courses or problems to meet the needs of advanced graduate students.

MS 205 ab. Dislocation Mechanics. *9 units (3-0-6); second, third terms. Prerequisite: MS 120.* The theory of crystal dislocations in isotropic and anisotropic crystals. Applications of dislocation theory to physical and mechanical properties of crystals taught at the level of Hirth and Lothe, *Theory of Dislocations.* Instructors: Vreeland, Wood.

MS 300. Thesis Research.

MATHEMATICS

Ma 1 abc. Freshman Mathematics. *9 units (4-0-5); first, second, third terms. Prerequisites: high school algebra and trigonometry.* Calculus, ordinary differential equations, and infinite series. Linear algebra, vectors, and analytic geometry. Instructor: Fuller.

Ma 2 abc. Sophomore Mathematics. *9 units (4-0-5); first, second, third terms.* A continuation of the topics introduced in Ma 1 and an introduction to partial differential equations, probability and numerical analysis. Instructors: Woodin, Anderson, Katok.

Ma 5 abc. Introduction to Abstract Algebra. *9 units (4-0-5); first, second, third terms.* Groups, rings, fields, and vector spaces are presented as axiomatic systems. The structure of these systems is studied, making use of the techniques of automorphisms, homomorphisms, linear transformations, subsystems, direct products, and representation theory. Many examples are treated in detail. Instructor: Segev.

CS/Ma 6 abc. Introduction to Discrete Mathematics. *9 units (3-0-6).* For course description, see Computer Science. Instructors: Wales, Velickovic.

Ma 10. Frontiers in Mathematics. *6 units (2-0-4); third term only.* Weekly seminar by a member of the mathematics faculty or a visitor to discuss his or her research at an introductory level; the other class meetings will be used to explore background material related to seminar topics and to answer questions that arise. The course will also help students, especially freshmen and sophomores, find faculty sponsors for individual research projects. Instructor: Wales.

The courses labeled Ma 91 or Ma 191 are one-shot courses reflecting the interests of faculty, visitors, and students. The list below is a selection of titles of Ma 91, Ma 191, and regular courses that have been offered in recent years: Harmonic Analysis in the Complex Plane, Several Complex Variables, Entire Functions and the Fourier Transform, Almost Periodic Functions, Elementary Theory of Meromorphic Functions, Banach Algebras, Asymptotic Series, Theory of von Neumann Algebras, Functional Equations, Uniformly Distributed Sequences Modulo 1, Operational Calculus, Algebraic Geometry, Diophantine Analysis, Representation Theory, Introduction to Lie Algebras, Geometry and Mechanics of Space Curves, Differential Topology, Fixed Point Theory, Coding Theory, Introduction to the Constructive Theory of Functions, Multiparticle Scattering Theory.

Ma 91 a. Introduction to Differential Topology. *9 units (3-0-6); third term.* Instructor: Hawkins. For a general description of the Ma 91 courses, see Ma 191.

Ma 92 abc. Senior Thesis. *9 units (0-0-9); first, second, third terms. Prerequisite: approval of adviser.* Open only to seniors who are qualified to pursue independent reading and research.

The work must begin in the first or second term and be supervised by a member of the staff. Students will submit a thesis at the end of the year. Graded pass/fail.

Ma 98. Reading. *3 units or more by arrangement.* Occasionally a reading course under the supervision of an instructor will be offered. Topics, hours, and units by arrangement. Only qualified students will be admitted after consultation with the instructor in charge of the course. Graded pass/fail.

Ma 100 ab. Introduction to Probability, Statistics, and Complex Variables. *9 units (3-0-6); first, second terms. Prerequisite: Ma 2 ab.* Terms may be taken independently. The first term is an introductory course in probability and statistics. The probability portion will review basic concepts such as random variables, expectations, conditioning and independence, and will introduce some of the most important distributions and stochastic processes, including Poisson processes and Brownian motion. Statistics topics include likelihood-based methods of estimation and hypothesis testing, chi-square and Student's t-test, confidence intervals, and regression analysis. The second term is an introduction to complex variables: topology of plane regions, Cauchy-Riemann equations, Cauchy integral formula, series expansions, analytic continuation, Laurent expansions, and residue calculus. Instructors: Dean, Luxemburg.

Ma 102 a. Differential Geometry of Curves and Surfaces. *9 units (3-0-6); third term. Prerequisite: Ma 108 ab or permission of instructor.* An introduction to the geometry of smooth curves and surfaces in three dimensions. Frenet formulae, first and second fundamental forms, curvature of surfaces, Gauss-Bonnet theorem. Instructor: Knieper.

Ma 108 abc. Advanced Calculus. *12 units (4-0-8); first, second, third terms. Prerequisite: Ma 2 abc or equivalent.* A basic course in analysis. Topics include metric spaces, Lebesgue integration, contraction mapping theorem and applications, differential and integral calculus on manifolds and differential forms. Additional topics chosen from: Fourier series and integrals, introduction to Hilbert space theory, Riemannian geometry and symplectic geometry with applications to classical mechanics. The emphasis is on fundamental concepts that equip the student for further reading and study. Instructors: Simon, Maddaly.

Ma 110 abc. Introduction to Real and Complex Analysis. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 108 a or equivalent.* First term: Theory of analytic functions, contour integration, conformal mappings. Additional material as time allows. Second and third terms: Measure theory and Lebesgue integration, Fubini's theorem, the Radon-Nikodym theorem and the Riesz representation theorem. General topology, Banach spaces, duality, Lebesgue L^{p}-spaces, Hilbert spaces. Applications to the theory of Fourier series and integrals. Instructors: Luxemburg, Hawkins.

Ma 112 ab. Statistics. *9 units (3-0-6); second, third terms. Prerequisite: Ma 100 a or equivalent.* A continuation of the introductory course Ma 100 a, including analysis of variance, nonparametric methods, sequential analysis, decision theory, and exploratory data analysis. Instructor: Lorden. Ma 112 b not offered in 1986–87.

Ma 116 ab. Mathematical Logic and Axiomatic Set Theory. *9 units (3-0-6); first, second terms. Prerequisite: Ma 5 abc or equivalent.* First order logic and model theory; computability theory, undecidability, and Gödel's incompleteness theorems; set theory, the axiom of choice, and the continuum hypothesis. Instructor: Velickovic.

CS/Ma 117 abc. Computability Theory. *9 units (3-0-6).* For course description, see Computer Science. Given in alternate years; not offered in 1986–87.

Ma 120 abc. Abstract Algebra. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 5.* Abstract development of the basic structure theorems of groups, commutative and non-commutative rings, lattices, and fields. Instructor: Aschbacher.

Ma 121 ab. Combinatorial Analysis. *9 units (3-0-6); first, second terms. Prerequisite: Ma 5.* Elementary and advanced theory of permutations and combinations. Theory of partitions. Theorems on choice including Ramsey's theorem and the Hall-König theorem. Existence and construction of block designs with reference to statistical design of experiments, linear programming, and finite geometries. Instructor: Wilson.

Ma 122 a. Topics in Group Theory. *9 units (3-0-6); first term. Prerequisite: Ma 5 abc.* Sporadic groups, including the Mathieu groups represented on Steiner systems, the Golay code, and the Todd module, and the Conway groups represented on the Leech lattice. Preliminary discussion of permutation groups and linear groups. Instructor: Aschbacher.

EE/Ma 126. Information Theory. *9 units (3-0-6).* For course description, see Electrical Engineering.

EE/Ma 127 ab. Error-Correcting Codes. *9 units (3-0-6).* For course description, see Electrical Engineering.

CS/EE/Ma 129 abc. Information and Complexity. *9 units (3-0-6).* For course description, see Computer Science.

Ma 142 abc. Introduction to Partial Differential Equations. *9 units (3-0-6). Prerequisite: Ma 108 or equivalent.*

First term: The theory of ordinary differential equations; existence, uniqueness and continuous dependence. Classification of singularities. Sturm-Liouville problems. Hamiltonian systems. Special topics.

Second term: The theory of partial differential equations; the classical examples; Laplace's equation, the heat equation, the wave equation. Linear and nonlinear first order theory. Characteristic manifolds and the Cauchy-Kovalevsky theorem. Hyperbolic equations in one and in several dimensions. Parabolic equations. Elliptic regularity.

Third term: Special topics chosen from: propagation of singularities, variational methods, quasilinear hyperbolic systems, Schauder estimates, nonlinear functional analysis, linear and quasilinear elliptic equations. Instructor: Taylor.

Ma 144 ab. Probability. *9 units (3-0-6); first, second terms.* Basic theory, including characteristic functions and limit theorems, random walk, Markov chains, Poisson process, Brownian motion. Not offered in 1986–87.

Ma 145 ab. Introduction to Unitary Group Representations. *9 units (3-0-6); first, second terms. Prerequisites: Ma 1 abc. It would be useful, but not required, to have Ma 5, and for the second term, Ma 137.* Representations of groups by unitary operators on Hilbert space. First term: finite groups, including the general theory, Frobenius semidirect product theory, and the representations of the symmetric group from the Frobenius character and the Young tableaux points of view. Second term: compact groups, including the Peter-Weyl theorem and the representations of the classical compact (Lie) groups. If time allows, representations of LCA groups and the Poincaré group will be discussed. In each term, some lectures will be devoted to applications to quantum physics. Graduate students graded pass/fail. Not offered in 1986–87.

Ma 147 abc. Introduction to Dynamical Systems and Ergodic Theory. *9 units (3-0-6). Prerequisite: Ma 110 b or equivalent (may be taken concurrently).* A general introduction to the concepts and techniques used in the theory of dynamical systems and ergodic theory.

First Term: Qualitative dynamics: Periodic orbits, bifurcations, index theory, rotation numbers, recurrence and strange attractors.

Second Term: Ergodic theory: Measure-preserving transformations, ergodic theorems, isomorphism problem, uniform distributions, Weyl's theorem, existence of invariant measures, Krylov-Bogoliubov theorem and the spectral approach.

Third Term: Hyperbolic systems and smooth ergodic theory: Structural theory, topological entropy, connections with statistical mechanics, Lyapunov exponents, the Pesin entropy formulas and non-uniform hyperbolicity. Instructors: Katok, Hawkins.

Ma 151 abc. Introduction to Topology and Geometry. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 108 ab or equivalent:* A basic graduate core course. Fundamental groups and covering spaces, homology, cohomology and calculation of homology groups, exact sequences. Fibrations, higher homotopy groups and exact sequences of fibrations, structure of differentiable manifolds, degree theory, De Rham cohomology, elements of Morse theory. Geometry of Riemannian manifolds, covariant derivatives, geodesics, curvature, relations between curvature and topology. Instructor: Gabai.

Ma 160 abc. Number Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 108 abc or equivalent.* Topics selected from: elementary number theory, zeta functions, distribution of primes, modular functions, asymptotic theory of partitions, geometry of numbers, ideal theory in algebraic number fields, units, valuations, discriminants, differents, and local theory. Not offered in 1986–87.

Ma 190 abc. Elementary Seminar. *9 units; first, second, third terms.* This seminar is restricted to first-year graduate students and is combined with independent reading. The topics will vary from year to year. Graded pass/fail. Instructors: Luxemburg, Kechris, Wales.

Ma 191 ab. Mathematical Methods of Classical Mechanics. *9 units (3-0-6); first, second terms.* Instructor: Knieper.

Ma 191 cd. Disordered Systems in Quantum Mechanics. *9 units (3-0-6); second, third terms.* Instructor: Maddaly.

Ma 191 ef. Topics in Set Theory. *9 units (3-0-6); second, third terms:* Instructor: Woodin.

Ma 216 abc. Advanced Mathematical Logic. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 116 or equivalent.* Topics to be chosen from model theory and its applications to algebra, infinitary logic and admissible sets, ordinary and generalized recursion theory, consistency and independence results in set theory, large cardinals, descriptive set theory. Content varies from year to year so that students may take the course in successive years. Instructor: Kechris.

Ma 218 ab. Advanced Complex Analysis. *9 units (3-0-6); first, second terms. Prerequisite: Ma 100 b or equivalent.* Topics will be selected from: linear spaces of analytic functions, conformal mapping, algebraic functions, Riemann surfaces, linear and nonlinear potential theory, extremal length, functions of several complex variables, approximation in the complex plane and singular integrals. Not offered in 1986–87.

Ma 290. Reading. *Hours and units by arrangement.* Occasionally, advanced work is given by a reading course under the direction of an instructor.

The following research courses and seminars, intended for advanced graduate students, are offered according to demand. They cover selected topics of current interest. The courses offered, and the topics covered, will be announced at the beginning of each term.

Ma 316 abc. Seminar in Mathematical Logic. *9 units. Three terms.* Instructor: Kechris.

Ma 324 abc. Seminar in Combinatorics. Instructor: Wilson.

Ma 325 abc. Seminar in Algebra. *6 units. Three terms.* Instructors: Aschbacher, Wales.

Ma 345 abc. Seminar in Analysis. *6 units. Three terms.* Instructor: Luxemburg.

Ma 347 abc. Seminar in Dynamical Systems. *9 units. Three terms.* Instructor: Katok.

Ma 365 abc. Seminar in Number Theory. *6 units. Three terms.* Instructor: Apostol.

Ma 390. Research. *Units by arrangement.*

Ma 392. Research Conference. *Three terms.*

See also the list of courses in Applied Mathematics.

MECHANICAL ENGINEERING

ME 1 ab. Introduction to Design. *9 units (1-6-2); second, third terms. Prerequisite: Gr 1 or instructor's permission.* Introduction to the field of design in its broadest sense through a coordinated series of short design projects, seminars by practicing designers, and related field trips. Useful graphical and analytical techniques as effective tools for rapid engineering approximations in preliminary layout and design. Elements of mechanisms and computer-aided design, along with other basic aspects of design such as selection of materials and standard components, manufacturing methods, functional, economic, and aesthetic considerations. At least one of the projects will involve some machine shop experience in the construction of a simple prototype or working model. Instructor: Welch.

APh/ME 17 abc. Thermodynamics. *9 units (3-0-6).* For course description, see Applied Physics.

ME 19 abc. Fluid Mechanics and Gasdynamics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 2 abc, Ph 1 abc.* Basic equations of fluid mechanics, theorems of energy, linear and angular momentum, potential flow, elements of airfoil theory. Flow of real fluids, similarity parameters, flow in closed ducts. Boundary layer theory in laminar and turbulent flow. Introduction to compressible flow. Flow and wave phenomena in open channels. The third term may also include topics related to energy production and conversion: theory of fluid machinery and heat transfer. Instructor: Raichlen.

ME 22 abc. Introduction to Thermal Engineering. *9 units (3-0-6); first, second, third terms. Prerequisites: APh 17 abc, ME 19 abc (may be taken concurrently).* The principles of thermal energy transfer and thermal power conversion. Heat transfer by conduction, convection, and radiation. Analyses of open and closed cycles with and without phase change, emphasizing applications to power generation, heat pumps, refrigeration, etc. The basic principles of fluid dynamic machines will introduce concepts of size and speed limitations. Basic studies of thermal, solar, and nuclear power generation. Instructors: Acosta, Cass.

ME 72 abc. Engineering Design. *9 units (3-4-2); first, second, third terms. Prerequisites: Gr 1, ME 1 ab, MS 15, or permission of instructor.* The design process in engineering, stressing the creative aspects, especially problem definition, and concept generation, as well as visual thinking and graphic communication. Techniques in analysis of engineering systems learned previously will be applied. An engineering design contest will be held the first term. The contest will include the design, fabrication, and operation of a device to compete with similar devices designed by other students. Instructors: Antonsson, Welch.

ME 100. Advanced Work in Mechanical Engineering. The staff in mechanical engineering will arrange special courses on problems to meet the needs of students working toward the M.S. degree or of qualified undergraduate students. Graded pass/fail for research and reading.

ME 110. Special Laboratory Work in Mechanical Engineering. *3-9 units per term; maximum two terms.* Special laboratory work or experimental research projects may be arranged by members of the staff to meet the needs of individual students as appropriate. Instructors: Staff.

ME 117. Case Studies in Thermal Systems. *9 units (3-0-6); first term. Prerequisite: ME 22 or equivalent, or permission of the instructor.* A case study approach of the role of heat transfer and fluid flow in the design and analysis of engineering systems. Cases for examination will be drawn from engineering practice. The course may include some participation by guest lecturers. Instructor: Hauptmann.

ME 118 abc. Advanced Thermodynamics and Energy Transfer. *9 units (3-0-6); first, second, third terms. Prerequisites: APh/ME 17 abc, ME 19 abc, or equivalents.* Review of basic equations of fluid flow, energy, and mass transfer. Heat conduction in solids, heat transfer for laminar and turbulent flows in forced and free convection. Introduction to mass transfer and radiation as well as selected topics such as boiling heat transfer, two-phase flow, evaporation and condensation. Instructors: Flagan, Sabersky.

ME 126. Fluid Mechanics and Heat Transfer Laboratory. *9 units (0-6-3); third term. Prerequisites: APh/ME 17 abc, ME 19 ab, or equivalents. Students with other background shall obtain instructor's permission prior to registration.* Introduction to some of the basic measurement techniques and phenomena in the fields of heat transfer and fluid mechanics. Several short projects selected from a rather wide list of possible experiments: free and forced convection, boiling heat transfer, combustion, solid-state energy conversion, free surface flow, turbomachines, and fluidic controls. Instructors: Staff.

ME 130 ab. Introduction to Robotics. *9 units (3-2-4); second and third terms. Prerequisites: AMa 95 abc, AM 35 abc, or equivalent.* Introduction to the theory and practice of robotics. Intended to form the basis for more advanced study, it also serves as a survey of the subject for those who wish to understand its technical foundations. Industrial practice and applications will be outlined, with emphasis on design and system organization issues. Coverage will be predominantly stationary robots in industrial settings. Topics: industrial applications; coordinate systems; spatial transformations; kinematics; dynamics; position and force control; system organization and architecture; computer vision; robot teaching systems; and elementary laboratory experiments with robots. A term project will be required. Instructors: Culick, Hayati.

ME 141 ab. Modeling the Dynamics of Physical Systems. *9 units (3-0-6); first and second terms. Prerequisites: AMa 95 abc or AMa 113 abc (may be taken concurrently), AM 35 abc, E 1 or CS 10, or equivalent.* Virtually all engineering systems exhibit a dynamic exchange of energy, often between regimes (e.g., electrical to mechanical in a motor). Modeling of these dynamic interactions, and the generation of the governing differential equations of state can be accomplished readily using the technique of Bond Graph modeling. Bond Graphs are particularly useful for non-linear systems, systems with multiple forms of energy transmission and storage, and transducer systems including oscillation, amplifiers, feedback and control. They provide a single comprehensive framework for the study of dynamic system behavior. Discussion to include energy transfer, power pairs, duality, causality, and physical analogs. Instructors: Staff.

ME 171 ab. Computer Aided Engineering Design. *9 units (3-0-6); second, third terms. Prerequisites: AMa 95 abc or AMa 113 abc, AM 35 abc, ME 72 abc, E 1 or CS 10, or equivalent. Knowledge of PASCAL, C, or FORTRAN.* The fundamentals of computing analysis and problem solving and graphics are brought together with the design experience providing both background and motivation. Engineering system design and synthesis, including mechanism design; experience in an interactive solid-modeling CAD environment; construction of geometric design models using modeling primitives; dimensioning and tolerancing; discussion of data representation and storage; interfaces to analysis codes; assessment of CAD as an aid to the design process, including the design of several parts and/or a complete device. The first part of the first term will include a brief review of general computing, and an introduction to engineering computer grapics. Instructor: Antonsson.

ME 200. Advanced Work in Mechanical Engineering. The staff in mechanical engineering will arrange special courses on problems to meet the needs of advanced graduate students.

ME 202 ab. Engineering Two-Phase Flows. *9 units (3-0-6); first and second terms. Prerequisites: AMa 95 abc, Hy 101 abc, or equivalents.* Selected topics in engineering two-phase flows with emphasis on practical problems in modern hydro-systems. Fundamental fluid mechanics and heat, mass, and energy transport in multiphase flows. Liquid/vapor/gas (LVG) flows, nucleation, bubble dynamics, cavitating and boiling flows, models of LVG flows; instabilities, dynamics and wave propagation; fluid/structure interactions. Discussion of two-phase flow problems in conventional, nuclear, and geothermal power plants, marine hydrofoils, and other hydraulic systems. Instructor: Brennen.

ME 300. Thesis Research.

Many advanced courses in the field of mechanical engineering may be found listed in other engineering options such as applied mechanics, applied physics, hydraulics, jet propulsion, and materials science.

MUSIC

Mu 21. Music and Dances of India. *9 units (3-0-6); second term.* Survey of music and dances of India, with live performances, films, and tapes. Also instruction in playing the sitar. Instructor: Rao.

Mu 22. Medieval and Renaissance Western Music History.* *9 units (3-0-6); first term.* Development of Western music from the ancient Greeks through medieval monasteries and cathedrals to the chapels, courts, and countryside of the high Renaissance. Includes listening and discussion of style of representative music. Given in alternate years. Instructor: Britton.

Mu 23. Western Music History of the Baroque Era.* *9 units (3-0-6); second term.* Survey of the musical forms and composers active between 1600 and 1750; spans the development of opera, cantata, oratorio, keyboard, chamber and orchestral music through the mature masterworks of Bach and Handel. Given in alternate years. Instructor: Britton.

Mu 24. Western Music of the Age of Enlightenment.* *9 units (3-0-6); third term.* Music of the so-called "pre-Classic" and "Classic" periods (circa 1750–1825), with emphasis on C.P.E. Bach, Haydn, Mozart, and the early works of Beethoven. Given in alternate years. Instructor: Britton.

Mu 25. Western Music History of the Romantic Age.* *9 units (3-0-6); second term.* Examines the concepts of Romanticism found in other ages, and a wealth of music from late Beethoven to the "post" Romantics, Mahler, and R. Strauss. Given in alternate years; not offered in 1986–87. Instructor: Britton.

Mu 26. The New Music: Western Music History of the 20th Century.* *9 units (3-0-6); third term.* The diversity of musical styles found in the 20th century. Impressionistic, tonal, atonal, aleatoric, electronic and other avant-garde compositions, and their philosophical-sociological implications. Given in alternate years; not offered in 1986–87. Instructor: Britton.

*Advanced courses with credit toward the 36-unit Humanities requirement. Other advanced courses receive credit toward the 36-unit H&SS requirement. See page 83.

Mu 27. Fundamentals of Music Theory and Elementary Ear Training. *9 units (3-0-6); first term. No prerequisite.* Basic vocabulary and concepts of music theory (rhythm and pitch notation, intervals, scales, function of key signatures, etc.); development of aural perception via elementary rhythmic and melodic dictation, and sight-singing exercises. Instructor: Britton.

Mu 28. Harmony I. *9 units (3-0-6); second term. Prerequisite: Mu 27 or entrance exam.* Study of tonal harmony and intermediate music theory; techniques of chord progression, modulation, and melody writing according to common practice; ear training continued. Instructor: Britton.

Mu 29. Harmony II. *9 units (3-0-6); third term. Prerequisite: Mu 28 or entrance exam.* More advanced concepts of music theory, including chromatic harmony, and 20th-century procedures relating to selected popular music styles; ear training continued. Instructor: Britton.

Mu 30. Special Topics in Western Music History. *9 units (3-0-6); first term; however, term offered may vary due to possibility of coordination with significant off-campus events.* A consideration of selected composers and/or subjects, e.g., the symphonic form, in greater depth than normally possible in the general survey courses. Specific course content to be announced prior to preregistration. Given in alternate years; not offered in 1986–87. Instructor: Britton.

Mu 101. Selected Topics in Music. *Units to be determined by arrangement with the instructor.* Instructors: Staff and visiting lecturers.

EE/Mu 107 abc. Projects in Music and Science. *Units to be individually arranged, up to a maximum of 9.* For course description, see Electrical Engineering.

PERFORMANCE AND ACTIVITIES

Courses under this heading cover the instructional content of a range of extracurricular activities and work in the fine arts and elsewhere. These courses will appear on the student's transcript, and will be graded pass/fail only. The units count toward the total unit requirement for graduation, but they do not count toward the 108-unit requirement in humanities and social sciences.

PA 15 abc. Journalism. *3 units (1-0-2); first, second, third terms.* The elementary principles of newspaper writing and editing, with special attention to student publications at the Institute. Instructor: Hutchings.

PA 20 abc. Debate. *3 units (1-0-2); first, second, third terms.* Study and discussion of the annual intercollegiate debate topic. Instructors: Staff.

PA 21. Forensic Methods. *3 units (1-0-2); first term.* Methods of argumentation in forensic activities, such as debate, extemporaneous speaking, and oratory. *May not be repeated for credit.* Instructors: Staff.

PA 30 abc. Choral Music. *2 units (2-0-0); first, second, third terms.* Instruction in choral ensembles, such as men's and women's glee clubs. Instructors: Staff.

PA 31 abc. Chamber Music. *2 units (2-0-0); first, second, third terms.* Instruction in performing chamber music. Instructors: Staff.

PA 32 abc. Orchestral Music. *2 units (2-0-0); first, second, third terms.* Instruction related to participation in a symphony orchestra. Instructors: Staff.

PA 33 abc. Instrumental Music. *2 units (2-0-0); first, second, third terms.* Instruction related to the performance of instrumental music either as solo instrument or in group performance. Currently offered in three sections: wind ensemble, jazz band, and guitar class. Instructors: Staff.

PA 34. Rhythmic Complexes. *9 units (3-0-6); third term.* Exploring simple to complex rhythms in various music using the Tala system of India. Also instruction in playing the sitar. Instructor: Rao.

PA 35. Music for Piano Ensemble: History, Analysis, Performance. *9 units (3-0-6); first, second terms.* A historical survey of original piano music for two players at one or two pianos from Bach to the present day (arrangements for eight hands will also be included). Attention will be focused on the stylistic trends of various periods and composers through written work and participation. Pianists with varying degrees of performing ability will be admitted to the class at the discretion of the instructor. Instructor: Schonbach.

PA 40 abc. Theater Arts. *3 units (2-0-1); first, second, third terms.* Instruction related to the production of dramatic presentations, including plays, musicals, dramatic readings, etc. Instructors: Staff.

PA 50 abc. Health Advocates. *3 units (1-1-1); first, second, third terms.* A course designed to involve students with health care and education, develop familiarity with common college health problems and provide peer health services on and off campus. First term: CPR and First Aid certification and basic anatomy and physiology. Second and third terms: lectures and discussions on current student and community health problems, symptoms and treatment. Each student will be expected to devote one hour per week to a supervised clinical internship at the Health Center. Instructors: Ketabgian and staff.

PHILOSOPHY

Courses above Pl 20 are open only to students who have fulfilled the freshman humanities requirements.

Pl 1. Introduction to Philosophy. *9 units (3-0-6); second term.* Topics and reading vary with instructor, but usually include discussion of problems of truth, meaning, and validity, with some treatment of common forms of fallacious argument. Introductory formal logic and/or discussion of issues of induction and probability may be included. Instructors: Staff.

Pl 2 abc. Introduction to Moral Philosophy. *9 units (3-0-6); first, second, third terms.* Basic problems in moral philosophy including such questions as: Are assertions about right and wrong true or false, or are they (for example) expressions of personal attitudes? Are there general criteria on the basis of which we can judge actions or characters to be good or bad? Do we have to believe in free will in order to hold people morally accountable for what they do? Instructor: Donagan.

Pl 3 ab. Introduction to Political Philosophy. *9 units (3-0-6); first, second terms.* Basic problems in political philosophy, including such questions as: Under what conditions can people cooperate in the absence of a state? What kinds of activity should states undertake? Does the obligation to obey the law depend on the form of government? The first term will be organized around the ideas of Thomas Hobbes; the second around those of Jean-Jacques Rousseau. Either term may be taken independently. Instructors: Staff.

Pl 4. Greek Philosophy. *9 units (3-0-6); third term.* The development of philosophy in Greece from the pre-Socratic philosophers to Aristotle. Particular attention to the ideas of Socrates (not only as he appears in the Socratic dialogues of Plato), Plato, and Aristotle. Instructor: Donagan.

Pl 5 abc. Special Topics in Philosophy. *9 units (3-0-6); second term.* A survey of the intellectual traditions that have shaped our understanding of human nature, with applications to the social and political realms. When offered, specific course content is announced prior to preregistration. Instructors: Staff.

Pl 30. Reading in Philosophy. *Units to be determined by the instructor. Elective in any term.* Reading in philosophy, done either in connection with the regular courses or independently of any course, but under the direction of members of the department. One or more short papers may be required. Graded pass/fail. *Not available for credit towards humanities-social science requirement.*

Pl 85. Philosophy and Current Issues.* *9 units (2-0-7).* Topics and reading will vary with instructor, but will include some of the following issues: medical experimentation and the allocation of medical resources, abortion and euthanasia, censorship, the use of criminal sanctions against drug-taking, gambling or prostitution, mandatory seat-belt use, tax policy, funding for the arts and sciences, and reverse discrimination. If the course is oversubscribed, preference will be given to students who have successfully completed Pl 2 or Pl 3. Instructors: Staff.

HSS 99. See page 224 for description.

Pl 102. Selected Topics in Philosophy. *9 units (3-0-6).* Instructors: Staff and visiting lecturers.

*Advanced courses with credit toward the 36-unit Humanities requirement. Other advanced courses receive credit toward the 36-unit H&SS requirement. See page 83.

Pl 104. Educational Issues and Problems.* *9 units (3-0-6); first term.* Emphasis on basic changes necessary to facilitate growth and restructuring of the public schools. Topics: innovative curricula, integration and the minority group student, new directions in teacher certification, student-teacher relations, political and financial control of the public schools, school administration and student rights, and the learning process. Selected requirements for credit include required reading, a documented paper, a journal, and visits to local schools. Selected guest speakers prominent in the fields of education and psychology. Instructor: Browne.

Pl 122. Philosophy of Science.* *9 units (3-0-6); first term.* An introduction to fundamental philosophical problems concerning the nature of science. Topics: the character of scientific explanation, criteria for the confirmation and falsification of scientific theories, the relationship between theory and observation, the objectivity of science, and issues having to do with the ways in which scientific knowledge changes over time. Instructor: Woodward.

Pl 181. Democracy.* *9 units (3-0-6); second term.* Alternative concepts of democracy and alternative justifications of a democratic political system, particularly the role of participation and representation in democratic theory. Relevant empirical materials will be presented. Instructors: Barry, Cain.

Pl 182. Ethics and International Relations.* *9 units (3-0-6).* The course considers whether moral criteria can have application in international affairs. The foci will be war and disarmament, economic distribution, and migration. Not offered in 1986–87. Instructors: Barry, Cain.

Pl 183. The Moral, Social, and Political Philosophy of John Stuart Mill.* *9 units (2-0-7); third term.* Students will read the *Autobiography, Utilitarianism, On Liberty, The Subjection of Women,* and part of the *Political Economy.* The course will also follow some of the controversies to which these works have given rise in the period of a century or so since their original publication. Not offered in 1986–87. Instructors: Staff.

Pl 190. Political Philosophy and Public Policy.* *9 units (2-0-7); third term.* A critical examination of methods used in the systematic analysis of public policy alternatives, such as cost-benefit and risk-benefit analysis. Not offered in 1986–87. Instructors: Staff.

*Advanced courses with credit toward the 36-unit Humanities requirement. Other advanced courses receive credit toward the 36-unit H&SS requirement. See page 83.

PHYSICS

Ph 1 abc. Classical Mechanics and Electromagnetism. *9 units (4-0-5); first, second, third terms.* The first year of a two-year course in introductory classical and modern physics. Topics: Newtonian mechanics, electricity and magnetism, and special relativity. Emphasis on both physical insight and the ability to solve problems. Graded pass/fail. Lecturers: Goodstein, Frautschi, Filippone. Section leaders: Newman, Sarachman, and others.

Ph 2 abc. Waves, Quantum Mechanics, and Statistical Physics. *9 units (4-0-5); first, second, third terms. Prerequisites: Ph 1 abc, Ma 1 abc, or their equivalents.* The second year of a two-year introductory course in classical and modern physics. Topics to be covered include electromagnetic waves, optics, introductory quantum mechanics, thermodynamics, and statistical mechanics. Lecturers: Prince, Porter.

Ph 3. Physics Laboratory. *6 units; first, second, third terms.* One three-hour laboratory session per week, an individual conference with the instructor, prelab preparation, and analysis of experimental results outside the laboratory period. This introductory course emphasizes quantitative measurements, the treatment of measurement errors, and graphical analysis. A variety of experimental techniques will be employed: studies of d.c. meters, the oscilloscope, the

Maxwell top, electrical and mechanical resonant systems, and radioactivity. The content of each term is identical and only one term may be taken for credit. Graded pass/fail. Instructor: Gomez.

Ph 4. Physics Laboratory. *6 units; third term only. Prerequisite: Ph 3 or equivalent.* One laboratory period per week, plus other activities outside the lab. Choice of a variety of experiments encompassing both classical and atomic physics. Examples: the transient response of a resonant circuit, the Millikan oil drop experiment, electron diffraction, viscosity, diffraction of electromagnetic waves, and sound waves in a cavity. Graded pass/fail. Instructor: Gomez.

Ph 5. Physics Laboratory. *9 units; first term. Prerequisites: Ph 1 abc, Ph 2 a or Ph 12 a (or taken concurrently), and Ph 3 or equivalent.* Continuation of Ph 3. Measurements of physical quantities, their analysis, and assignment of errors are stressed. Most of the experiments are concerned with topics in the theoretical courses Ph 2 a or Ph 12 a, but experiments in electrostatics and direct currents are also included. Instructor: Gomez.

Ph 6. Physics Laboratory. *9 units; second term. Prerequisites: Ph 1 abc, Ph 2 b or Ph 12 b (or taken concurrently) and Ph 3 or equivalent.* Experiments in electromagnetic phenomena such as electromagnetic induction, properties of magnetic materials and high-frequency circuits. The mobility of ions in gases; precise measurement of the value of e/m of the electron. Instructor: Gomez.

Ph 7. Physics Laboratory. *9 units; third term. Prerequisite: Ph 5 or Ph 6 or equivalent.* Experiments in atomic and nuclear physics, including studies of the Balmer series of hydrogen and deuterium, the decay of radioactive nuclei, absorption of X-rays and gamma rays, ratios of abundances of isotopes, and the Stern-Gerlach experiment. Instructor: Gomez.

Ph 10 abc. Frontiers in Physics. *6 units (2-0-4); first, second, third terms. Open for credit to freshmen and sophomores.* Weekly seminar by a member of the physics department or a visitor to discuss his or her research at an introductory level; the other class meetings will be used to explore background material related to seminar topics and to answer questions that arise. The course will also help students find faculty sponsors for individual research projects. Graded pass/fail. Instructor: Barish.

Ph 12 abc. Quantum and Statistical Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 1 abc, Ma 1 abc, or equivalents.* A one-year course primarily for students intending further work in the physics option. Topics in quantum mechanics: interpretation of the wave-function, one-dimensional problems, and central potentials. Statistical mechanics topics: thermodynamics, introductory kinetic theory, and quantum statistics. May be taken to fulfill the Institute Ph 2 requirement. Instructor: Politzer.

Ph 20, 21, 22. Freshman/Sophomore Computational Physics Laboratory. A series of courses on the application of computers to simulate or solve simple physical systems, to help both physics understanding and programming ability. Instructor: Peck.

20. *4 units (1-3-0); first, second terms. Prerequisite: CCO 1 or equivalent experience with computers.* Introduction to computing and its applications to problems in classical mechanics. Vector operations, numerical integration, and numerical solution of differential equations of motion.

21. *3 units (0-3-0); second, third terms. Prerequisite: Ph 20 or extensive experience with computers.* Computer applications to problems in electricity and magnetism. Graphics, multidimensional integration, field mapping.

22. *3 units (0-3-0); third term. Prerequisite: Ph 20 or 21.* Introduction to numerical methods useful in physics, including Monte Carlo techniques. One supervised but unstructured project is required.

Bi/Ph 50. Introduction to Biophysics of the Nervous System. *9 units (3-0-6).* For course description, see Biology.

Ph 76 ab. Advanced Computational Physics Laboratory. *6 units (0-5-1); second, third terms. Prerequisites: Ph 98, Ph 106, AMa 95 (all may be taken concurrently).* A two-term course in the use of computers to model classical and quantum mechanical systems, with emphasis on numerical techniques and on building intuition for the behavior of these simulations. Students are guided through a series of projects carried out on small computers. Instructor: Fox.

Ph 77 ab. Advanced Physics Laboratory. *9 units; first, second, third terms. Prerequisites: Ph 5 or Ph 6, and Ph 7.* A two-term laboratory course open to junior and senior physics majors to familiarize students with equipment and procedures used in the research laboratory. Experiments illustrate fundamental physical phenomena in atomic, low temperature, nuclear, and particle physics, such as NMR, critical fields in superconductors, positron annihilation, and muon lifetime. Instructor: Phillips.

Ph 78 abc. Senior Thesis Experimental. *9 units; first, second, third terms. Prerequisite: instructor's permission.* Supervised experimental research, open only to senior physics majors. Requirements will be set by individual faculty members, but will include a term paper based upon laboratory experience. Selection of topics and final report must be approved by the Physics Undergraduate Committee. Not offered on pass/fail basis. Instructors: Staff. See note under Ph 79.

Ph 79 abc. Senior Thesis Theoretical. *9 units; first, second, third terms. Prerequisite: instructor's permission.* Supervised theoretical research, open only to senior physics majors. Requirements will be set by individual faculty members, but will include a term paper based on the work performed. Selection of topics and final report must be approved by the Physics Undergraduate Committee. Not offered on pass/fail basis. Instructors: Staff.

Note: Students wishing assistance in finding an adviser and/or a topic for a senior thesis are invited to consult with the chairperson of the Physics Undergraduate Committee, or any other member of the committee. A grade will not be assigned in Ph 78 or Ph 79 until the completion of the thesis, which is normally expected to take three terms. P grades will be given the first two terms, and then changed at the end of the course to the appropriate letter grade.

Ph 98 abc. Quantum Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 12 abc or, with permission of the instructor, Ph 2 abc, Ma 2 abc, or their equivalents.* A one-year course in quantum mechanics and its applications, for students who have completed Ph 12. Scattering theory, approximation methods, symmetries, spin-½ systems, and selected topics in atomic, solid-state, nuclear, and particle physics. Instructor: Tombrello.

Ph 101 abc. Critical Transitions. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 2 or Ph 12.* How simple, microscopic laws produce phenomena with many relevant scales. Familiar critical transitions (liquid-gas and magnetization) occur as temperature varies, while in quantum systems they can occur as a function of field strength. Tools of statistical mechanics and the renormalization group will be developed to address these and a variety of analogous problems in solid-state, low-temperature, and high-energy physics. Other applications include percolation, polymerization, liquid crystals, and chaotic non-linear systems. Not offered in 1986–87.

Ph 103 abc. Topics in Contemporary Physics. *9 units (3-0-6); first, second, third terms. Prerequisite: permission of the instructor.* A series of introductory one-term, independent courses. In 1986–87, the first term will be an introduction to particle physics, the second term will be a discussion of great experiments in modern physics, and the third term will be an introduction to electronics as used in experimental physics research. Students may register for any particular term or terms. Instructors: Stroynowski, Telegdi, Gomez.

Ph 106 abc. Topics in Classical Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 2 abc or Ph 12 abc, Ma 2 abc.* An intermediate course in the application of the basic principles of classical physics to a wide variety of subjects. Roughly half of the year will be devoted to mechanics, and half to electromagnetism. Topics include the Lagrangian and Hamiltonian formulations of mechanics, small oscillations and normal modes, boundary value problems, multipole expansions and various applications of electromagnetic theory. Instructors: two independent sections: 1) Barnes, 2) Koonin.

Ph 118 abc. Electronic Circuits and Their Application to Physical Research. *9 units (3-0-6); first, second, third terms.* Fundamentals of analog and digital electronics with emphasis on proven techniques of instrumentation for scientific research. Both the physical principles and properties of electronic components and circuits and the logical design of digital systems. Common electronic instruments, computer interfaces, and typical digital control logic in scientific research used as examples. Given in alternate years. Not offered in 1986–87.

Ph 125 abc. Quantum Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 2 abc. Recommended: AMa 95 abc or Ma 108 abc. Not available to students who have completed Ph 98 abc.* A fundamental course in quantum mechanics aimed at understanding the mathematical structure of the theory and its application to physical phenomena at the atomic and nuclear levels. Various formulations of quantum mechanics, properties of operators, one-dimensional and central potentials, angular momentum and spin, scattering theory, perturbation theory, identical particles, and introductory relativistic quantum theory. Instructor: Boehm.

Ph 127 abc. Statistical Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 98 abc or Ph 125 abc, Ph 106 abc.* A thorough introduction to statistical problems in physics. Topics: fundamental laws and concepts of thermodynamics, kinetic theory and transport phenomena, statistical mechanics and the connection between macroscopic and atomic laws. Not offered in 1986–87.

Ph 129 abc. Mathematical Methods of Physics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 106 abc or the equivalent. Recommended: AMa 95 abc or Ma 108 abc.* Practical methods of summing series, integrating, and solving differential equations, including numerical methods. The special functions (Bessel, Elliptic, Gamma, etc.) arising in physics, as well as partial differential equations, orthogonal functions, integral equations and transforms, tensors, linear spaces and operators, group theory, and probability and statistics. Instructors: Porter, Schwarz.

Ph 135 abc. Applications of Quantum Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 125 abc or equivalent.* Applications of quantum mechanics to topics in contemporary physics. Atomic, molecular, nuclear, and elementary particle physics; solid state physics; quantum electronics; lasers; superconductivity and superfluidity. Instructor: Whaling.

Ph 136 abc. Applications of Classical Physics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 106 abc or equivalent.* Applications of classical physics to topics of interest in contemporary "macroscopic" physics. Continuum physics and classical field theory; elasticity and hydrodynamics; plasma physics; magnetohydrodynamics; thermodynamics and statistical mechanics; gravitation theory including general relativity and cosmology; modern optics. Content will vary from year to year, depending on the instructor. An attempt will be made to organize the material so that the terms may be taken independently. Instructors: Thorne, Blandford.

Bi/Ph 151. Topics in Nervous System Biophysics. *6 units (2-0-4).* For course description, see Biology.

Ph 171. Reading and Independent Study. *Units in accordance with work accomplished.* Occasionally, advanced work involving reading, special problems, or independent study is carried out under the supervision of an instructor. Approval of the instructor and of the student's departmental adviser or registration representative must be obtained before registering. Graded pass/fail.

Ph 172. Experimental Research in Physics. *Units in accordance with work accomplished.* Approval of the student's research supervisor and of his or her department adviser or registration representative must be obtained before registering. Graded pass/fail.

Ph 173. Theoretical Research in Physics. *Units in accordance with work accomplished.* Approval of the student's research supervisor and of his or her departmental adviser or registration representative must be obtained before registering. Graded pass/fail.

Bi/CS/Ph 185. Collective Computation. *9 units (2-4-3).* For course description, see Computer Science.

CS/Ph 186 ab. Experimental Projects in Collective Computation. *9 units (0-9-0).* For course description, see Computer Science.

CS/Ph 187 abc. Potentialities and Limitations of Computing Machines. *9 units (3-0-6).* For course description, see Computer Science.

Ph 203 abc. Nuclear Physics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 98 or Ph 125 or equivalent.* The fundamental structure and properties of nuclear systems from the nucleon to nuclear matter. Topics include independent-particle models, collective excitations, electromagnetic properties, weak interaction studies, hadronic probes, mesonic and other non-nucleonic degrees of freedom. In 1986–87, offered first and third terms only. Instructor: McKeown.

Ph 205 abc. Relativistic Quantum Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 125 or Ph 98.* Topics: the Dirac equation, second quantization, quantum electrodynamics, scattering theory, Feynman diagrams, non-abelian gauge theories, Higgs symmetry-breaking, the Weinberg-Salam model, and renormalization. Instructor: Preskill.

Ph 209 abc. Classical Electromagnetism. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 106.* Electromagnetic fields in vacuum and in matter; boundary-value problems and Green's functions; retarded potentials; wave propagation; wave guides and cavities; radiation, dispersion and absorption; and special relativity. Instructor: Kavanagh.

Ph 222 abc. Many-Body Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 125 or Ph 98.* The concepts and formal tools needed to study many-particle systems. Applications to specific physical systems of interest in condensed matter and nuclear physics: electron gas, superconductors, liquid helium, nuclear matter, and finite nuclei. Instructor: Cross.

Ph 224 abc. Space Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 98, Ph 106 or equivalent.* The experimental and theoretical aspects of X-ray, cosmic ray, and gamma ray astrophysics, with emphasis on topics of current research interest. Not offered in 1986–87.

Ph 228 ab. Topics in Mathematical Physics. *9 units (3-0-6). Prerequisite: instructor's permission.* Content changes from year to year. Not offered in 1986–87.

Ph 229. Advanced Mathematical Methods of Physics. *9 units (3-0-6); first term. Prerequisite: instructor's permission.* Content changes from year to year. Not offered in 1986–87.

Ph 230 abc. Elementary Particle Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 205 abc or equivalent.* Advanced methods in quantum field theory, with applications to elementary particle physics, including the renormalization group, quark confinement, chiral symmetry, anomalies, lattice gauge theories, and other topics of current interest. Instructor: Zachariasen.

Ph 231 abc. High Energy Physics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 98 or Ph 125 or equivalent.* An introduction to elementary particle physics, stressing experimental phenomenology, theoretical interpretations of this phenomenology, and experimental techniques. Classification of elementary particles using invariance principles, evidence for fundamental constituents, and examination of the experimental basis for currently interesting ideas, such as quantum chromodynamics, the "standard model" of weak and electromagnetic interactions, and supersymmetric and unified theories. Instructor: Hitlin.

Ph 234 abc. Topics in Theoretical Physics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 205 or equivalent.* In 1986–87, the course covers the standard model for strong, weak, and electromagnetic interactions based on the gauge group SU(3) x SU(2) x U(1). Techniques such as the renormalization group and chiral perturbation theory will be used to make comparisons with experiment. Problems and extensions such as grand unification, low energy supersymmetry, and axions will be discussed. Instructor: Wise.

Ph 236 abc. Relativity. *9 units (3-0-6); first, second, third terms. Prerequisite: a mastery of special relativity at the level of Goldstein,* Classical Mechanics, *or of Leighton,* Principles of Modern Physics. A systematic exposition of Einstein's general theory of relativity, with emphasis on applications to astrophysical and cosmological problems. Topics: a review of special relativity; accelerated observers in special relativity; modern differential geometry; the foundations of general relativity and of other geometric theories of gravity; past and future experimental tests of general relativity; relativistic stars; gravitational collapse; black holes; gravitational radiation; cosmology; singularities and singularity theorems. Given in alternate years; not offered in 1986–87.

Ph 237 abc. Theoretical Nuclear Physics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 98 or equivalent.* Microscopic models for finite nuclei. Topics: second quantization, Slater determinants, nuclear shell model, Hartree-Fock model, pairing, collective vibrations and rotations. Not offered in 1986–87.

Ph 240 abc. Current Theoretical Problems in Particle Physics. *6 units (2-0-4); first, second, third terms.* In 1986–87, course title is "Quantum Mechanics and This Specific Universe." Interpretation of quantum mechanics, with reference to measurement and observation, quantum cosmology, the second law of thermodynamics and the arrow of time, the notion of complexity, and the relation of physics to the other sciences. Discussion and argument are encouraged. Graded pass/fail. Undergraduates admitted with permission of instructor. Only offered second and third terms in 1986–87. Instructor: Gell-Mann.

Ph 241. Research Conference in Physics. *No credit; first, second, third terms.* Meets once a week for a report and discussion of the work appearing in the literature and that in progress at Caltech and elsewhere. Advanced students in physics and members of the physics staff take part.

Ph 242 ab. Physics Seminar. *3 units (2-0-1); first and second terms.* Topics in physics emphasizing current research at Caltech. One two-hour meeting per week. Speakers will be chosen from both faculty and students. Graded pass/fail. Instructor: Drever.

Ph 300. Research in Physics. *Units in accordance with work accomplished.* Ph 300 is elected in place of Ph 172 or Ph 173 when the student has progressed to the point where his or her research leads directly toward the thesis for the degree of Doctor of Philosophy. Approval of the student's research supervisor and of his or her department adviser or registration representative must be obtained before registering. Graded pass/fail.

POLITICAL SCIENCE

HSS 99. See page 224 for description.

PS/SS 12. Introduction to Political Science. *9 units (3-0-6); second and third terms.* Introduction to the tools and concepts of analytical political science. Subject matter is primarily American political processes, and institutions. Topics: spatial models of voting, redistributive voting, games, presidential campaign strategy, coverage of political issues by the mass media, Congress, and congressional-bureaucratic relations. Instructors: Staff.

PS 101. Selected Topics in Political Science. *Units to be determined by arrangement with the instructor.* Instructors: Staff.

PS 102. Black Africa 800 A.D. to the Present. *9 units (2-0-7); second term.* The origins of Americans of African descent, including African empires such as Ghana and Songhai, the slave trade, and the emergence of independent nations. Not offered in 1986–87. Instructors: Staff.

PS 109. The Presidency. *9 units (3-0-6); first term.* Presidential elections, executive branch relations, the role of the president in shaping foreign and domestic policy, and the substantial institutional constraints on the exercise of presidential power. Instructors: Staff.

PS 112. Behavioral Basis of Politics. *9 units (3-0-6).* The development of political attitudes and public opinion. Topics: the role of the mass media, peer groups, and social institutions in the formation and stabilization of political opinions. Not offered in 1986–87. Instructor: Kiewiet.

PS/SS 116. War, Diplomacy, and International Politics. *9 units (3-0-6). Prerequisite: PS/SS 12 or SS 13.* Various theories of the sources and resolution of international conflicts. The second half will be devoted to applying these theories to case studies of conflicts such as the First and Second World Wars, the Vietnam War, the Cold War, and the Arab-Israeli conflict. Instructor: Cain.

PS 118. Democratic Theory. *9 units (3-0-6); second term.* This course will raise several types of questions and answer none. Is it possible to have a democracy; how ought citizens to act in a democracy; how do democratic governments and citizens of democratic politics actually behave; and is a democratic government necessarily just? Instructor: Cain.

PS/SS 119. The Politics of the Industrial State. *9 units (3-0-6). Prerequisite: PS/SS 12 or equivalent.* The institutions of and the behavior within industrialized democracies of the western world. Instructors: Cain, Kiewiet.

PS 120. American Electoral Behavior and Party Strategy. *9 units (3-0-6).* A consideration of existing literature on the voting behavior of the citizen, and an examination of theoretical and empirical views of the strategies followed by the parties. Not offered in 1986–87. Instructors: Cain, Kiewiet.

PS 121. Congressional Policy Formation and Legislative Process. *9 units (3-0-6); second term.* Decisionmaking in legislative bodies, with emphasis on the American Congress. An investigation into the impact of Congressional structure and practices on the policies adopted by the federal government. Instructor: Wright.

PS/SS 122. Noncooperative Games in Social Science. *9 units (3-0-6); first term. Prerequisite: PS/SS 12 or equivalent.* The axiomatic structure and the behavioral interpretations of game theory models in social science. Axiomatic utility theory and general noncooperative games. Instructor: McKelvey.

PS/SS 123. Cooperative Games in Social Science. *9 units (3-0-6). Prerequisite: PS/SS 122.* Various cooperative solutions to games, with particular application to voting, bargaining, and market games. Solution concepts and existence theorems. Not offered in 1986–87. Instructors: Staff.

PS/SS 125. Peasant Politics. *9 units (3-0-6); second term. Prerequisite: PS/SS 12 or SS 13.* The political role of the peasantry, with attention to rural political organization and the effect of market relationships. Instructor: Hoffman.

PS 126. Bureaucratic Politics. *9 units (3-0-6); first term.* Survey and critical analysis of the literature on bureaucratic politics. Topics: bureaucracies as organizations, bureaucracies as part of a larger political environment, and formal models of bureaucratic behavior. Instructor: Rothenberg.

PS 127. Interest Groups in American Politics. *9 units (3-0-6); second term.* Survey of the literature on organized groups. Topics: who joins, the internal politics of organizations, and the activities of interest groups in the larger political arena. An effort will be made to assess interest groups within the context of theories of democracy. Instructor: Rothenberg.

PS 132. Formal Theories in Political Science. *9 units (3-0-6); third term. Prerequisite: PS/SS 12 or equivalent.* The axiomatic structure and the behavioral interpretations of game theoretic and social choice models and models of political processes based on them. Instructor: Austen-Smith.

Ec/PS 134. The Political Economy of Urban Areas. *9 units (3-0-6).* For course description, see Economics.

PS 135. Political Geography of Developing Countries. *9 units (2-0-7); first term.* A study of the swift transition from colonialism or an undeveloped state to the present that includes the growth of one-party states; the role of the military; tribal, religious, and class pressures; the internal and external role of boundaries; and new foreign policies. Instructor: Munger.

PS/SS 139. Comparative Politics. *9 units (3-0-6); second term. Prerequisite: PS/SS 12 or SS 13.* The politics of non-American political systems. Areas of study: the politics of non-democratic states, including the Communist nations; the politics of developing societies; the politics of the Western European democracies. Emphasis on the effect of distinctive institutions on the performance of government and the content of public policy. Instructor: Cain.

PS 141 ab. African Studies. *9 units (2-0-7); second, third terms.* Political and social change in sub-Saharan Africa. Instructor: Munger.

PSYCHOLOGY

Psy 10. Introduction to Psychological Development. *9 units (3-0-6); first, second terms.* A study of the psychological development of the individual within a context of biological, cultural, and social evolution. Not offered in 1986–87. Instructor: Breger.

Psy 12. Introduction to Abnormal Psychology. *9 units (3-0-6); first term.* The development of mental and emotional disturbances. Basic theory will be reviewed in relation to selected case material and relevant research. Instructor: Breger.

Psy 25. Reading and Research in Psychology. *Units to be determined by the instructor.* A written report will be required. Graded pass/fail. Not available for credit toward humanities-social science requirement.

Psy 101. Selected Topics in Psychology. *Units to be determined by arrangement with the instructor; third term.* Instructor: Breger.

Psy 110. Psychological Development. *9 units (3-0-6); first, second terms. Prerequisite: Psy 10.* A study of the psychological development of the individual within a context of biological, cultural, and social evolution. Not offered in 1986–87. Instructor: Breger.

Psy 112. Abnormal Psychology. *9 units (3-0-6); second term. Prerequisite: Psy 12 or consent of instructor.* Continuation of material covered in Psy 12. The development of mental and emotional disturbances. Basic theory will be reviewed in relation to selected case material and relevant research. Instructor: Breger.

Psy 125. Reading and Research in Psychology. Same as Psy 25, but for graduate credit. *Not available for credit toward humanities-social science requirement.*

Lit/Psy 150 ab. Psychoanalysis and Literature.* *9 units (3-0-6).* For course description, see Literature.

*Advanced courses with credit toward the 36-unit Humanities requirement. Other advanced courses receive credit toward the 36-unit H&SS requirement. See page 83.

RUSSIAN *(See Languages)*

SOCIAL SCIENCE

Ec/SS 11. Introduction to Economics. *9 units (3-0-6).* For course description, see Economics.

PS/SS 12. Introduction to Political Science. *9 units (3-0-6).* For course description, see Political Science.

SS 13. The Application of Social Scientific Methods to Problems in History. *9 units (3-0-6); first term.* The application of theory from economics, political science, and demography to historical subjects, with an emphasis on questions of institutional change. The historical topics covered will depend upon the instructor. Instructors: Davis, Hoffman, Kousser.

SS 33. Introduction to the Law. *9 units (3-0-6).* An introduction to Anglo-American law from both the legal and the social scientific point of view. Subject can vary from year to year. Available for introductory social science credit. Instructors: Schwartz, Strnad.

SS 98. Reading in Social Science. *Units to be determined for the individual by the department. Elective, in any term.* Reading in social science and related subjects, done either in connection with the regular courses or independently of any course, but under the direction of members of the department. A brief written report will usually be required. Graded pass/fail. *Not available for credit toward humanities-social science requirement.*

SS 101. Selected Topics in Social Science. *9 units (3-0-6).* Not available for social science credit unless specifically approved by social science faculty. Instructors: Staff, visiting lecturers.

Lin/SS 103. Psycholinguistics. *9 units (2-1-6).* For course description, see Linguistics.

Lin/SS 104. Sociolinguistics. *9 units (2-1-6).* For course description, see Linguistics.

Lin/SS 105. Computational Linguistics. *9 units (2-1-6).* For course description, see Linguistics.

Ec/SS 112. History of Economic Analysis. *9 units (3-0-6).* For course description, see Economics.

PS/SS 116. War, Diplomacy, and International Politics. *9 units (3-0-6).* For course description, see Political Science.

SS 117. Problems of Urban Society. *9 units (3-0-6); third term.* Some of the significant urban problems of contemporary America and alternative policies. Not offered in 1986–87. Instructor: Oliver.

PS/SS 119. The Politics of the Industrial State. *9 units (3-0-6).* For course description, see Political Science.

PS/SS 122. Noncooperative Games in Social Science. *9 units (3-0-6).* For course description, see Political Science.

PS/SS 123. Cooperative Games in Social Science. *9 units (3-0-6).* For course description, see Political Science.

PS/SS 125. Peasant Politics. *9 units (3-0-6).* For course description, see Political Science.

Ec/SS 129. Economic History of the United States. *9 units (3-0-6).* For course description, see Economics.

SS 133. Topics in Anglo-American Law. *9 units (3-0-6); second, third terms.* An introduction to the American legal system through the study of a particular sub-area of law, which may vary from term to term or year to year. Instructor: Schwartz. *May be taken more than once if the topic is different.*

PS/SS 139. Comparative Politics. *9 units (3-0-6).* For course description, see Political Science.

SS 140 ab. Laboratory Experiments in the Social Sciences. *9 units (3-0-6); first, second terms.* An examination of recent work in laboratory testing in the social sciences with particular reference to work done in social psychology, economics, and political science. Instructor: Plott.

Ec/SS 145. Public Finance. *9 units (3-0-6).* For course description, see Economics.

H/SS 150. Problems in the History of English Law and Society.* *9 units (3-0-6).* For course description, see History.

The graduate courses listed below are not necessarily taught each year. They will be offered as need dictates.

SS 200. Selected Topics in Social Science. *Units to be determined by arrangement with instructors.* Instructors: Staff and visiting lecturers.

SS 201. Game Theory. *9 units (3-0-6); first term.* An introduction to utility theory, decision theory, and the theory of games. Both noncooperative and cooperative theories are dealt with, concentrating on applications to problems in the social sciences. Instructor: Border.

SS 202. Congress and the Executive. *9 units (3-0-6); second term.* Analysis of executive and congressional decisionmaking. Emphasis on the theory of committees and bureaucratic theory. Instructor: Kiewiet.

SS 203. American Electoral Processes. *9 units (3-0-6); third term.* An in-depth analysis of American electoral processes with emphasis on the application of new theory and quantitative techniques. Instructor: Cain.

SS 204. Analytical Political Theory. *9 units (3-0-6); first term.* A survey of theoretical topics in social choice, voting, and electoral competition. Instructor: McKelvey.

SS 205. Microeconomic Theory I. *9 units (3-0-6); first term. Prerequisite: Ec 121 a or equivalent.* An introduction to economic theory and its applications. Problems in modeling and specification; maximization. Instructors: Border, Davis, Plott, Reinganum.

*Advanced courses with credit toward the 36-unit Humanities requirement. Other advanced courses receive credit toward the 36-unit H&SS requirement. See page 83.

SS 206. Microeconomic Theory II. *9 units (3-0-6); second term. Prerequisite: SS 205.* Classical consumption theory, the theory of production, markets, externalities, and the question of public goods. Instructors: Plott, Border.

SS 207. Microeconomic Theory III. *9 units (3-0-6); third term. Prerequisite: SS 206.* Modern economic theory, including decision theory, game theory, the role of uncertainty, and investment theory. Instructor: Wilde.

SS 210 abc. Foundations of Political Economy. *9 units (3-0-6). Prerequisites: PS/SS 204 and SS 206.* Mathematical theories of individual and social choice applied to problems of welfare economics and political decisionmaking as well as construction of political economic processes consistent with stipulated ethical postulates, political platform formulation, the theory of political coalitions and decisionmaking in political organizations. Instructors: McKelvey, Austen-Smith.

SS 211 abc. Advanced Economic Theory. *9 units (3-0-6). May be repeated for credit.* Advanced work in a specialized area of economic theory, with topics varying from year to year according to the interests of students. Instructors: Border, Ledyard.

SS 212 abc. Application of Microeconomic Theory. *9 units (3-0-6). May be repeated for credit.* A working seminar in which the tools of microeconomic theory are applied to the explanation of events and the evaluation of policy. Instructors: Gilligan, Plott, Wilde.

SS 214. The Economics of Regulation. *9 units (3-0-6); first term.* An analysis of government controls on prices, profits, entry, and product quality in the private sector, with special emphasis on the energy sector. Instructors: Staff.

SS 215. Legal Aspects of the Economics and Politics of Regulation. *9 units (3-0-6).* The relationship between the law and governmental regulation of economic enterprise. Instructors: Staff.

SS 216. Interdisciplinary Studies in Law and Social Policy. *9 units (3-0-6).* A policy problem or problems involving the legal system will be studied, using concepts from at least one social science discipline. Each offering will be taught by a law professor, alone or in conjunction with a member of the social science faculty. The topic will differ from term to term so the course may be taken more than once. Selected undergraduates may enroll in this course with the permission of the instructor. Instructor: Strnad.

SS 222 abc. Econometrics. *9 units (3-0-6); first, second, third terms.* Regression analysis. Introduction to the use of multivariate and nonlinear methods in the social sciences. Students will be required to complete a major empirical project. Instructors: Dubin, Rivers, Vuong.

SS 223 abc. Advanced Topics in Econometric Theory. *9 units (3-0-6). Prerequisite: SS 222 ab; may be repeated for credit.* A course in quantitative methods for second- and third-year social science graduate students. Theory of identification and estimation of simultaneous equations system. Instructors: Andrews, Dubin, Rivers, Vuong.

SS 225. Advanced Topics in Quantitative Methods for Policy Analysis. *9 units (3-0-6). Prerequisite: SS 222 ab; may be repeated for credit.* For second- and third-year social science graduate students. Students will analyze recent empirical studies that relate to current policy questions using modern econometric techniques. Instructors: Cain, Grether, Kousser, Rivers.

SS 228. Selected Topics in European Medieval History. *9 units (3-0-6).* The bibliography, sources, and methods of analysis appropriate for research on a variety of topics in medieval history, such as peasant life and production, organization of government, law and land tenure, demography, church-state relations, and history of mentalities. Instructors: Benton, Searle.

SS 229 abc. Theoretical and Quantitative Dimensions of Historical Development. *9 units (3-0-6); first, second, third terms. May be repeated for credit.* Introduction to modern quantitative history. The tools of economic and political theory applied to problems of economic, social, and political development in a historical context. Instructors: Davis, Hoffman, Kousser.

SS 231 abc. American Politics. *9 units (3-0-6).* A three-term course in American politics and political behavior. While drawing from contemporary materials, the course will emphasize the historical background of American political institutions. Instructor: Wright.

SS 232 abc. Historical and Comparative Perspectives in Political Analysis. *9 units (3-0-6). Prerequisite: PS/SS 204.* Provides a knowledge and understanding of developments in both the American past and in other parts of the world. Instructors: Cain, Kousser.

SS 234. Research Seminar in Modern Political Science. *9 units (3-0-6); may be repeated for credit.* Instructors: Staff.

SS 238. Optimal Control Theory in Economics. *9 units (3-0-6); first term. Prerequisite: Ec 121 a or equivalent.* The subject material of this course is the optimal control of dynamic economic systems with applications to resource extraction, limit pricing, research and development, and capital accumulation. Instructor: Reinganum.

SS 240. Techniques of Policy Research. *9 units (3-0-6); third term. Prerequisites: SS 205, SS 206.* The application of social science theory and methods to the formulation and evaluation of public policy. Instructors: Gilligan, Dubin.

SS 241 ab. Workshop in Policy Research. *9 units (3-0-6); first, second terms. Prerequisite: SS 240.* A working seminar in which the students and participating faculty apply the techniques examined in SS 240 to a policy problem of mutual interest. Instructors: Staff.

SS 260. Experimental Methods of Political Economy. *9 units (3-0-6).* Survey of laboratory experimental research related to the broad field of political economy. Topics: the behavior of markets, organizations, committee processes and election processes. Emphasis on experimental methods and techniques. Students will design and conduct experiments. Instructor: Plott.

SS 300. Research in Social Science. *Variable units.* Instructors: Staff.

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6

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INDEPENDENT STUDIES—*D. H. Fender*

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[1]Acting Chairman, January 1, 1986, to September 30, 1986
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Chi-Ming Che, Ph.D.
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Chemistry
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[1]In residence 1985–86
[2]Part time

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[1]In residence 1985-86
[2]Part time

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[1]On leave of absence first and third terms 1986–87

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Amnon Yariv, Ph.D.
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Edward E. Zukoski, Ph.D.
Jet Propulsion and Mechanical Engineering

Associate Professors

Paul M. Bellan, Ph.D.
Applied Physics
Glen R. Cass, Ph.D.
Environmental Engineering
Slobodan M. Cuk, Ph.D.
Electrical Engineering
Rodney M. F. Goodman, Ph.D.
Electrical Engineering
James T. Kajiya, Ph.D.
Computer Science
Demetri Psaltis, Ph.D.
Electrical Engineering
David B. Rutledge, Ph.D.
Electrical Engineering

Assistant Professors

Yaser S. Abu-Mostafa, Ph.D.
Electrical Engineering and Computer Science
Erik K. Antonsson, Ph.D.
Mechanical Engineering
Alan H. Barr, Ph.D.
Computer Science
James L. Beck, Ph.D.
Civil Engineering
Brent Fultz, Ph.D.
Materials Science
John F. Hall, Ph.D.
Civil Engineering
Christof Koch, Ph.D.
Computation and Neural Systems
Jens Lorenz, Dr. rer. Nat., Habil.
Applied Mathematics
Daniel I. Meiron, Sc.D.
Applied Mathematics
Ares J. Rosakis, Ph.D.
Aeronautics and Applied Mechanics
Athanasios Sideris, Ph.D.
Electrical Engineering
Kerry J. Vahala, Ph.D.
Applied Physics
P. P. Vaidyanathan, Ph.D.
Electrical Engineering

Instructor

Stephen Wiggins, Ph.D.[1]
Applied Mathematics

Lecturers[2]

Ronald F. Ayres, Ph.D.
Computer Science
Stanley H. Bacon
Electrical Engineering
James F. Blinn, Ph.D.
Computer Science
James B. Breckinridge, Ph.D.
Applied Physics
Charles Elachi, Ph.D.
Electrical Engineering
Ahmed-W. M. Elgamal, Ph.D.
Civil Engineering
Samad A. Hayati, Ph.D.
Mechanical Engineering
Manoochehr M. Koochesfahani, Ph.D.
Aeronautics
David H. Lewis, Jr., Ph.D.
Mechanical Engineering
Thomas R. McDonough, Ph.D.
Engineering
Frank J. Mullin, Ph.D.
Electrical Engineering
Charles B. Ray, M.S.
Computer Science
Homayoun Seraji, Ph.D.
Electrical Engineering
Kenneth S. Smith, Ph.D.
Applied Mechanics
Laif Swanson, Ph.D.
Electrical Engineering
Richard F. Whitbeck, Ph.D.
Aeronautics

Senior Research Associate

Robert C. Y. Koh, Ph.D.
Environmental Engineering Science

Senior Research Fellow

Eung Gi Paek, Ph.D.
Electrical Engineering

Research Fellows

Khaled A. S. Abdel-Ghaffar, Ph.D.
Electrical Engineering
Aaron Agranat, Ph.D.
Applied Physics
Eric A. Betterton, Ph.D.
Environmental Engineering Science
Eric J. Cotts, Ph.D.
Applied Physics
William J. Dally, Ph.D.[2]
Computer Science
Michel Delpech, Dr. Eng.
Mechanical Engineering
Alicia C. Gonzalez, Ph.D.
Environmental Engineering Science
Gavin J. Hendricks, Ph.D.
Mechanical Engineering and Jet Propulsion
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Environmental Engineering Science
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Richard C. Miake-Lye, Ph.D.
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Michael J. Naughton, Ph.D.
Applied Mathematics
Lars Nielsen, Ph.D.
Computer Science

[1]von Kármán Instructor
[2]In residence 1985–86
[3]Chaim Weizmann Research Fellow

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Civil Engineering
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Aeronautics
Harry F. Robey III, Ph.D.
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Donald Schwendeman, Ph.D.
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Jakob J. van Zyl, Ph.D.[1]
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Haila Wang, Ph.D.
Applied Physics
Keh-Han Wang, Ph.D.
Engineering Science
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Aeronautics
Hwa-Yueh Yang, Ph.D.
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Edward C. Posner, Ph.D.
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Berken Chang, Ph.D.
Applied Physics
Tirong Chen, M.Sc.
Applied Physics
Joshua Chover, Ph.D.[1]
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Bruno Crosignani, Lib.Doc.[1]
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Eusebius J. Doedel, Ph.D.
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Erdinc Edgu, Ph.D.
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Computer Science
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Paul Nelson, Ph.D.[1]
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Shlomo Putter, M. Sc.
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Djordje Radosevic, Ph.D.
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Ricardo B. Schwarz, Ph.D.
Geophysics and Materials Science
Tom Smedsaas, Ph.D.[1]
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Noel F. Smyth, Ph.D.[1]
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Vibeke Sorensen, M.A.H.
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Michael Stiassnie, D.Sc.[1]
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Yoshihiro Takeuchi, D.Eng.[1]
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Jawahar L. Tandon, Ph.D.
Applied Physics
Saleh Tanveer, Ph.D.[1]
Applied Mathematics
Naresh Thadhani, Ph.D.
Materials Science
Akira Urai, M.S.
Electrical Engineering
Telle E. Whitney, Ph.D.
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Howard Winet, Ph.D.
Engineering Science
Xin-an Zhao, Ph.D.
Applied Physics

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Engineer
James E. Broadwell, Ph.D.
Senior Scientist
Jonathan D. Melvin, Ph.D.
Senior Scientist
George T. Yates, Ph.D.
Senior Scientist

[1]In residence 1985–86

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Donald S. Burnett, *Academic Officer*
Don L. Anderson, *Director, Seismological Laboratory*

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Paleoecology
Robert P. Sharp, Ph.D.
Robert P. Sharp Professor of Geology

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Barclay Kamb, Ph.D.
Geology and Geophysics

Hiroo Kanamori, Ph.D.
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Duane O. Muhleman, Ph.D.
Planetary Science
Bruce C. Murray, Ph.D.
Planetary Science
George R. Rossman, Ph.D.
Mineralogy
Kerry E. Sieh, Ph.D.
Geology
Leon T. Silver, Ph.D.
W. M. Keck Foundation Professor for Resource Geology
David J. Stevenson, Ph.D.
Planetary Science
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Geology
Hugh P. Taylor, Jr., Ph.D.
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Gerald J. Wasserburg, Ph.D.
John D. MacArthur Professor of Geology and Geophysics
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Yuk L. Yung, Ph.D.
Planetary Science

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Jason B. Saleeby, Ph.D.
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Dimitri A. Papanastassiou, Ph.D.
Geochemistry
Clair C. Patterson, Ph.D., D.Sc.
Geochemistry

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Michael R. Carroll, Ph.D.
Experimental Petrology
David Crisp, Ph.D.
Planetary Science
Brian Curtiss, Ph.D.
Geology
Melinda Darby Dyar, Ph.D.
Geochemistry
Hubert Gnaser
Geochemistry
Jeffrey Hester, Ph.D.
Planetary Science and Astronomy
Satoru Honda, Ph.D.
Geophysics
Hitoshi Kawakatsu, Ph.D.
Geophysics
R.V. Krishnamurthy, Ph.D.
Geochemistry
Hal B. Maring, Ph.D.
Geochemistry
Glen Mattioli, Ph.D.
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M. Meghan Miller, Ph.D.
IBM Research Fellow in Geology
David K. Potter, Ph.D.
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Michael J. Rutter, Ph.D.
Experimental Petrology
Leslie J. Sonders, Ph.D.
Dr. Chaim Weizmann Postdoctoral Fellow in Geophysics
Arthur J. Spivack, Ph.D.
Geochemistry
Kiyoshi Yomogida
Geophysics

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Stephen Sparks, Ph.D.
Geology

Visiting Professors

Marcia M. Neugebauer
Planetary Sciences

J. John Sepkoski, Ph.D.
Geology

Visiting Associate Professors

Steven Squyres, Ph.D.
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Richard W. Zurek, Ph.D.
Planetary Science

Visiting Associates

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Jay Bass, Ph.D.
Geophysics
Jinfu Deng, B.S.
Petrology
Jonathon E. Ericson, Ph.D.
Geochemistry
Russell A. Flegal, Ph.D.
Geochemistry
Stephen H. Hartzell, Ph.D.
Geophysics
Thomas H. Heaton, Ph.D.
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John D. Hestenes, Ph.D.
Geology
Ryosuke Inoue, Ph.D.
Geophysics
Lucile M. Jones, Ph.D.
Geophysics
Stephanie M. Mattson, Ph.D.
Geology
Franz R. Niederer, Ph.D.
Geochemistry
Alexander A. Ogilvy, D.Sc.
Geology
John D. O'Keefe, Ph.D.
Planetary Science
F. Peter Schloerb, Ph.D.
Planetary Science
Ricardo B. Schwarz, Ph.D.
Geophysics and Materials Science
Laurence Soderblom, Ph.D.
Planetary Science
John F. Stolz, Ph.D.
Geobiology
William D. Stuart, Ph.D.
Geophysics
John T. Trauger, Ph.D.
Planetary Science
Michael M. Walker, Ph.D.
Geobiology
Ray J. Weldon, Ph.D.
Geology
Stephen M. Wickham, Ph.D.
Geochemistry
Dorothy S. Woolum, Ph.D.
Geochemistry
Chengnan Zhu, B.S.
Geology
Yuru Zhuo, Ph.D.
Geophysics

Members of the Professional Staff

Glenn L. Berge, Ph.D.
Planetary Science
James H. Chen, Ph.D.
Geochemistry
Arthur A. Chodos, M.S.
Geology
G. Ed Danielson, M.S.
Planetary Science
Gladys Engen, B.S.
Geophysics
Katherine Hutton, Ph.D.
Geophysics
Wayne F. Miller, B.S.
Geophysics
Dorothy Settle, M.S.
Geochemistry

Division of the Humanities and Social Sciences

David M. Grether, *Chairman*
Louis L. Wilde, *Executive Officer for the Social Sciences*
John A. Sutherland, *Executive Officer for the Humanities*

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Modern Languages
J. Kent Clark, Ph.D.
Literature
David C. Elliot, Ph.D.
History
Horace N. Gilbert, M.B.A., D.B.A.
Business Economics
William T. Jones, Ph.D.
Philosophy
Burton H. Klein, Ph.D.
Economics
George P. Mayhew, Ph.D.
English
Rodman W. Paul, Ph.D.
Edward S. Harkness Professor of History
Hallett D. Smith, Ph.D., L.H.D.
English
Alan R. Sweezy, Ph.D.
Economics

Associate Professor Emeritus

Robert D. Wayne, M.A.
German

Lecturer Emeritus

Charles Newton, Ph.B.
English

Professors

Brian M. Barry, D.Phil.[1]
Edie and Lew Wasserman Professor of Philosophy
John F. Benton, Ph.D.
History
Louis Breger, Ph.D.
Psychoanalytic Studies
Ronald Bush, Ph.D.
Literature
Lance E. Davis, Ph.D.
Mary Stillman Harkness Professor of Social Science
Alan Donagan, B. Phil.
Philosophy
Peter W. Fay, Ph.D.
History
Philip Gaskell, Litt. D.[2]
Literature
David M. Grether, Ph.D.
Economics
Daniel J. Kevles, Ph.D.[1]
History
J. Morgan Kousser, Ph.D.
History and Social Science
John O. Ledyard, Ph.D.
Economics and Social Sciences
Oscar Mandel, Ph.D.
Literature
Jerome J. McGann, Ph.D.
Doris and Henry Dreyfuss Professor of the Humanities
Richard D. McKelvey, Ph.D.
Political Science
Edwin S. Munger, Ph.D.
Geography
Robert W. Oliver, Ph.D.
Economics
Thomas R. Palfrey, Ph.D.[1]
Economics and Political Science
Charles R. Plott, Ph.D.
Economics
James P. Quirk, Ph.D.
Economics
Martin Ridge, Ph.D.[2]
History
Robert A. Rosenstone, Ph.D.
History
Alan Schwartz, LL.B.[2]
Law and Social Science
Thayer Scudder, Ph.D.
Anthropology

[1]Leave of absence 1986–87
[2]Part-time

Eleanor M. Searle, D.M.S.
History
Annette J. Smith, Ph.D.
French
David R. Smith, Ph.D.[1]
Literature
John A. Sutherland, Ph.D.
Literature
Frederick B. Thompson, Ph.D.
Applied Philosophy and Computer Science
Louis L. Wilde, Ph.D.
Economics

Associate Professors

Kim C. Border, Ph.D.
Economics
Bruce E. Cain, Ph.D.
Political Science
Nicholas B. Dirks, Ph.D.
History
Heinz E. Ellersieck, Ph.D.
History
Stuart A. Ende, Ph.D.
Literature
Philip T. Hoffman, Ph.D.
History and Social Science
D. Roderick Kiewiet, Ph.D.
Political Science
Jenijoy La Belle, Ph.D.
Literature
George W. Pigman III, Ph.D.
Literature
Jennifer F. Reinganum, Ph.D.
Economics
James F. Strnad II, Ph.D.[2]
Law and Economics

Assistant Professors

Jeffrey A. Dubin, Ph.D.
Economics
Thomas W. Gilligan, Ph.D.
Economics
James Lee, Ph.D.
History
Douglas Rivers, Jr., Ph.D.
Political Science
Lawrence S. Rothenberg, Ph.D.
Political Science
Quang H. Vuong, Ph.D.
Economics
James F. Woodward, Ph.D.
Philosophy

Mellon Postdoctoral Instructors

Randall Curren, Ph.D.
Philosophy
Leonard J. Moore, Ph.D.
History
Gyan Prakash, Ph.D.
History
Lawrence S. Rainey, Ph.D.
Literature
Alan Strudler, Ph.D., J.D.
Philosophy

Instructor

Nanette C. Le Coat, Ph.D.
French

Lecturers

Andreas Aebi, Ph.D.
German
Joseph A. Belloli IV, M.A.
Art History
Mary G. Berg, Ph.D.
Literature
David J. Britton, D.M.A.
Music
Lee F. Browne, M.S.
Education
Donald Caldwell, D.M.A.
Choral Music
George Cheron, Ph.D.
Russian

[1]Leave of absence 1986–87
[2]Part-time

Mary L. Fonseca, M.A.
English as a Second Language
Cheryl F. Giuliano, Ph.D.
Basic English Composition
Edward Hutchings Jr., B.A.
Journalism
Michael Linden-Martin, B.A.
English as a Second Language
Valentina A. Lindholm, M.A.
Russian
James G. McCoy, M.B.A.
Business Economics
David W. Morrisroe, M.B.A.
Business Economics
Harihar Rao
Music
Elma Schonbach, B.M.
Music
Robert R. Wark, Ph.D.
Art
Sigrid Washburn, Ph.D.
German

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Bozena Henisz-Dostert Thompson, Ph.D.
Linguistics

Faculty Associates

Judith R. Goodstein, Ph.D.
History
Robert Middlekauff, Ph.D.
History
William A. Ringler, Jr., Ph.D.
Literature
Mary L. Robertson, Ph.D.
History

Visiting Professors

Richard Helgerson, Ph.D.
Literature
Charles W. Howe, Ph.D.
Economics

Visiting Associate Professor

David Austen-Smith, Ph.D.
Political Science

Visiting Assistant Professors

Donald W. K. Andrews, Ph.D.
Economics
Colin Camerer, Ph.D.
Business
John R. Wright, Ph.D.
Political Science

Division of Physics, Mathematics and Astronomy

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David B. Wales, *Executive Officer for Mathematics*
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Thomas G. Phillips, *Director, Caltech Submillimeter Observatory*
Anthony C. S. Readhead, *Director, Owens Valley Radio Observatory*
Harold Zirin, *Director, Big Bear Solar Observatory*

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Mathematics
Robert F. Christy, Ph.D.
Institute Professor of Theoretical Physics
Eugene W. Cowan, Ph.D.
Physics
Leverett Davis, Jr., Ph.D.
Theoretical Physics
Charles R. De Prima, Ph.D.
Mathematics
Robert P. Dilworth, Ph.D.
Mathematics
William A. Fowler, Ph.D., D.Sc., D.h.c., D.H.L., Nobel Laureate
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Lee A. DuBridge Professor of Astrophysics
Marshall Hall, Jr., Ph.D.
IBM Professor of Mathematics
Robert B. Leighton, Ph.D.
William L. Valentine Professor of Physics
H. Victor Neher, Ph.D., Sc.D.
Physics
William R. Smythe, Ph.D.
Physics
John Todd, B.Sc.
Mathematics
Olga Taussky Todd, Ph.D.
Mathematics
Robert L. Walker, Ph.D.
Physics

Professors

Tom M. Apostol, Ph.D.
Mathematics
Michael Aschbacher, Ph.D.
Mathematics
Barry C. Barish, Ph.D.
Physics
Charles A. Barnes, Ph.D.
Physics
Roger D. Blandford, Ph.D.
Theoretical Astrophysics
Felix H. Boehm, Ph.D.
William L. Valentine Professor of Physics
Marshall H. Cohen, Ph.D.
Radio Astronomy
Michael C. Cross, Ph.D.
Theoretical Physics
Richard A. Dean, Ph.D.
Mathematics
Ronald W. P. Drever, Ph.D.
Physics
Richard P. Feynman, Ph.D., Nobel Laureate
Richard Chace Tolman Professor of Theoretical Physics
Geoffrey Fox, Ph.D.
Theoretical Physics
Steven C. Frautschi, Ph.D.
Theoretical Physics
F. Brock Fuller, Ph.D.
Mathematics
Murray Gell-Mann, Ph.D., Sc.D., D.Sc., Nobel Laureate
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Mathematics
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Herbert B. Keller, Ph.D.
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Steven E. Koonin, Ph.D.
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Radio Astronomy
Gerry Neugebauer, Ph.D.
Howard Hughes Professor and Professor of Physics
J. Beverley Oke, Ph.D.
Astronomy

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Physics
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Physics
Jerome Pine, Ph.D.
Physics
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Theoretical Physics
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Ward Whaling, Ph.D.
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Charles Lee Powell Professor of Applied Mathematics
Richard M. Wilson, Ph.D.
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Mark Wise, Ph.D.
Theoretical Physics
W. Hugh Woodin, Ph.D.
Mathematics
Fredrik Zachariasen, Ph.D.
Theoretical Physics
Harold Zirin, Ph.D.
Astrophysics

Associate Professors

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Jeremy Mould, Ph.D.
Astronomy
Harvey Newman, Sc.D.
Physics
John Preskill, Ph.D.
Theoretical Physics
Thomas A. Prince, Ph.D.
Physics

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Michael T. Anderson, Ph.D.
Mathematics
Bradley W. Filippone, Ph.D.
Physics
Kenneth G. Libbrecht, Ph.D.
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Kwok-Yung Lo, Ph.D.
Radio Astronomy
Robert D. McKeown, Ph.D.
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E. Sterl Phinney, Ph.D.
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Physics
Ryszard Stroynowski, Doctorat
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Instructors

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Mathematics
Krishna Maddaly, Ph.D.
Mathematics
Yoav Segev, Ph.D.
Mathematics
Boban Velickovic, Ph.D.
Mathematics

[1]Part-time

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Theoretical Physics
Peter Haff, Ph.D.
Physics
Colin Masson, Ph.D.
Physics
Richard A. Mewaldt, Ph.D.
Physics
B. Thomas Soifer, Ph.D.
Physics
Ryszard Stroynowski, Doctorat
Physics
Petr Vogel, Ph.D.
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Jonathan Elias, Ph.D.
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Dale E. Gary, Ph.D.
Astrophysics
Jocelyn B. Keene, Ph.D.
Physics
Charles R. Lawrence, Ph.D.
Radio Astronomy
Richard P. Mount, Ph.D.
Physics
Mark E. Nelson, Ph.D.
Physics
I. Neill Reid, Ph.D
Astronomy
James Thomas, Ph.D.
Physics
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Physics

Research Fellows

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Robert S. Anderson, Ph.D.
Physics
Clive Baillie, Ph.D.
Physics
Roger Ball, Ph.D.
Astronomy
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Radio Astronomy
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