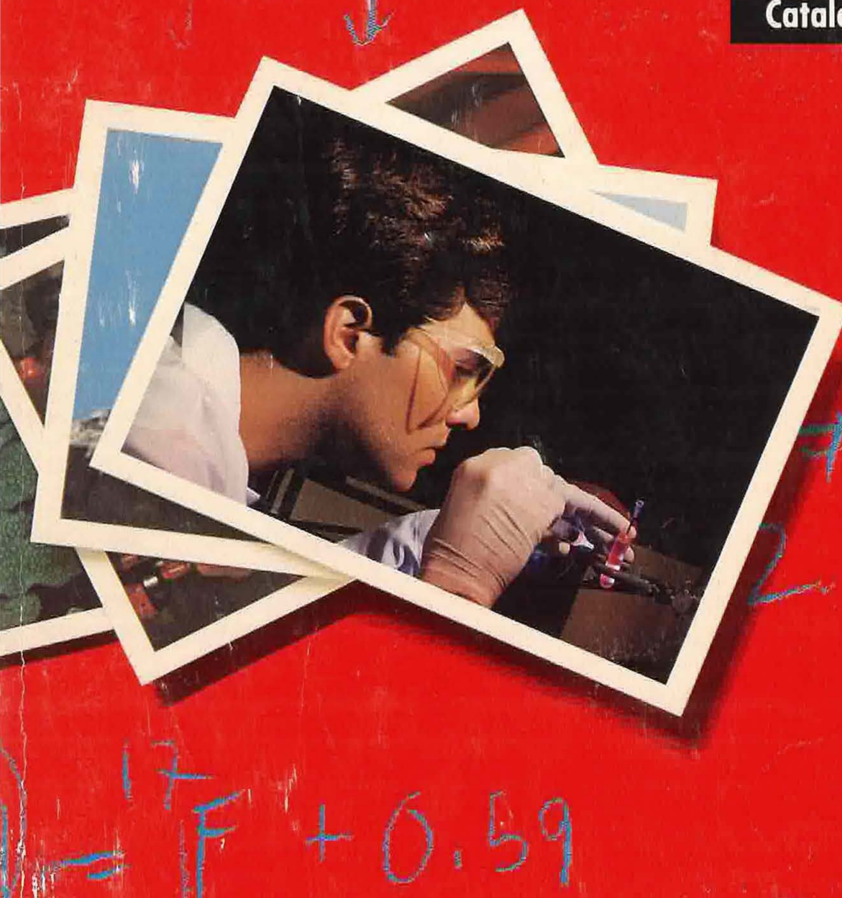
1988-89

Caltech

Catalog



CALTECH CATALOG 1988–89

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

September 1988

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1988	**FIRST TERM**
September 21	Registration of new students: graduate students–8:30 a.m.–12 noon; undergraduates–1:00-4:00 p.m.
September 22–24	New Student Orientation
September 26	Beginning of instruction–8:00 a.m.
	General Registration 8:30 a.m.-3:30 p.m.
	Undergraduate Academic Standards and Honors Committee–9:00 a.m.
October 14	Last day for adding courses and removing conditions and incompletes
October 31—November 4	Mid-term week
November 4	Last day for admission to candidacy for Master's and Engineer's degrees
November 7	Mid-term deficiency notices due–9:00 a.m.
November 14–18	Pre-registration for second term, 1988–89
November 24–27	Thanksgiving recess
November 24–25	Thanksgiving holidays
November 28	Last day for dropping courses and changing sections
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December 7*–9	Final examinations, first term, 1988–89
December 10	End of first term, 1988–89
December 11-January 3	Christmas recess
December 12	Instructors' final grade reports due–9:00 a.m.
December 23–27	Christmas holidays
January 2	New Year's holiday
1989	**SECOND TERM**
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	General Registration–8:30 a.m.-3:30 p.m.
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March 17	Last day for obtaining admission to candidacy for the degree of Doctor of Philosophy
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*First due date for final examinations

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	General Registration—8:30 a.m.-3:30 p.m.
	Undergraduate Academic Standards and Honors Committee–9:00 a.m.
April 21	Last day for adding courses and removing conditions and incompletes
May 1—5	Mid-term week
May 8	Mid-term deficiency notices due–9:00 a.m.
May 15–19	Pre-registration for first term, 1989–90, and registration for summer research (graduate and undergraduate)
May 26	Last day for dropping courses and changing sections
May 29	Memorial Day holiday
June 2	Last day for presenting theses for the degrees of Doctor of Philosophy and Engineer
June 2	Last day of classes—seniors and graduate students
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June 7*—9	Final examinations for seniors and graduate students, third term 1988–89
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June 12	Instructors' final grade reports due for seniors and graduate students–9:00 a.m.
June 14*– 16	Final examinations for undergraduates, third term 1988–89
June 14	Undergraduate Academic Standards and Honors Committee–9:00 a.m.
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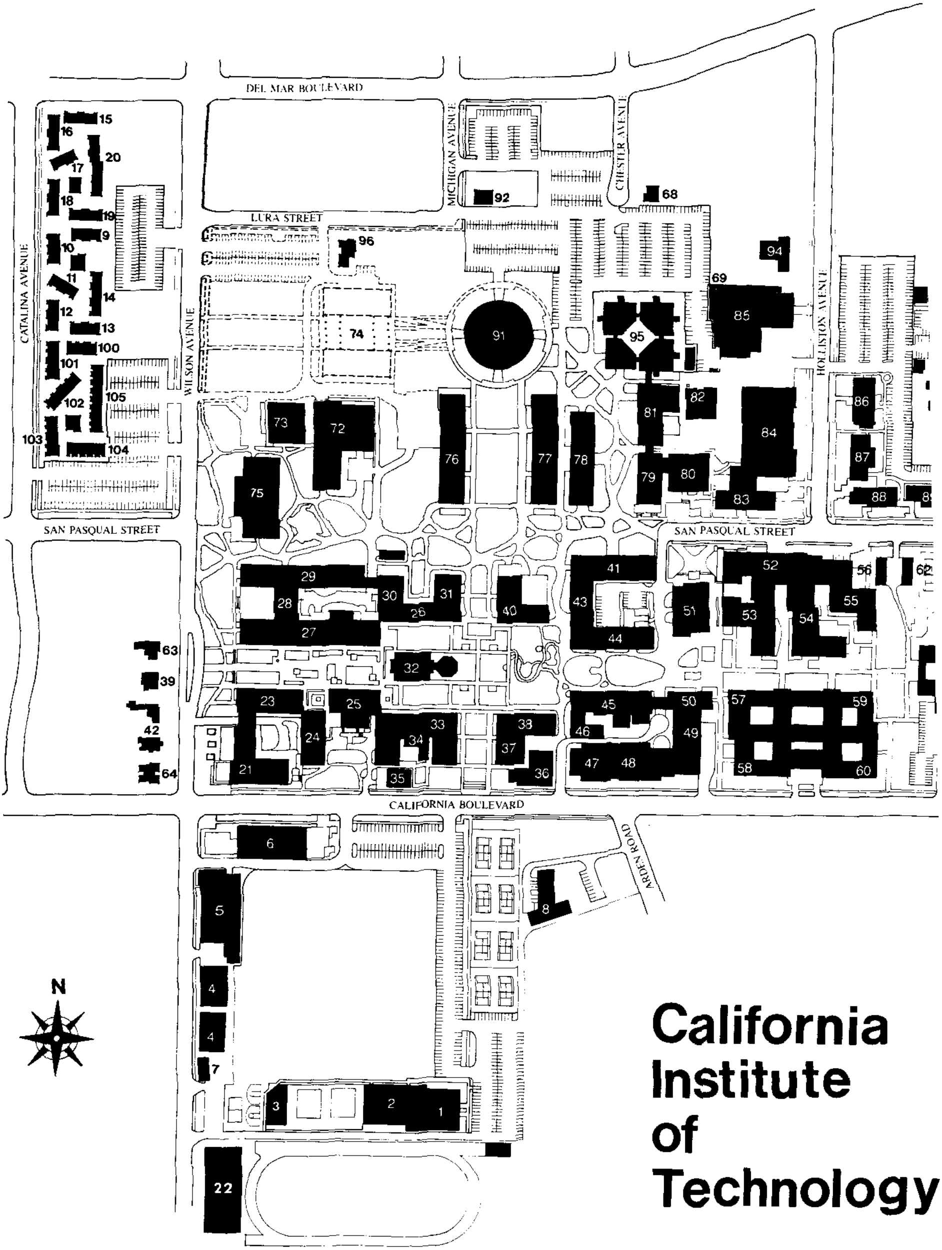
September 4	Labor Day holiday

1989	FIRST TERM 1989–90
September 20	Registration of new students: graduate students–8:30 a.m.-12 noon; undergraduates–1:00-4:00 p.m.
September 21– 23	New Student Orientation
September 25	Beginning of instruction–8:00 a.m.
	General Registration–8:30 a.m.-3:30 p.m.
	Undergraduate Academic Standards and Honors Committee–9:00 a.m.

*First due date for final examinations



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GENERAL INFORMATION

1

INTRODUCTION

The California Institute of Technology is an independent, privately supported institution officially classed as a university and 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 850 undergraduate and 1,000 graduate students) and the members of a relatively large research staff (approximately 800 faculty members).

In his recent inaugural address, Caltech President Thomas E. Everhart evaluated the nature and stature of the Institute as follows: "In 1988, when we hear concerns about economic competitiveness, when we are still recovering from the Challenger disaster, when our grade schools and high schools are not as competitive as we would like, when we cannot find the will to balance our national budget, there need to be a few places that look ahead and still dare to do the most ambitious things that human beings can accomplish. Caltech still has that ambition and that daring."

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 slightly over 50 percent of the total student body. Jointly engaged in research problems with faculty members, they contribute materially to the general atmosphere of intellectual curiosity and creative activity generated on the Institute campus.

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 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. The dedication by these men of their time, their minds, and their fortunes 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 who soon attracted graduate students. In 1920 the enrollment was 9 graduate students and 359 undergraduates with 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 850 undergraduates, 1,000 graduate students, and 800 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.

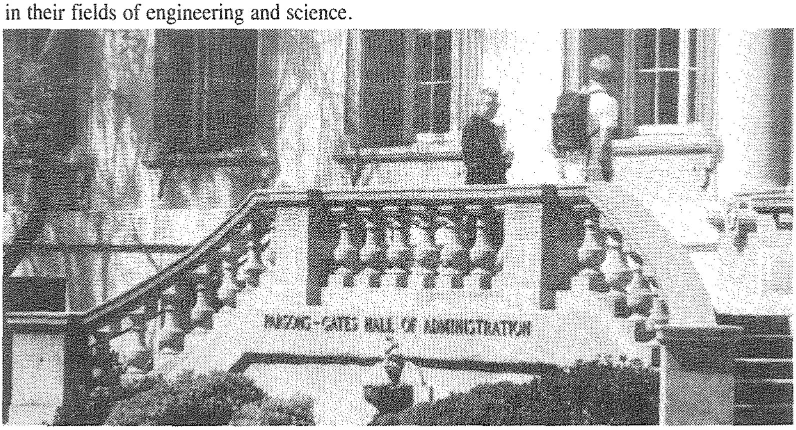
Dr. Harold Brown came to Caltech as president in 1969. A physicist who received his Ph.D. from Columbia in 1949, he had succeeded Dr. Edward Teller as director of the University of California's Lawrence Radiation Laboratory in Livermore in 1960. President Lyndon Johnson named Brown Secretary of the Air 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 in 1977 to become Secretary of Defense under President Carter.

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. Among the major accomplishments of the Goldberger administration were the addition of three new laboratories; the acquisition of a $70 million grant for construction of the W. M. Keck Observatory to house the world's most powerful optical telescope; and a $50 million pledge for the establishment of the Beckman Institute. Goldberger resigned in 1987 to become director of the Institute for Advanced Study in Princeton, New Jersey.

In the fall of 1987, Dr. Thomas E. Everhart became president of Caltech, coming to the Institute from his position as chancellor at the University of Illinois at Urbana-Champaign. Prior to that he had been dean of Cornell University's College of Engineering. Dr. Everhart did his undergraduate work at Harvard, where he graduated magna cum laude with an A.B. in physics. He earned an M.Sc. in applied physics at UCLA and a Ph.D. in engineering at Cambridge University. He has gained international recognition for his work in the development of electron microscopy; he has also done research on electron beams as applied to the analysis and fabrication of semiconductors.

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 $329,000,000 and those invested in endowment about $418,000,000. Very substantial grants and contracts from the federal government support many research activities.

Today Caltech has about 16,000 alumni scattered all over the world, many of them 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

Caltech Crafoord Laureate

*Gerald J. Wasserburg, Ph.D. '54	geochemistry	1986

*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 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, 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 and the Caltech Y.

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** within the hall. 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, 1988.

Infrared Processing and Analysis Center, 1986.

Beckman Institute. Built with funds provided by the Arnold and Mabel Beckman Foundation and other private donors. Under construction.

Off-Campus Facilities

Kresge Building, Seismological Laboratory (Division of Geological and Planetary Sciences), 1928, 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, 1986, Mauna Kea, Hawaii. Built with funds provided by the National Science Foundation and the Kresge Foundation.

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 6,600 journals, contain 428,300 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 and reference works. The main card catalog, including the records of the books held in the major collections on campus, is 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 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.

Beckman Institute

Now under construction, the Beckman Institute represents a major new addition to Caltech. The mission of the theoretical and experimental biologists and chemists working there will be to invent new methods, new materials, and new instrumentation for fundamental research in biology and chemistry. Their results will open the way to new possibilities for the application of scientific discoveries to human needs. Dedication of this pioneering new facility is planned for fall 1989.

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 9370, 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 Industrial Relations Center develops and offers to executives and managers in technology-based organizations programs that focus on linking emerging technologies with management strategies and practices, improving the effectiveness of manufacturing operations, developing the managerial and leadership skills of technical professionals, and encouraging new business ventures. Courses and forums are presented on campus and are open to Caltech students, faculty, and staff. Fees are waived for Caltech students who participate in the Center's programs.

The Center's Management Library assists corporate clients and members of the Caltech community in locating information on managing technology, starting new business ventures, and developing the managerial skills of technical professionals.

The Center is located on campus at 383 S. Hill Avenue. The latest calendar of programs or more information may be obtained by calling extension 4041.

POSTDOCTORAL APPOINTMENTS

Each year Caltech appoints a number of postdoctoral research fellows for definite terms, usually one year. The postdoctoral program generally consists of fundamental research in one of the Caltech laboratories in close association with one or more regular faculty members. Caltech is an affirmative action employer subject to the requirements of Executive Order 11246. 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 discussions, 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 to nine months during the academic 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 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; 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 research sponsor, usually a member of the Caltech/JPL research community, but occasionally a faculty member at another college or university. Students write research proposals in collaboration with their sponsors. Proposals and recommendations are reviewed by the members of the SURF administrative committee. The work is carried out during a ten-week period in the summer. In addition, students are encouraged to attend weekly seminars presented by members of the Caltech faculty and JPL technical staff each Wednesday of the program. Students may participate in luncheon roundtable discussions which are held bi-weekly with leaders in business, government, and academia, and with distinguished alumni. Students may also attend communications workshops on technical writing, presenting an oral report, and preparing visual aids. At the conclusion of the summer, SURFers submit a 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 1988, SURF students were paid $3,000. Applications are available in January and are due in early March. Awards are announced in mid-April. For further information regarding this program, call the SURF office, room 3 Dabney, (818) 356-4285.

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, as well as an Associate Master who shares the responsibilities for counseling students.

In addition to the student houses, the Institute maintains two apartment buildings, two dormitories, and a number of 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 handling of 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 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 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 11 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 nine 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.

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. ASCIT subsidizes the Friday night ASCIT movies, a weekly presentation of late vintage popular films. 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 usually held in alternate years, most recently in 1986, and serve a very useful purpose in promoting cooperation and communication.

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 scholastic and 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 Board of Control, which is composed of elected student representatives, is charged with monitoring the Honor System for undergraduates, while the Graduate Review Board performs the same function for graduate students. Suspected violations are reported to the appropriate board, which conducts investigations and hearings with strict confidentiality. If necessary, recommendations for actions are made 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 wide range of 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 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, and religious thought.

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 a used-textbook exchange and the lost and found, 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 serves students, faculty, and staff, and is located on the ground floor of the Winnett Student Center. Owned and operated by the Institute, the store carries a complete stock of required books and supplies, reference books, greeting cards, sweatshirts, and sundries as well as 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 nurse practitioners; (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 out-patient treatment for injury or illness. Benefits continue for 12 months, on 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.

Day on the Job. Students participating in the Day on the Job program have the opportunity to visit Caltech alumni on the job to discuss career options and to tour company facilities.

Part-Time Employment. Job listings (both on and off campus) are maintained in the Employment Information Library for students seeking part-time employment or work-study employment during the school year. Part-time employment provides students with the opportunity to help finance their education and to gain relevant work experience. (See also Student Employment under Financial Aid in Section 3.)

Summer Work Experience Program. Summer job listings (both on and off campus) are actively solicited from companies nationwide to aid students seeking career-relevant summer work experience. Workshops on resume preparation and all phases of the summer job search are presented, and counselors are available to answer specific questions. In addition, several major employers arrange on-campus interviews for summer employment.

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 members of the faculty 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 (Incomplete) 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.

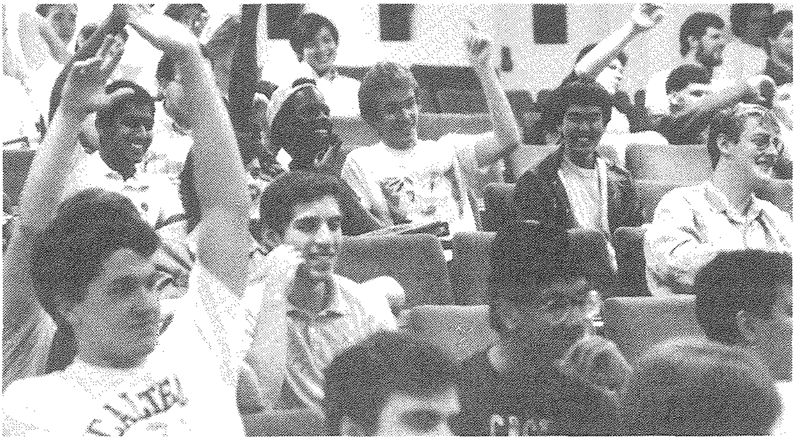
No. of Units	A+	A	A−	B+	B	B−	C+	C	C−	D+	D	F
1	4	4	4	3	3	3	2	2	2	1	1	0
2	9	8	7	7	6	5	5	4	3	3	2	0
3	13	12	11	10	9	8	7	6	5	4	3	0
4	17	16	15	13	12	11	9	8	7	5	4	0
5	22	20	18	17	15	13	12	10	8	7	5	0
6	26	24	22	20	18	16	14	12	10	8	6	0
7	30	28	26	23	21	19	16	14	12	9	7	0
8	35	32	29	27	24	21	19	16	13	11	8	0
9	39	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:

- 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.
- 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.
- 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.
- 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.
- 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.
- 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.

- 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.
- 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 Post-secondary 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. 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. Informal assistance and consultation about grievance procedures may be obtained from the Human Relations Adviser.

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 (see below). Any member of the Caltech community may consult with the Human Relations Adviser regarding harassment.

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 Human Relations Adviser, who acts as an ombudsman for the entire Caltech community, may be confidentially consulted about any problem not resolved by other offices.

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, the Dean of Graduate Studies, or the Human Relations Adviser.

Employment Experience of Recent Graduates

A survey was made at the end of June 1987 of the future plans of those students who had graduated at the commencement ceremony on June 12, 1987.

Of those receiving the B.S. degree about whom we have definite information, 60% had been accepted for admission to graduate school for further education, 30% had accepted employment, 7% were uncommitted, and 3% had other plans. The average salary of those accepting employment was $2,554 per month. At the M.S. level, 64% were continuing in graduate school, 23% were employed at an average salary of $2,778 per month, 2% were uncommitted, and 11% had other plans. Of those receiving the Ph.D. degree, 94% were employed at an average salary of $3,558 per month, 2% were uncommitted,and 4% had other plans.

Student Retention

Most undergraduates enter Caltech 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 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 re-enrolls 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.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AND
CHEMISTRY
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STUDY AND RESEARCH

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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 for 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 that 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; the development of laser scattering diagnostic techniques for fluid-flow measurements; and studies of two-phase flows, vapor explosions, 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. Computers 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, the 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 mechanisms in a wide range of fracture problems. Aspects that are studied include quasi-static and dynamic crack growth phenomena in brittle and plastically deforming solids, polymers and advanced composites, and fatigue and failure of adhesive bonds. Research areas adjunct to fracture studies in polymers are the non-linearly viscoelastic behavior of polymeric solids, and issues of structural durability in advanced aerospace structures.

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, including three servohydraulic facilities, two of which operate on a "tension/torsion" mode. 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 500,000 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 hypercubes, 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, dynamical systems, and advanced elasticity. Through 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, chaotic behavior of dynamical systems, and material instabilities and phase transformations in solids.

Physical Facilities

In addition to the regular facilities in the Division of Engineering and Applied Science, which include extensive computing facilities, 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 make 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, amorphous solids, 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, plus 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, and 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 university-related radio observatory in the world.

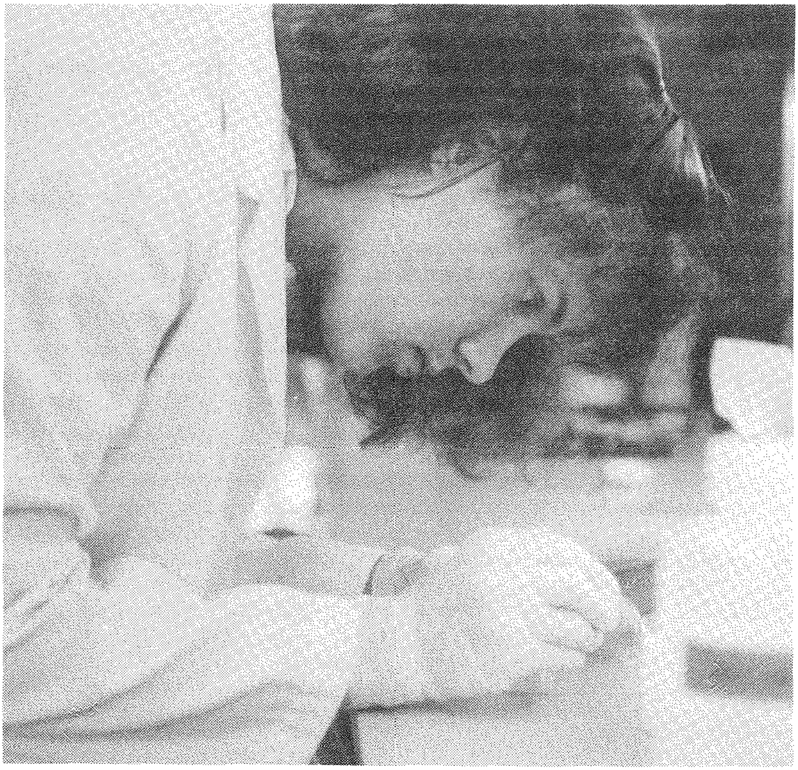
A major new facility is under construction on Mauna Kea, in Hawaii. The Caltech 10-m submillimeter telescope was completed in 1986. The Keck 10-m optical telescope, which is to be operated jointly with the University of California, will have four times the power of the Palomar 200-inch when it is completed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

Robinson Laboratory on campus houses the Astronomy Data Processing Facility. This contains VAX 11/780 and Convex C-1 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 the 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 because 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 cellular, molecular, and developmental biology are based upon approaches derived from biochemistry, biophysics, and genetics that offer new possibilities for expanded insight into long-standing problems. Neurobiology is a major area of emphasis within the Division of Biology. A comprehensive program of research instruction in neurobiology has been formulated to span the disciplines from neuron physiology to the study of animal and human behavior and the computational modeling of neural processes.

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 mutant types of Drosophila, a monoclonal antibody production facility, a fluorescence-activated cell sorter, scanning and transmission electron microscopes, and a state-of-the-art microchemical facility for sequencing and synthesizing biologically important macromolecules.

About 50 miles from Pasadena, in 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:

- Biochemical engineering: Dynamics of microbial populations in chemical reactors. Enzyme catalysis. Protein structure by nuclear magnetic resonance.

- Chemical reaction engineering: Applied catalysis, dynamics of catalytic reactions. Gas solid reactions. Development of supported regenerable sorbents for gas cleaning.
- Control: Modern control methods for chemical reactors and other systems. Interfacing process design and control systems design. Robustness in process control system design. Optimal control and estimation theory with application to petroleum reservoir engineering.
- Design: Novel design tools for complex processes with recycle loops. Computer-aided process design.
- Energy: Coal gasification and liquefaction. Coal pretreatment for clean combustion. Flue gas desulfurization. Petroleum reservoir engineering and recovery methods.
- 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.
- 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. Stokesian dynamics.
- 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.
- Structure and dynamics of liquid systems: Macromolecular modeling and hydrodynamics. Rayleigh and Brillouin laser light-scattering studies of 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.

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, conformations 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, scanning tunneling microscopy, 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 beams, and picosecond/femtosecond laser techniques. In organic chemistry, research focuses on the behavior of very reactive intermediates in the gas phase, in solution, and in inert matrices. 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, and 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 such as 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 experimental and modeling studies of the visual system; the circuitry, computational function, and modeling of the 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 computations; 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, a unified approach to the design and analysis of computing structures is taken both in courses and in research.

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 the curriculum and research. Design is not only a creative activity, but also a formal or, at least, systematic one. Managing 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; theory of computation; programming languages; semantics; programming methods and correctness; the human-machine interface, including natural language; information theory; computer vision; computer graphics and computer-aided design. Research projects frequently involve work in several of these areas, with both the theoretical and experimental aspects, as well as connections with such fields 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 it has been realized from the department's recent beginnings 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; these may be addressed by design disciplines such as "self-timed" systems, in which sequencing does not depend on global timing assumptions.

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 the 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 computer vision emphasizes the creation of realistic images. Physics is used to create realistic shapes and motions of computer models. Constraints on the physics allow controlled animation of the models. Rendering techniques that accurately simulate optics generate pictures with almost photographic realism. Computer vision is the inverse problem to computer graphics. Shape representations and constraints are equally applicable to computer graphics and computer vision problems.

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 35 Sun workstations, four VAXs, and an AT&T 3B20S, run UNIX. Our graphics laboratory includes three Symbolics 3600 LISP machines with color frame buffers and video digitization capability; ten 68020-based Hewlett-Packard workstations with SRX rendering machines, which allow very fast rendering of models; and a complete system for generating computer animation, using a VPR-3 one-inch videotape recorder. There are also numerous smaller machines in use, such as HP 9836Cs and IBM PCs, most with color displays. The Cosmic Cube multicomputers, and several of their commercial descendants (an Intel iPSC/1, an Intel iPSC/2, and an Ametek Series 2010) are on the department network for system and application experiments. Laser printers and color plotting devices are distributed through the offices and laboratories.

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 and VLSI laboratories are 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, ion implantation damage, 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 and the growth of nonlinear optical crystals for holographic image processing and optical computing, phased-array waveguide gas lasers, submillimeter wave techniques, and dielectric waveguides.

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 re-arrangeable switches; traffic capacities of mobile services, enhanced switches, and integrated services digital networks; distribution architectures for combined fiber-copper subscriber loops 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 computer vision, 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 Millimeter-Wave Integrated Circuits Laboratory is oriented toward developing integrated circuits and antennas for wavelengths ranging from the microwave bands through the submillimeter range. Current projects involve computer-aided-design software for microwave integrated circuits, network analyzers on a single chip, oscillator arrays, and millimeter-wave television cameras for radio astronomy and tokamak diagnostics, and for seeing through smoke and dust.

Research in pattern recognition is actively pursued, based on information theory, the theory of computation, and neural systems.

The optical information processing laboratory is engaged in research to develop optical techniques and devices for information processing. Current areas of interest include acousto optic devices and systems, photorefractive crystals, synthetic aperture radar, image processing, pattern recognition, neural network models of computation, optical memories, and optical neural 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.

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; forced nonlinear wave phenomena; dynamics of vortical flows and structural excitation; 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. They are 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 the protection and control of our environment. Research and instruction stress basic studies that aim to answer such questions as: How can we improve the air quality in urban and industrial centers while maintaining clean air in pristine rural areas? How can we ensure a supply of water of adequate quality and quantity for population centers and industry? How can we safeguard the 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 particles; applied microbiology, 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; and 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 elements in the environment; coagulation and settling of particles in seawater; aerosol chemistry and physics; acid rain and fog; interactions between toxicants and marine kelp; kinetics of oxidation processes in aqueous systems; genetics and physiology of microbial transformations; in situ bioremediation processes; 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 works of art.

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 in the various laboratories described below.

One of the air quality laboratories is a facility located on the roof of Keck that has been specially designed for studies of gaseous and particulate pollutants, both in smog chambers and in the ambient atmosphere. In other laboratories are facilities for single particle studies of aerosol thermodynamics and chemistry, including FTIR analysis of individual micron-sized particles, and a variety of facilities for the study of aerosol dynamics. A drop tube furnace, a fast flow reactor, and a single particle thermogravimetric analyzer are available. These laboratories are equipped with a broad range of instrumentation for the measurement of aerosol properties (differential mobility analysis, optical particle counters, condensation nuclei counters, cascade impactors, filter samplers, etc.) and for the measurement of gaseous pollutants (gas chromatography for hydrocarbons NO_x, SO_2, and O_3) as well as facilities for laser spectroscopy, reflectance spectrophotometry, and optical microscopy. Equipment is available sufficient to conduct field experiments involving measurement of atmospheric particulate matter concentration, chemical composition and size distribution, and gaseous pollutant concentration simultaneously at up to ten monitoring sites.

The water quality laboratory is equipped for chemical analysis (atomic absorption, polarography, plasma emission spectrophotometry, gas chromatography, mass spectrometry, x-ray fluorescence electrometry, high performance liquid chromatography, fluorescence spectroscopy, multi-wavelength, Mössbauer, EPR, NMR, FTIR, GC/MS spectrometry, multi-component UV-VIS spectroscopy, ion-chromotography), carbon compound identification and determination, radiologic measurements, particle size determinations (conductance, electrophoresis, electron microscopy, ultracentrifuge), microbiological measurements (biological fermenters), and kinetic measurements (T-jump and stopped-flow kinetics, ion-potentiometry, photochemical reactors, laser flash photolysis).

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. Four 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 laboratory computer system that can accomplish real-time multi-user processing and experiment control with data presentation by video graphics or hard-copy plotter. Additional computers are available for data analysis.

The applied microbiology laboratory includes a facility for preparation of bacterial media, as well as equipment for large and small scale culture, continuous culture, DNA isolation and manipulation, DNA sequencing and sequence data manipulation, protein purification and enzyme assays, and field sampling and analyses. In addition, access is available to the electron microscope facility on campus, as well as the oligonucleotide probe synthesizer and the microprotein sequenator.

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 VAXs 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, and staff 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:

- *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).
- *Water resources and water quality* (pollution control for coastal waters; sewage sludge disposal; acid deposition; water usage by energy industries; ground water contamination and control).
- *Control of hazardous substances and residuals management* (toxic substances in air and water; economics and regulation).
- *Energy policy, with emphasis on environmental tradeoffs* (energy markets and pricing; energy demand and conservation; load management).

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. Programs of study and research are pursued in geology, geobiology, geochemistry, geophysics, and planetary science. The curriculum is flexible so that students with degrees in biology, chemistry, engineering, or physics may carry out graduate work within the division. Interdisciplinary studies are encouraged and students may carry out academic and research programs within and between different divisions.

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. The dynamics and geometry of crustal movements are studied by geological and geophysical methods both on planetary and local scales in order to understand the evolution of continents. Major processes and events in the chemical and physical evolution of the earth can be identified by studying the structure, chemistry, and isotopic composition of rocks formed or modified in these events. The 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 broad scale structure of the earth is inferred from isotopic-geochemical studies and is interrelated with geophysical studies. 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. The early history of the solar system can be approached by studies of lunar samples and meteorites. The earliest solar and presolar history is being studied by seeking the connection between the residual planetary materials and the physical-chemical processes within the solar nebula and the precursor interstellar medium.

Physical Facilities

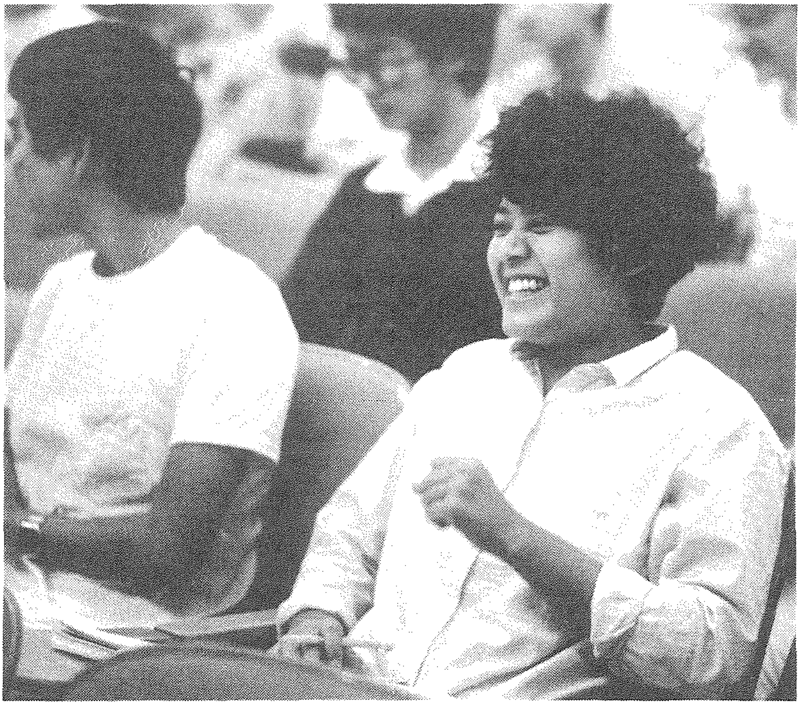
The division is housed in three adjacent buildings which are modern and well equipped for instruction and laboratory work. They contain several comfortable seminar rooms and the library as well as student and faculty offices. Various computer capabilities are also distributed throughout the division. There is an analytical facility (which includes an electron microprobe, a scanning electron microscope, and x-ray diffraction equipment). There is a machine shop for design and fabrication of experimental equipment. Specimen collection and sample preparation areas are available. There are modern laboratories for chemistry (at the trace and ultra low levels), mass spectrometry (electron impact, thermal ionization, and ion microprobe), experimental petrology, infrared spectroscopy and laser spectroscopy. In addition, there is a laboratory for the study of the behavior of rocks and minerals and their elastic constants in the pressure and temperature environments of planetary interiors. This includes a shock wave laboratory for studying ultra high pressure equations of state and shock effects. A field laboratory for measuring in situ stress is under development.

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. There are active field programs in diverse areas in North America.

The Seismological Laboratory of the Institute is housed in the Seeley G. Mudd Building. This has excellent computer facilities and maintains a seismological observatory which includes the Kresge Laboratory 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.

State-of-the-art tunable far-infrared and infrared laser spectrometers in a newly created laser facility are available for the study of gas phase and surface processes of importance in cosmochemical and geochemical environments. This facility is used to study the mechanisms of chemical reactions that govern the formation of the protosolar nebula and the earth's upper atmosphere.

The Jet Propulsion Laboratory, NASA's lead center for planetary exploration, is located seven miles from campus and is administered by the Institute. Students and faculty have the opportunity to participate in JPL activities through joint research, instrument development, mission operations, and data analysis. Planetary science minicomputers and image processing systems are linked, through the campus network, to the Image Processing Laboratory at JPL and to supercomputers across the country. In addition, Caltech owns and operates several optical and radio observatories that are used partly for planetary research. A particularly active program of planetary studies is pursued at the Owens Valley Radio Observatory.



HUMANITIES

Literature at Caltech spans the major periods of American, British, 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.

A variety of courses in modern European languages and in music and art history are available.

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 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 Curriculum 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 a complete description see page 107.)

MATERIALS SCIENCE

Materials scientists study relationships between the properties of materials and their internal structure, and how this structure can be controlled by methods of synthesis and by chemical composition. There are three main classes of pure materials: metals, ceramics, and polymers. Recently composite materials comprising one or more of these three classes have become a topic in themselves. The field of materials science at the California Institute of Technology is oriented towards fundamental issues in metals and (semiconducting or superconducting) ceramics. Additional faculty in electrical engineering, applied physics, physics, and chemistry are concerned with semiconductors and superconductors. Work in polymers is performed by faculty in aeronautics , chemistry, and chemical engineering.

Areas of Research
The current areas of research by materials science faculty are oriented towards solid materials that are far removed from their equilibrium structures, which are perfect crystals. Examples of such materials include glasses, with their disorder in atomic positions, crystalline alloys containing chemical disorder, and crystalline materials that are severely deformed and contain an extensive structure of dislocations and other defects. Interfaces of perfect materials are also of interest. In all these materials the non-equilibrium structure is being characterized and its origins understood, and the studies often monitor how these structures relax towards equilibrium.

The Caltech Materials Group
Materials science is inherently a cross-disciplinary field, and investigators in several options at Caltech have recognized that it is mutually beneficial to collaborate in order to promote interdisciplinary projects and to facilitate the acquisition of major equipment items that benefit many research programs. Toward this end, the Caltech Materials Group (CMG) was formed in 1985 with faculty from materials science, physics, applied physics, electrical engineering, chemistry, and mechanical engineering. Within the CMG, it is our expectation that the orientation of materials science towards the more fundamental and the orientation of physics and chemistry towards the more complex will lead to a type of materials science with a rigorous fundamental footing.

Physical Facilities
Research by the faculty, graduate students, and a few advanced undergraduates is conducted in the W. M. Keck Laboratory of Engineering Materials. Facilities for the preparation of materials that have been built recently or are under construction include equipment for: physical vapor deposition under ultrahigh vacuum conditions, shock wave consolidation of powders, rapid solidification, high-energy ball milling, and ion beam modifications of materials (with accelerators located elsewhere at Caltech). Facilities for the characterization of materials include an extensive array of x-ray diffraction equipment including a double crystal diffractometer, an extended x-ray absorption fine-structure spectrometer, a Rutherford backscattering spectrometer, Mössbauer spectrometers, a differential scanning calorimeter and differential thermal analyzer, cryogenic facilities for the characterization of superconductors, and test systems for the measurement of mechanical properties. Caltech faculty have just completed the installation of a state-of-the-art Philips EM 430 300 keV transmission electron microscope with high resolution as well as analytical capabilities. Two other 100 keV transmission electron microscopes are dedicated to materials research, and analytical scanning electron microscopes and microprobes are available elsewhere at Caltech. Networked computing facilities are available.

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, and quadratic forms; *Analysis:* classical real and complex analysis, ordinary and partial differential equations, harmonic analysis, integration theory and functional analysis, and dynamical systems and ergodic theory; *Combinatorics:* block designs, coding theory, and combinatorial matrix theory; *Math-*

ematical 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, and analysis of 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 applies 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; and 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 the 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) and the European Center for Nuclear Research (CERN). Activities include studies of Z° decay at the new SLC accelerator at SLAC and at the LEP storage ring at CERN. A large detector to search for magnetic monopoles is under construction at the Gran Sasso underground laboratory in Italy.

A phenomenology group is concentrating on quantitative tests of quantum chromodynamics (QCD) in lepton and high transverse momentum processes and on design and planning for the superconducting supercollider (SSC).

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 experiments in the GeV range, carried out at 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 and Particle Physics. This group focuses on fundamental properties of nuclei and elementary particles, particularly neutrinos. Experiments on neutrino oscillations being carried out at a nuclear reactor and on double beta decay in an underground laboratory in the Gotthard tunnel in Switzerland are designed to help understand neutrino mixing and neutrino mass. The experimental program is complemented by theoretical studies of nuclear structure and particle properties.

Cosmic Rays and Gamma Ray Astronomy. Measurements of energy and mass spectra of charged particles in space are carried out with detectors carried on spacecraft and balloons. The data 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 1-mm wavelengths are carried out with ground-based telescopes at Palomar and other observatories. This group is heavily involved in making preparations for the new 10-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 being analyzed.

Submillimeter Astronomy. Star formation, interstellar gas, galaxies, and quasars are studied using the 10-meter telescope at Caltech's Submillimeter Observatory on 14,000-foot Mauna Kea in Hawaii. Far infrared observations are made from NASA's Kuiper Airborne Observatory.

Research is conducted on superconducting tunnel junction detectors for use in future telescopes.

Condensed Matter Physics. Two-dimensional matter, phase transitions in two and three dimensions, phonon physics, and high-temperature super conductivity are areas of interest.

Applied Physics. Techniques of theoretical and experimental physics are applied to problems in surfaces, materials, and planets. As part of the interdisciplinary Materials Research Group, work is done with on-campus facilities, including ion accelerators and UHV thin-film preparation equipment, as well as off campus, at both industrial and other academic laboratories. Recent studies include sputtering, damage by high-energy ions, modification of semiconductors by ion implantation, and the behavior 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 nature of elementary particles and their fundamental interactions is the focus of studies in quantum cosmology, superstring theory, large-scale astrophysics, and particle phenomenology at accelerator energies. Many astrophysical interests are pursued in collaboration with the astronomy faculty, including problems in general relativity and cosmology, in interplanetary and interstellar media, in stellar structure and evolution, in helioseismology, and in quasars, pulsars, and neutron stars.

Theoretical studies also include atomic nuclear structure and reactions, condensed matter physics, including quantum theory of solids and turbulent fluids, and various aspects of mathematical physics. Computational physics studies new systems such as parallel processors and neural networks as models of physical systems and prototypes for new computers.

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 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 empirical techniques and mathematical modeling. Particular emphasis is placed on studying the relationships among economics, politics, and public policy in a rigorous scientific manner. Students can use their considerable quantitative talents to great advantage in these areas.

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.

Areas of Research

The social science program is characterized by collaborative, multidisciplinary research, exploring such areas as group decision making, voting procedures, and market behavior.

Among the areas of basic and applied research in political science are (1) formal models of interdependent decision making, especially in the context of elections, congressional behavior, and cooperative committee processes and (2) statistical analyses of the impact of economic conditions on voting, the creation and functioning of regulatory bureaucracies, redistricting, and the appropriations process in Congress.

Research in quantitative history incorporates economic and political models and statistical methods into historiography, yielding new insights into the effects of tax policy on productivity and wealth distribution, the extent of racial discrimination in the U.S., and the process that leads to the adoption of new technologies.

Current research in economics includes analysis of the effects of consumer information on the price and quality of goods and services, energy policy, and tax compliance. Faculty members are also in the forefront of the design and analysis of incentive schemes, and that research promises exciting possibilities for the systematic improvement and design of institutions.

Finally, Caltech is a major center for the experimental investigation of economic and political decision making, for the development of experimental methods of analysis, and for the application of these methods to public policy.

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 are described below. Personal interviews with applicants and two or three of their teachers may be held at their schools when feasible. An application fee of $25 is due at the time an application for admission is submitted. The fee is not refundable, but it is applied to 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 applications and the $25 application fee must reach the Admissions Office not later than January 1. (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 Composition 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 not 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 23060, Oakland, CA 94623-2306. 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. Because 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 may 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 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 the admission or rejection decision 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 financial aid 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 acknowledgment. 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.

Applicants for admission under the early decision plan must have credentials on file by October 15 of the senior year. (If 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 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. In exceptional cases, students with a particularly strong background in chemistry may elect to take 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 21 abc (9 units each term), or (ii) Ch 41 abc (9 units each term). The student's qualification for Advanced Placement in Chemistry will be determined in personal interviews with the chairman of the undergraduate student committee in chemistry and the course 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 considerably more rigorous than most advanced placement work, and entering freshmen are encouraged to take Ph 1. A test is administered during the summer to aid in the organization of Ph1; students who perform particularly well can discuss the possibilities for advanced placement with the physics representative during orientation. A second test may then be required.

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 also urged to attend.

The orientation, usually off campus, takes place during three days immediately following new student 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 calculus-based (engineering) 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 juniors.

An applicant for admission as a transfer student must write to the Admissions Office of the California Institute of Technology by March 1. The applicant must state his or her desire to transfer, the choice of engineering or one of the options in science or humanities and social science, 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 an official transcript of his or her academic record to date, showing in detail the character of previous training and the grades received in college. Official transcripts should also clearly indicate courses in progress in the latter half of the year. After the postcard has been received and the official transcripts have been evaluated by the Admissions Office, an application blank will be sent, provided the grades and subjects on the official 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 official transcripts have been received and evaluated. Official 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. Official transcripts should, therefore, be sent no later than March 1. 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 official 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 63) 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, Men's Gym, #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

- turned in a signed registration card with their approved study list, and
- 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. A student who withdraws, or is absent for a term (or longer), without an approved leave of absence, must petition for reinstatement to return to the Institute. Reinstatement rules are the same as those listed under scholastic requirements. A student must withdraw by the last day of classes in any term. No courses or grades for that term will appear on the permanent record of the student. However, the date of withdrawal will be noted on the record. The record will also indicate if a leave of absence was granted.

A student leaving the Institute at any time during the term without filing a formal withdrawal card will not be considered withdrawn. In such a case, 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 Registrar's Office 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:

- 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.
- 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.)
- 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 requirement as above to complete a full load of at least 36 units with a grade-point average of at least 1.9.

If a late grade received on or before the last day for adding classes makes a reinstated student 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, 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. At the end of the spring term a student will be declared ineligible to register if he or she has not completed an average of 33 units per completed term (excluding summers) in residence or has not completed an average of 30 units in the three most recent terms in residence.

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 54 units by an upperclassman or more than 51 units by a freshman. 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 of the Dean or Associate Dean of Students. Petitions for overloads will not be accepted later than the last day for adding classes in any term.

Underloads with 27 or more units may be approved by the Dean or Associate Dean if the student has not previously had an underload. Seniors may take an underload by presenting for the Registrar's approval a course plan for graduation the following June, provided that the plan does not require an overload in any term. In all other cases the student must petition the Undergraduate Academic Standards and Honors Committee for approval. The committee has the latitude 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 and take this, with the transcript, to the representative of the option in which credit is desired. 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 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 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 1988–89

General:	
General Deposit	$ 25.00[1]
Tuition	11,600.00
Student Body Dues, including *The California Tech*	60.00[2]
Assessment for *Big T*	24.00[2]
	$11,709.00
Other:	
Student Housing: (Rates are subject to change)	
Room	2,007.84
Board (provides 10 meals per week while Institute is in session)	1,680.53
Dues	105.00
Books and Supplies (approx.)	525.00
Personal Expenses (approx.)	1,028.00
Meals not on Board contract (approx.)	1,047.00
	6,393.37

The following is a list of undergraduate student fees at the California Institute of Technology for the academic year 1988–89 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 21, 1988	General Deposit	$ 25.00
(Freshmen)	Tuition	3,867.00
September 26, 1988	Associated Student Body Dues	20.00
(All Others)	Assessment for *Big T*	8.00
	Room and Board (for on-campus residence)	1,334.09
	Student House Dues and Assessment	35.00
	Second Term	
January 4, 1989	Tuition	3,867.00
	Associated Student Body Dues	20.00
	Assessment for *Big T*	8.00
	Room and Board (for on-campus residence)	1,215.71
	Student House Dues and Assessment	35.00
	Third Term	
April 3, 1989	Tuition	$3,866.00
	Associated Student Body Dues	20.00
	Assessment for *Big T*	8.00
	Room and Board (for on-campus residence)	1,138.57
	Student House Dues and Assessment	35.00

Tuition Fees for fewer than normal number of units:

36 units or more	Full Tuition
Per unit per term	$ 108.00
Minimum tuition per term	1,080.00

Audit Fee $108.00 per lecture hour, per term.

[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.

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:

- date of approval of the request by the Dean of Students for *withdrawals;*
- 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 believes that qualified students who wish to attend Caltech should not be prevented from doing so for financial reasons. The Institute is therefore strongly committed to meeting the demonstrated financial need of students whose families cannot afford the total cost of a Caltech education.

Financial need is the difference between the cost of attending Caltech and the amount the student and parents can reasonably be expected to contribute toward those costs. Costs include actual tuition and fees, room and board, and allowances for meals not covered in the board contract, books and supplies, personal expenses, and a travel allowance based on airfare for two round trips. (Caltech is unable to include a travel allowance for students whose residence is outside the U.S., Mexico, or Canada.) Caltech's estimate of a family's ability to contribute is determined on a yearly basis from the information provided on the financial aid application. The information is analyzed using a federally mandated formula called Congressional Methodology.

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. U.S. citizens or eligible noncitizens (as defined in the application) may apply for state and federally funded programs. International students may apply for institutionally funded programs. Students do not have to be accepted for admission to Caltech before applying for financial aid. Students with complete financial aid applications on file will be considered for all applicable types of need-based assistance. A renewal application must be submitted each year.

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 and prizes, see pages 78 and 80–83.)

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

- *Early Decision Admission Candidates* should file an Early Version Financial Aid Form (FAF) with the Caltech Financial Aid Office between October 15 and November 15 of the year preceding the year in which they plan to enter Caltech. Preliminary estimates of financial aid eligibility will be issued with the admissions offer. The application procedures for *freshman admission candidates* (below) must be completed before a final award can be offered.
- *Freshman Admission Candidates* should submit a completed Financial Aid Form (FAF) to the College Scholarship Service (CSS) for processing between January 1 and February 1 and

designate Caltech as a recipient. California residents must use the Student Aid Application for California (SAAC) instead of the FAF and apply for a Cal Grant. Preliminary awards will be issued with offers of admission. Awards will become final after tax returns and all other requested documents are received by the Financial Aid Office and any necessary award adjustments are made.

- *Returning Students* should obtain a copy of the SAAC and accompanying documents from the Caltech Financial Aid Office. The SAAC should be submitted to the College Scholarship Service by March 2. California residents must apply for Cal Grant, if eligible. Accompanying documents should be submitted directly to the Financial Aid Office by May 1.
- *Transfer Admission Applicants* should submit a completed FAF or SAAC to the College Scholarship Service by April 1. California residents must apply for a Cal Grant by the published deadline. Preliminary awards will be issued with offers of admission. Awards will become final after tax returns and all requested documents are received by the Financial Aid Office and any necessary award adjustments are made. Financial aid transcripts from each college previously attended are required.
- *International Student Applicants* (with the exception of Canadians and Mexicans, who should follow the procedures for the appropriate domestic students listed above) must submit to the Financial Aid Office the Foreign Student Financial Aid Application and Certification of Finances. This must be done at the time of application for admission to Caltech. Preliminary awards will be issued with offers of admission. Awards will become final after tax returns and all other requested documents are received by the Financial Aid Office, and any necessary award adjustments are made. Those offered assistance will be eligible to apply for aid in subsequent years. International students who do not apply for aid at the time of admission, or who are denied aid, will be ineligible for aid during any other academic period while they are undergraduates at Caltech. (Canadians and Mexicans are exempt from this rule.)
- *Returning International Students* should file the Foreign Student Financial Aid Application and Certification of Finances in accordance with the dates listed for *Returning Students* (above).

Please note: In addition to the application forms described, all financial aid applicants must submit signed copies of their parents' and their own federal income tax returns, complete with all schedules. If a tax return will not be filed, a statement to that effect will be required. International students must submit translated returns from their country of nationality and/or from the country where their parents are employed.

TYPES OF AID AVAILABLE

Once financial need has been determined, that need can be met either by a single type of aid or by a combination of scholarships or grants, loans, and student employment. Together, they make up a financial aid "package," which is simply a combination of awards. For the 1988-89 academic year, students will typically receive $3,750 in a combination of work and/or loan, with remaining need being met with grant money.

Scholarships and Grants

Caltech Grants are awarded from an institutional fund or endowment specifically established for the purpose of assisting undergraduates. The amount of the award depends on financial need.

"Name" Scholarships are awarded to undergraduates with financial need. Funds are given to the Institute by individuals or organizations for scholarship purposes, and are named by or for the donor.

Pell Grants and Supplemental Educational Opportunity Grants (SEOG) are federally funded grants. All eligible students are required to apply for Pell Grants and submit to the Financial Aid Office the Student Aid Reports received from the processor.

Cal Grants are awarded by the California Student Aid Commission to California residents. All eligible California residents are required to apply.

Many other states provide scholarships and grants. A complete list of state scholarship agencies and their addresses is available in the Financial Aid Office. Students should contact the agency in their state of residence regarding programs available and application procedures.

Employment

Student employment is generally available to all students regardless of whether they apply for financial aid. Interested students should contact the Caltech Career Development Office. Because all income earned during the academic year must be considered as a resource for students receiving financial aid, they should notify the Financial Aid Office when they begin employment during the academic year. Undergraduate students must receive approval from the Dean of Students to work more than 16 hours per week. It is recommended that freshman students do not commence employment until second term. They must receive permission from the Dean of Students to commence employment.

College Work-Study is a federally funded program that provides part-time employment for students with demonstrated financial need. College Work-Study jobs are available on campus, at JPL, and off campus with non-profit organizations and with some profit-making organizations that offer academically relevant jobs. Interested students should contact the Career Development Office. *Summer College Work-Study* is also available.

The Foreign Student Employment Program is funded by the Institute to provide part-time employment for international students with demonstrated financial need. Jobs are available on campus or at JPL. *Summer Foreign Student Employment Program* funding is also available.

Loans

Perkins Loans (formerly National Direct Student Loans) are awarded by the Institute to students with demonstrated financial need. Funds are obtained from the federal government and from former Caltech students who are in the process of repaying their loans. No interest is charged on the loan while a student maintains at least a half-time academic load. Repayment begins six months after leaving school or dropping below half-time status (nine months for new borrowers). Interest is then charged at a rate of 5 percent on the unpaid balance. Perkins Loans are limited to a total of $4,500 during the first two years of undergraduate study, a total of $9,000 for undergraduate study, and a maximum of $18,000 for the entire undergraduate and graduate career. Information concerning deferment, postponement, and cancellation will be provided to each borrower on the loan promissory note.

Caltech Loans are a variety of loan funds from many sources and are used to supplement the Institute's Perkins Loan (NDSL) funds. Generally, no interest is charged and no repayment of principal is required while a student maintains a continuous course of study as an undergraduate at Caltech. Repayment begins ninety days after the student leaves school, graduates, or earns a final degree. Interest begins at 4 percent on the unpaid balance, increasing to 5 percent after three years and to 6 percent after five years, at which point it remains constant until the loan has been repaid in full. If the student transfers to another institution or attends graduate school, here or at another institution, no payments need be made on the principal, but interest is charged at 3 percent per year on the unpaid balance as long as attendance is maintained at the other institution. More specific information is provided to each borrower on the promissory note.

Guaranteed Student Loans (GSL) are federally insured loans available through banks and other lending institutions. The current interest rate is 8 percent. For new borrowers after July 1, 1988, the interest rate increases to 10 percent with the fifth year of repayment. A separate application form in addition to the FAF or SAAC is required, and may be obtained from the lender or the Financial Aid Office. The current loan maximums are $2,625 per year for undergraduates in the first two years of study, and $4,000 per year for subsequent undergraduate years. The aggregate undergraduate GSL limit is $17,250. Graduate students may borrow $7,500 yearly, with an aggregate limit of $54,750 including undergraduate loans.

Supplemental Loans for Students (formerly part of the PLUS/CLAS program) allow independent undergraduate or graduate students to borrow up to $4,000 per year with an aggregate limit of $20,000. Loans disbursed after July 1, 1987, have a variable interest rate, adjusted yearly. For the 1987–88 academic year, the interest rate was 10.27 percent. Repayment generally begins within 60 days of when the loan is made. A separate loan application is required. Specific details on the SLS Loan, applications, and repayment and deferment information are available from lenders or the Financial Aid Office.

PLUS or CLAS Loans are federal loans that help parents of dependent undergraduates prorate payment of their contribution toward educational costs. A parent may borrow up to $4,000 a year for each dependent undergraduate, with an aggregate limit of $20,000 for each student. Loans disbursed after July 1, 1987, have a variable interest rate, adjusted yearly. For the 1987–88 academic year, the interest rate was 10.27 percent. Repayment generally begins 60 days after the loan is made. A separate loan application is required. Specific details on the PLUS or CLAS Loan, applications, and repayment and deferment information are available from lenders or the Financial Aid Office.

No-Need Scholarships

A number of scholarships are available to returning students regardless of financial need. Each year the Committee on Scholarships and Financial Aid recommends a number of the Institute's most academically talented freshmen, sophomores, and juniors for Merit Awards. Recommendation for these awards is made solely on the basis of academic merit. These awards are made from the Caltech Prize and Carnation Scholarship endowments. The John Stauffer Merit Scholarship is also awarded to a student with a chemistry related major. In 1987–88, 32 students received Merit Awards in the amount of $8,500 or $11,000. The honor is recorded on transcripts and listed in the commencement bulletin when the scholars graduate.

Several corporations, including General Motors, Hughes Aircraft, and Xerox, offer partial or full tuition scholarships to students demonstrating particular facility in the options that represent the types of expertise the corporations need in their research and development groups. As these and other organizations announce competitions throughout the year, eligibility criteria and deadlines are advertised by the Financial Aid Office in the student newspaper, *The California Tech.*

Satisfactory Academic Progress

In order to continue receiving financial aid at Caltech, students must maintain satisfactory progress toward completion of the baccalaureate degree as defined on page 84. Approval for reinstatement by the Undergraduate Academic Standards and Honors Committee or the Dean of Undergraduate Students (as described on page 70) shall re-establish satisfactory progress for purposes of financial aid eligibility.

In general, assistance is available to eligible students for the first 12 terms of registration (or the equivalent for transfer or part-time students). Exceptions may be approved after submission of a petition to the Financial Aid Office.

Refund and Repayment Policy

Caltech has established an equitable refund policy for students who find it necessary to drop a course or withdraw from the Institute.

Dropping a Course: A student's financial aid package will be adjusted to reflect any tuition adjustment made by the Student Accounts Office.

Withdrawal from the Institute: Students who officially withdraw from the Institute during an academic term will receive a tuition refund based on the schedule published on page 74. Students living in Caltech housing may also be eligible for a partial refund from the Housing Office.

When granting refunds to financial aid recipients, it is Caltech's policy to reduce the aid award by the amount of the refund and any adjustments in the actual living costs. Therefore, an aid recipient's refund is, in most cases, returned to the original aid account.

An overpayment or overaward occurs when a student receives more aid than he or she is eligible to receive. Therefore, the Financial Aid Office will compare actual costs to aid disbursed in accordance with federal guidelines. If aid disbursed exceeds costs, the student may be responsible for the overpayment. Any overpayment will be charged to the student on his or her student account. Additional information is available in the Financial Aid Office.

Financial Payment Plans

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

- 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.
- EFI Fund Management Corporation, 2700 Sanders Road, Prospect Heights, IL 60070 (800-323-8399), 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.
- Knight Tuition Payment Plans, 855 Boylston Street, Boston, MA 02116 (617-267-1500) or (800-225-6783), 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 parent repays the loan in up to 120 months. Interest is at an attractive variable rate and is charged on the actual amount paid to the university and not yet repaid. The rate in effect on March 1, 1988, is 10.25 percent.
- 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 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 or senior 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.

Caltech Prize Scholarships and Carnation Scholarships

Each year Caltech awards these prizes for academic excellence. They are based solely on merit (selection is made on the basis of grades, faculty recommendations, and demonstrated research productivity) with no consideration given to need or any other nonacademic criteria.

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.

Deans' Cup and Masters' Cup

Two awards, selected by the Deans and Masters, respectively, are presented to undergraduates whose concern for their fellow students has been demonstrated by persistent efforts to improve the quality of undergraduate life and by effective communication with members of the faculty and administration.

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 recipient.

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 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.

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.

Rodman W. Paul History Prize

The Rodman W. Paul History Prize was established in 1986 by some of his many colleagues and friends to honor Professor Paul's 35 years of teaching and research at the Institute. The prize is awarded annually to a graduating senior who has shown unusual interest in and talent for history.

H. J. Ryser Scholarships

The H. J. Ryser Scholarships were established in 1986 in memory of H. J. Ryser, who was professor of mathematics 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, freshman, sophomore, and junior students, 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 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[1])	27
3.	Freshman Physics (Ph 1 abc)	27
4.	Sophomore Physics (Ph 2 abc[2] or Ph 12 abc)	27
5.	Freshman Chemistry (Ch 1 abc)[3]	18
6.	Freshman Chemistry Laboratory (Ch 3 a)	6
7.	Additional Introductory Laboratory	6
8.	Humanities Courses (as defined below)	36
9.	Social Sciences Courses (as defined below)	36
10.	Additional Humanities and Social Sciences Courses	36
11.	Physical Education	9

[1]One term from the following courses may be substituted for Ma 2 c: Ma 112 abc, Ma 144 ab, AMa 153 abc.
[2]One term from the following courses may be substituted for Ph 2 c: Ph 12 c, APh/ME 17 c, Ch 21 bc.
[3]This requirement can also be met by completing Ch 2 ab or any two terms of Ch 41 abc.

Introductory Laboratory Requirement. All students are required to take at least 12 units of laboratory work in experimental science during their freshman and sophomore years. Ch 3 a (6 units) shall be taken during the freshman year. The additional 6 units must be chosen from one of the following: APh 9 (6 units), Bi 10 (6 units), Ch 3 b (6 units), Ch 4 ab (6 units per term), CS/EE 11 (6 units), E 5 (6 units), Ph 3 (6 units), Ph 4 (6 units), or a more advanced laboratory course.

Humanities and Social Sciences Requirements. All students must complete satisfactorily 108 units in the Division of the Humanities and Social Sciences. Of these, 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 humanities and social sciences, including work done under the HSS Tutorial Program and courses (to the limit of 27 units) in business economics and management. 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.

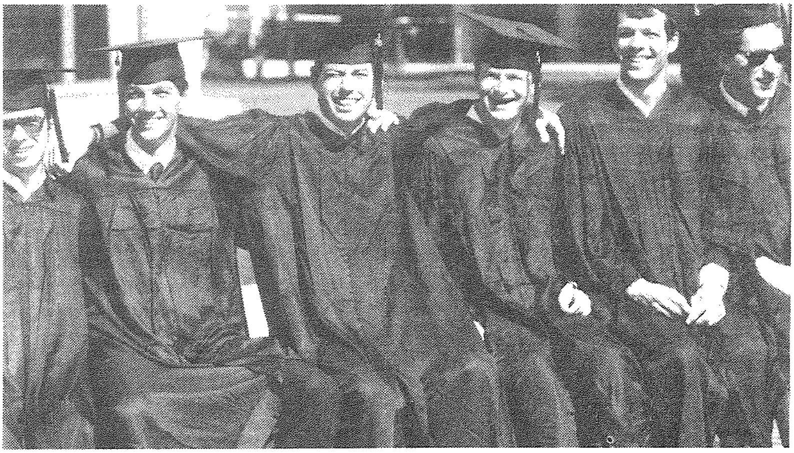
Entering freshmen are required to take two terms of "Freshman Humanities," humanities courses numbered 20 or below in the catalog that require 4,000 words of essay writing a term. Successful completion of two terms is a prerequisite for advanced humanities (numbered above 20), but *not* for introductory social sciences. 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.

A student must take 18 units of advanced humanities courses. 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 and sixth terms of a language count toward 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 Anthropology: An 22, Economics: Ec/SS 11, Ec 15, Law: SS 33, Political Science: PS/SS 12, Psychology: Psy 10, 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. All 18 units of advanced social science credit can be taken from the same area as long as the appropriate introductory course has been taken. SS 13 can serve as the introductory course for Ec 129, PS 119, and PS/SS 125.

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 defined 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
	Introductory 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 6 units must be chosen from one of the following: APh 9 (6 units), Bi 10 (6 units), Ch 3 b (6 units), Ch 4 ab (6 units per term), CS/EE 11 (6 units), E 5 (6 units), Ph 3 (6 units), Ph 4 (6 units), or a more advanced laboratory course.
[3]A partial list of electives particularly recommended for freshmen includes the following: APh/MS 4, Ay 1, Bi 5, Bi 8, 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 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 120 abc, Ma 121 abc, Ma 142 abc, Ma 147 abc, Ma 151 abc.
4. Passing grades must be obtained in a total of 486 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 are 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 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, amorphous solids, 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 53, CS/EE 54, 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 486 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
Fourth Year				
APh 78 abc	Senior Thesis, Experimental[3]	6	6	6
or				
APh 77	Laboratory in Applied Physics[3]	9	9	–
APh 106 abc or Ph 106 abc	Topics in Classical Physics	9	9	9
	APh Electives[4]	9	9	9
	Humanities Electives	9	9	9
	Other Electives	18	18	18
		51–54	51–54	51

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

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.

Second Year	*Third Year*	*Fourth Year*
APh 23, APh 24, Ge 1, Ge 2, Bi 8, Ay 1, ME 1 ab, EE 14 abc, EE 90 abc, Ma 5 abc, MS 15 abc	APh 77, Ph 77 ab, EE 114 abc, Ch 6 ab, Ge 154 abc, APh 100, ME 19 abc	APh 77, APh 100, Ae/APh 101 abc, APh 105 abc, APh 114 abc, AMa 101 abc, AMa 104, AMa 105 ab, Ch 125 abc, Ph 125 abc, Ph 129 abc, Ph 77 ab

More Specialized Courses
APh 154, APh 156 abc, APh 181 abc, APh 190 abc, APh/EE 130, AM 135 abc, ChE 103 abc, ChE 126 abc, Ch 113 abc, EE 91 abc, EE 155 abc, Ge 104 abc, Ge 166

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 486 units, including the courses listed above.

Typical Course Schedule

		Units per term		
Second Year		1st	2nd	3rd
Ph 2 abc or	Waves, Quantum Mechanics and 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]	6	0-6	0-6
	Humanities Electives	9	9	9
	Electives[3]	3-6	0-9	12-15
	Suggested total number of units	36-39	38-53	48-57

[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.

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[1], 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[1], Ph 129, Ph 136[1].

[1]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 8, Bi 9, Bi 11, Bi/Ch 110 abc, Bi 122, Bi 123, Bi 150, 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 486 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 8	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
Third Year				
	Humanities Electives	9	9	9
Bi 11	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

[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.

Suggested Electives

Second Year

Second Term: 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
Second Term: Bi 22, Bi 23, Bi 106, Ch 21 b, Ch 24 a, Ch 90
Third Term: Bi 22, Bi 23, Bi 115, Bi 137, Bi 156, Bi 157, Bi 158, Ch 21 c, Ch 24 b, Env 144

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 225, Ch 144 b, Ch 244 b, CNS/Bi 186, Env 145 a, Env/Bi 166
Third Term: Bi 90c, Bi/Ch 132 b, Bi 190, Bi 218, Bi 219, Bi 241, Env 145 b, Env/Bi 168, Ge 5

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 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 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. 36 units of science and engineering electives[3].
4. Passing grades must be earned in a total of 486 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	9	18
		48	48	48
Fourth Year				
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	27	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 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 486 units, including courses listed above.

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 Graduate Work in Particular Areas of Chemistry[1,2]

	Second Year	*Third Year*	*Fourth Year*
Inorganic Chemistry	Ch 5 ab[3], Ch 41 abc, Ma 2 abc, Ph 2 abc, HSS elective, other elective	Ch 14, Ch 21 abc, Ch elective(s)[4], Ch laboratory[5], Ch 80[6], Ch 90, HSS elective	Ch electives[4,5], Ch 80[6], HSS elective
Chemical Physics	Ch 21 abc[7], Ch 6 ab[7], Ch 14, Ma 2 abc, Ph 2 abc, HSS elective	Ch laboratory[8], Ch 41 abc[7], Ch elective(s)[9], Ch 80[6], Ch 90, HSS elective, AMa 95 ab	Ch 125 abc, Ch electives[8,9], Ch 80[6], HSS elective
Organic Chemistry	Ch 5 ab[3], Ch 41 abc, Ma 2 abc, Ph 2 abc, HSS elective, other elective	Ch 14, Ch 21 abc, Ch elective(s)[10], Ch laboratory[5], Ch 80[6], Ch 90, HSS elective	Ch electives[5,10], Ch 80[6], HSS elective
Chemical Biology	Ch 5 a[3], Ch 41 abc, Bi 1, Bi 9, Ma 2 abc, Ph 2 abc, HSS elective	Ch laboratory[11], Ch 14, Ch 21 a, Ch 24 ab (or Ch 21 bc), Ch 80[6] (or Bi 22), Ch 90, Bi/Ch 110 ab, Bi 10, HSS elective	Ch (Bi) electives[11,12], Ch 80[6] (or Bi 22), 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, Ch E/Ch 165, 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.

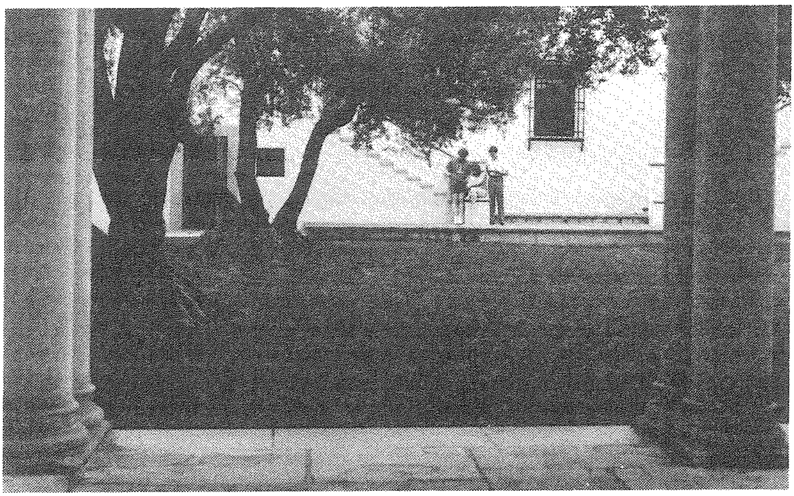
Suggested Elective Courses for the Chemistry Option

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 economics option provides students with an understanding of the basic principles underlying the functioning of economic institutions. It offers a modern and quantitative approach to economics seldom available to undergraduates. The emphasis on economic principles and modern methodology provides students with an excellent preparation for graduate study in economics or for professional study in the fields of business or law and economics.

The option is sufficiently flexible that students can combine their pursuit of economics with studies in other areas, such as engineering, physics, or mathematics. The core of the option consists of Introduction to Economics, Ec/SS 11; Intermediate Microeconomics, Ec 121; Econometrics, Ec 122; and Money, Income, and Growth, Ec 126. Students are encouraged to supplement this core with additional electives in economics, political science, and mathematics.



Option Requirements

1. Ec/SS 11, Ec 121 ab, Ec 122, and Ec 126 ab.
2. Ma 112 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 introductory laboratory requirement or by any course with a number less than 10.
5. Passing grades must be earned in a total of 486 units, including all courses used to satisfy the above requirements.

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 112 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; electromagnetics, EE 151; and solid state devices, EE/APh 180. 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, EE 90 ab, EE 160, EE/APh 180.
4. CS/EE 4 or CS 51.
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 486 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	Engineering Electromagnetics (3-1-8)	–	12	–
EE 160	Communication System Fundamentals (3-0-6)	–	–	9
EE/APh 180	Solid-State Devices (3-0-6)	–	–	9
	Electives	9	9	9
		48	51	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

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

Suggested Electives

First-year students interested in electrical engineering should consider selecting one or two courses per term from 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.

	Second Year	*Third Year*	*Fourth Year*
Communications	Selected from APh/ME 17 abc, APh 23, APh 24, CS 112, CS 114, CS/EE 53, CS/EE 54	EE/Ma 126, EE/Ma 127 ab, Ma 112 a, APh/EE 130	EE 112 abc, EE 162, EE 163 ab, EE 165, CS/EE 183 abc
Computer Engineering	CS 112, CS 114, CS/EE 53, CS/EE 54	CS 137, CS 138 ab, CS 139 ab	CS/EE 181 abc and selections from EE 114 abc, CS/EE/Ma 129 abc, CS 171 ab, CS/EE 183 ab
Control	APh/ME 17 abc, E 13, E 101	EE 117, ab, EE/ChE 170 ab	Selected from EE/ChE 171 ab, EE 112 abc, EE 114 abc, EE 162
Electronic Circuits	APh/ME 17 abc, E 13, E 101	CS 112, CS 114, CS/EE 121	EE 112 abc, EE 114 abc, EE 117 ab
Quantum Electronics	APh/ME 17 abc, APh 23, APh 24	APh 50 abc, APh/EE 130	Selected from APh 105 abc, APh 114 abc, APh 153 abc, APh 190 abc, Ph 125 abc
Solid-State Electronics	APh/ME 17 abc	APh 50 abc	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, 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, 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, CE 105, CE 180, CS/EE 53 and 54, CS 174 abc, CS/EE 181 abc, EE 90 abc, EE 91 abc, EE 153, Env 116, Env 143, Hy 111, Hy 121, JP 170, MS 90, ME 110, 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 486 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:

- Suggested electives suitable for particular fields of interest follow.
- The programs formed with these suggested electives are only samples of typical programs and are *not* meant to represent special option requirements.
- These electives must be chosen so as to satisfy the laboratory requirements already given.

Suggested Electives

	First Year	*Second Year*	*Third Year*	*Fourth Year*
Aeronautics	One course per term selected from: ChE 10, E5, CS/EE 4, CS 10, E1	APh/ME 17 abc; one course per term selected from: MS 15 a, APh 23, APh 24, Ay 1	AM 35 abc, ME 19 abc; one course per term selected from: APh 50 abc, EE 90 abc, ME 22 abc, MS 5 abc, E101	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 126, JP 121 abc, APh 105 abc, APh 153 abc
Applied Mechanics	One course per term selected from: E 5, Ge 1, CS/EE 4, CS 10, CS/EE 11	One course per term APh/ME 17 abc, MS 15 abc, Ge 1, Bi 1, AM 35 abc	AM 35 abc or AM 151 abc, ME 19 abc, one course per term selected from: Ma 112 ab, EE 90 abc, APh 50 abc, MS 5 abc	AM 151 abc or Ae/AM 102 abc, AM 125 abc or AMa 101 abc; one or two courses per term selected from: ME 126, AM 135 abc, Hy 101 abc, Ph 106 abc, AMa 104, AMa 105

Civil Engineering: Structural and Soil Mechanics	One course per term selected from: ME 70, CS 10, E 5, Ge 1	One course per term selected from: APh/ME 17 abc, Ph 3, Ph 4, CS/EE 4, CS/EE 11, MS 15 a, AM 35 abc	CE 10 abc, ME 19 abc	Ae/AM 102 abc, CE 115 ab and CE 105, AM 151 abc, CE 180, 181, and 182 or Hy 113 ab and Hy 111, Env 112 abc or Env 146
Civil Engineering: Hydraulics and Water Resources	One course per term selected from: CS 10, E 5, Ge 1, Env 1	One course per term selected from: APh/ME 17 abc, Ph 3, Ph 4, CS/EE 4, CS/EE 11, MS 15 a, AM 35 abc	AM 102 abc, ME 19 abc, Ec/SS 11	CE 10 abc, CE 115 ab and CE 150, Hy 111 or ME 126, Hy 113 ab, Env 112 abc or Env 146, 147
Computer Science	CE/EE 4, CS 10, CS 12, CS/EE 11	CS 51, CS 52, CS/EE 53, CS/EE 54, CS/Ma 6 abc	CS 136 or CS 137, CS/AMa 138 ab, CS 139 ab, CS/EE 181 abc, CS/EE/Ma 129 abc, one or two courses per term selected from: CS/Ma 117 abc, CS 142 abc, CS 144 abc, CS 170 abc, CS 174 abc, Lin 101 ab, Lin/SS 105	
Electrical Engineering	*See "Option Requirements" and "Suggested Electives" under: Electrical Engineering Option*			
Environmental Engineering Science[1]	Env 1; one course per term selected from: ChE 10, Bi 8, Bi 9, Ch 3 ab, E 5, Ge 1, CS 10	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, Ge 5, MS 15 a	ME 19 abc or ChE 103 abc, Env 142 ab and Env 143; one course per term selected from: Ch 21 abc, Ch 24 ab, Bi/Ch 110 abc	ChE/Env 157, 158, 159, plus Env 116 or Env 112 abc plus Hy 111; one course per term selected from: Ge 103 abc, Hy 101 abc, Hy 113 ab, Env 146, Env 147, AMa 101 abc, AMa 104, AMa 105
Materials Science	One course per term selected from: E 5, CS/EE 4, CS 10, ChE 10, APh 3, APh 9	APh/ME 17 abc	Three courses selected from: AM 35 abc, MS 5 abc, APh 50abc, MS 15a	MS 120, APh/MS 122, APh/MS 123

[1]Electives in humanities and social sciences especially appropriate to this field are Ec/SS 11, Ec 115, Ec 118.

Mechanical Engineering: Fluids and Thermal Systems	One course per term selected from: E 1, E 5, CS 10, APh 9, ME 70	One course per term selected from: APh/ME 17 abc or ChE 63 abc, APh 3, CS/EE 4, APh/MS 4	ME 19 abc, AM 35 abc; one course per term from: ME 22 abc, MS 15, EE 14 abc	ME 118 abc or JP 121 abc; one course per term from: Hy 101 abc, Ae/AM 102, ME 126, Hy 111, ME 72, ME 73 ab, ME 22 abc
Mechanical Engineering Systems and Design	Ph 3, Ch 3 a, CCO 1, E 1 or CS 10, APh/MS 4, E 5, APh 23, Env 1, Bi 8 (one per term)	APh/ME 17 abc or ChE 63, AM 35 abc, CS 112, MS 5, ME 70, ME 71 ab	EE 32 ab, EE 14 abc or (APh 3, CS/EE 4, CS/EE 11), ME 19 abc, ME 72, ME 73 ab	ME 141 ab, ME 130 abc, ME 115, Ae/AM 102 abc, Ae 104 abc, ME 171 ab, Ma 100 a, AMa 104, AMa 105 ab, ME 22 ab
Structure and Properties of Alloys	One course per term selected from: E 5, CS 10, ChE 10, CS/EE 4, APh 3, APh 9	APh/ME 17 abc; one course per term selected from: MS 15 a, EE 5	Three courses per term selected from: AM 35 abc, MS 5 abc and APh 105 abc, Ch 21 abc, APh 50 abc	Three courses per term selected from: APh 114 abc, MS 120, APh/MS 122, Ph 125 abc

Geology, Geochemistry, Geophysics, and Planetary Science Options

The aim of this undergraduate program is to provide thorough training in the geological and planetary sciences and, wherever possible, to integrate these studies with, and build upon, the courses in mathematics, physics, chemistry, and biology taken during the earlier years at the Institute. Active involvement in research, particularly during the summer, is encouraged. For geologists, 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 the other planets are likely to find their niche in these options, especially if they enjoy grappling with complex problems involving many variables. Most students majoring in the earth and planetary sciences now find further training at the graduate level necessary.

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 and planetary science options.

Option Requirements and Typical Course Schedules		YEAR 1	2	3	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 first or 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.

Division Requirements—All Options		YEAR 1	2	3	4
Ge 100	Geology Club Recommended	–	–	1	1
Ge 101	Intro to Geology	–	–	9	–
Ge 102	Intro to Geophysics	–	–	9	–
Ge 103	Intro to Planetary Science	–	–	–	9
Ge 105	The Geologic Record	–	–	9	–
Ge 107	Field Geology	–	–	9	–
Ge 109	Oral Presentation	–	–	–	2
	Total required courses	126	108	63	38
Geology Option Requirements					
Ge 106	Structural Geology			9	–
Ge 110	Sedimentary Geology			9	–
Ge 114	Mineralogy			12	–
Ge 115 ab	Petrology & Petrography			24	–
Ge 121 abc	Advanced Field Geology			–	36
	Math, Science & Eng. Electives[1]			–	54
	Total Required Courses			117	128

[1]Ch 21, Ch 41, or Ph 106 recommended.

The student should particularly note the opportunity for undergraduate research provided by Ge 40 and Ge 41.

Geochemistry Option Requirements		YEAR 3	4
Ge 114	Mineralogy	12	–
Ge 115 ab	Petrology & Petrography	24	–
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
	Math, Science & Eng. Electives	–	54
	Total Required Courses	126	108

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

Geophysics and Planetary Science Option Requirements		YEAR 3	4
Ph 106 abc	Topics in Classical Physics	27	–
AMa 95 abc	Introductory Methods of Applied Mathematics	36	–
	Option Electives	–	54
	Math, Science & Eng. Electives	–	27
	Total required courses	126	119

History Option

History majors must take not less than 99 units of history courses (including Freshman Humanities) 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 Hum 2, 6, 7, 8, or 9. 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 some of the science and math courses that a history major takes beyond the sophomore year (to satisfy the 54-unit Institute requirement) be in that area. 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 introductory laboratory 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 486 units, including the courses listed above.

Typical Course Schedule

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 in any of the other available options. A student's program may include regular 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 all of the specific courses or groups of courses listed in the formulated Institute requirements for undergraduates.

The Curriculum 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. Application material may be obtained at the Registrar's office or from the Dean of Students.

Administrative Procedures and Guidelines

1. An interested student must 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." 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.

2. The student must submit a written proposal to the Dean of Students, endorsed by the committee of three, describing his or her goals, reasons for applying, and plan of study for at least the next year. If persuaded that the proposal is sound and workable, the Dean endorses it and passes it on to the Curriculum Committee. This committee, in turn, reviews the proposal and, if it is acceptable, assumes responsibility for oversight of the program.

3. To implement the program, a written contract is now drawn up among the student, the committee of three, and the Curriculum Committee. 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. This contract may of course be amended, but any amendments must be approved by the committee of three and the Curriculum Committee. Copies of each student's contract and of all amendments thereto, along with all ISP records for each student and his or her transcript, are kept in the permanent files of the Registrar's Office.

4. The progress of each student in the ISP is monitored each quarter by the Registrar and any deviations from the terms of the contract are reported to the Chairman of the Curriculum Committee. Standards for acceptable progress and for satisfactory completion of the terms of the contract are the responsibility of the Curriculum Committee. When the 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. In order that credit be received for an ISP course, a written course contract specifying the work to be accomplished, time schedule for progress reports and completed work, units of credit, and form of grading must be agreed upon by the instructor, the student, and the committee of three, and submitted to the Registrar *prior* to initiating the work in the course. 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-20th-century English literature: Lit 106 a, Lit 112 a or b, Lit 116, Lit 120, Lit 122 a or b, Lit 125.
   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 introductory laboratory 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 486 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 their 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 486 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 or APh 24.
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.
6. Ph 98 or Ph 125.

Electives:

7. 54 units, in addition to the above, of any of the following: 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 486 units, including the courses listed above.

[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.

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 their 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 112 a, Ec 122, PS/SS 122.
2. One of the following: An 22, An 101, 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 introductory laboratory requirement or by any course with a number less than 10.
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 486 units, including all courses used to satisfy the above requirements.

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 112 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.

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 1988-89 are as follows:

Aeronautics	Prof. W. G. Knauss
Applied Mathematics	Prof. J. Lorenz
Applied Mechanics	Prof. F. S. Buffington
Applied Physics	Prof. P. M. Bellan
Astronomy	Prof. K. Libbrecht
Biology	Prof. C. J. Brokaw
Chemical Engineering	Prof. G. Gavalas
Chemistry	Prof. D. Dougherty
Civil Engineering	Prof. F. S. Buffington
Computation and Neural Systems	Prof. D. Van Essen
Computer Science	Prof. C. Seitz
Electrical Engineering	Prof. D. B. Rutledge
Engineering Science	Prof. F. S. Buffington
Environmental Engineering Science	Prof. N. Brooks
Geological and Planetary Sciences	Prof. R. W. Clayton

Materials Science	Prof. F. S. Buffington
Mathematics	Prof. A. S. Kechris
Mechanical Engineering	Prof. F. S. Buffington
Physics	Prof. S. C. Frautschi
Social Science	Prof. D. R. Kiewiet

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 fitness 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 by all options and required by some 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 provided for those students who need to improve their command of oral English. Information regarding these classes can be obtained from the Graduate Office. It is strongly recommended that students who achieve a low TOEFL score or who have little opportunity to communicate in English make arrangements for intensive work during the summer preceding their registration. The Graduate Office can provide information on schools that provide such intensive study.

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 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 Dean of Graduate Studies, 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. 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 a lapse in graduate standing, readmission must be sought before academic work may be resumed or requirements for the degree completed. Registration is required for the quarter in which the thesis defense is undertaken, with the exception of the first week of the quarter.

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

- Applicants for the part-time program must submit a regular application form.
- Any research work done for academic credit shall be supervised by a Caltech faculty member.
- 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.
- 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.
- 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.
- 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

- 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.
- 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 that it is not likely to be preempted by the laboratory.
- 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.
- 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 at the Institute 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 in place of specifically required courses. An examination may be required to determine the acceptability of such courses. Course credit, if granted, shall not count toward the 135-unit and residency requirements.

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 a 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.

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. Registration is required for the quarter in which the thesis defense is undertaken, with the exception of the first week of the quarter.

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.

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.

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 $11,600 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 $108 a unit for fewer than 36 units, with a minimum of $1,080 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 1988–89

General:	
General Deposit	$ 25.00[1]
Tuition	11,600.00
Graduate Student Council Dues	18.00[2]
	$11,643.00
Other:	
Books and Supplies (approx.)	$700.00
Graduate House Living Expenses	
Room—$245.00 to $320.00 (for single students) per month[3]	
$530.00 to $640.00 (for married students) per month[3]	
(Room rates are subject to change.)	
Meals—Available at Chandler Dining Hall or the Athenaeum (members only)	

[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 $6.00 Graduate Student Council dues.
[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 1988–89, 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 26, 1988	General Deposit	$ 25.00
	Tuition	3,867.00
	Graduate Student Council Dues	6.00

	Second Term	
January 4, 1989	Tuition	$3,867.00
	Graduate Student Council Dues	6.00
	Third Term	
April 3, 1989	Tuition	$3,866.00
	Graduate Student Council Dues	6.00

Tuition fees for fewer than normal number of units:

36 units	Full Tuition
Per unit per term	$ 108.00
Minimum per term	1,080.00

Audit Fee, $108.00 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 $18 are currently charged to each graduate student for the academic year. In addition, $6 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 of benefit 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 in Section 3. 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 two dormitories on campus providing single rooms for 105 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 furnished units. Catalina II, completed in September 1986, has 156 single rooms in two-bedroom furnished units. Catalina III, scheduled for completion in September 1988, has 54 single rooms in two-bedroom furnished units, and 30 one-bedroom furnished 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 $100 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; 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.

Students preferring to live in non-Institute housing typically pay approximately $350–$450 per month in rent for a shared apartment, and slightly more for a private apartment. 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. Breakfast, lunch, and snacks are served cafeteria style.

Health Services. Health services available to graduate students are explained in Section 1.

The International Desk. The International Desk is maintained to help foreign students and visiting scholars with nonacademic 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

Caltech 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. 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 Perkins Loans (Carl D. Perkins National Direct Student Loan) 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. Perkins Loan 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.

Lawrence L. and Audrey W. Ferguson Prize

Awarded to the graduating Ph.D. candidate in biology who has produced the outstanding Ph.D. thesis for the past year.

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.

The Herbert Newby McCoy Award

A cash award is made annually to a graduate student in chemisty to acknowledge an "outstanding contribution to the science of chemisty." The awardee is chosen by a faculty committee, based on solicited nominating packages, and the award-winning research is presented in a formal divisional seminar given by the awardee.

The McCoy award was established in 1965 as a result of a bequest of Mrs. Ethel Terry McCoy to honor her husband, who did pioneering work in the chemistry of rare earths and was associated with Caltech through collaboration with chemists Linus Pauling and Howard Lucas.

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 to seek admission to work toward the Master's Degree in Aeronautics. Applicants are encouraged to indicate their desire to continue studies past the master's degree.

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.

Admission to More Advanced Degrees
Students wishing to pursue the more advanced degrees of Aeronautical Engineer or Ph.D. must

file a petition to continue work toward the desired degree. Students registering for the Engineer's degree may transfer to study for the Ph.D. upon satisfactory completion of the same qualifying examination required of those working for the Ph.D. However, once admitted to work for the Ph.D. degree, students are not normally permitted to register for work leading to the Engineer's 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 than the master's degree permits, and with less emphasis on research than is appropriate for the Ph.D. degree.

Admission. Students with a Master of Science degree equivalent to that given by the Institute may seek 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:

- not less than 60 units of research in aeronautics or jet propulsion (Ae 200 or JP 280);
- three units of an advanced seminar such as Ae 208, Ae/AM 209, or JP 290; and
- 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 Master of Science degree equivalent to that given by the Institute may seek admission to work for the Ph.D. degree. In special cases students may be admitted to Ph.D. work without first obtaining the Master's 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. 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. The qualifying examination generally covers the following broad subjects:

a. Mathematics/Applied Mathematics
b. Fluid Mechanics/Propulsion/Thermodynamics
c. Solid Mechanics/Structures/Materials
d. Applied Aeronautics/Mechanics/Controls
e. Physics/Applied Physics

The examinations are offered all on one or two days, during the first half of the winter term, in the second year of graduate residence at the Institute.

A student is examined on three of these topics, selected with the approval of the adviser, with the following restrictions:

1. The mathematics/applied mathematics topic is required.
2. A student must choose fluids or solids, or both, as the second and third topics for the examination.
3. The fluids or solids topic, whichever was not covered in the qualifying examination, will then be covered in the candidacy examination (through a corresponding faculty representative on the candidacy committee).

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):

- at least 45 units of aeronautics courses numbered Ae 200 or higher, excluding research and seminars
- 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, which includes the topic of mathematics or applied mathematics, 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 204, Ma 108, Ma 142, Ma 144, Ma 147, Ma 151.

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 151, AMa 152, AMa 153, AMa 181, AMa 220, AMa 251, AMa 261.

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 types 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. The program must include E 150 abc and one course from among the following: AM 114 abc, AM 125 abc, AMa 101 abc, Ma 108 abc. Note that neither AM 114 nor Ma 108 may be used to fulfill the advanced mathematics requirement for the Ph.D. in Applied Mechanics. 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:

- complete 12 units of research;
- 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;

- 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 the second requirement above and shall not be counted toward a minor;
- 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/EE 130, 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:

- 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.
- 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.
- 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, and 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 181, APh 214

Group C: APh/EE 130, 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

Aims and Scope of the Graduate Program in Astronomy
The primary aim of the graduate astronomy program at Caltech is to prepare students for creative and productive careers in astrophysical research. The astronomy program emphasizes independent research by graduate students, who are free to pursue study in virtually any area of astrophysics. The opportunity exists to take advantage of the many observational facilities owned and operated by Caltech.

Admission
Incoming students should have a strong background in physics, and although a good preparation in astronomy is helpful, this is not required for admission to the graduate program. All applicants, including those from foreign countries, are requested 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 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 in the first year. 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.

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. Although the department believes strongly that knowledge of foreign languages is useful in astronomy, there is no formal foreign language requirement. However, graduate students for whom English is a second language will be required to demonstrate fluency in oral and written English at the time of their candidacy exam. The examining committee will administer a test when this is deemed necessary.

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:

- complete satisfactorily 36 units of research, Ay 142, or reading, Ay 143;
- pass with a grade of C or better, or by special examination, Ay 151, Ay 152, Ay 153, Ay 154, Ay 155, Ay 156;
- pass a written examination (see below);
- pass an oral examination (see below);
- fulfill the language requirement (see above); and
- 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. An oral exam dealing with the student's proposed thesis research should be taken before the end of the first term of the third year. The date and time of the exam are the responsibility of the student to arrange. The examining committee is chosen in consultation with the student's adviser and approved by the option representative. Special permission will be required for further registration if the candidacy course requirements and the written and the 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 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 second 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 first 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.

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, 103 abc, 105, and 110 ab, 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. All placement examination requirements must be satisfied before a student can be admitted to candidacy.

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 a student is 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 Requirement. There is no formal foreign language requirement for the Ph.D. in chemistry. However, the division believes strongly in the professional importance to chemists of a knowledge of foreign languages and encourages their study prior to graduate work or while in graduate school.

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 a 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 either AM 113 abc or AM 114 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:

- complete a program of advanced courses as arranged in consultation with his or her advisory committee, and approved by the faculty in civil engineering;
- 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;
- 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 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;
- 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 principally covers 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, may, with the approval of the civil engineering faculty, 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 to the option 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. 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 for the distribution requirements of the option are:

Computer Science and Collective Computation: CNS/EE 124, EE/Ma 126, EE/Ma 127, CS/EE/Ma 129, EE 162, EE 163, CS/CNS 174, CS/EE 181, CNS/Bi/Ph 185

Neurobiology: Bi 150, Bi 152, Bi 154, Bi 157, Bi 161, Bi 162, Bi 211, Bi 212, Bi 217, Bi 218, CNS/Bi 186, CNS 256

Physical Computational Devices: CNS/CS/EE 182, APh/EE 132, APh 181

Mathematics and Modeling: AMa 105, AMa 153, AMa 204, Ph 101, Ph 127, Ph 222, Ph 229, 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 221, Computational Neurobiology. 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 the 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 must pass an oral candidacy examination that covers both the depth and the breadth of the student's training. The depth component will evaluate the student's knowledge in the area of the proposed thesis research. In advance of the examination, the student must provide the

committee with a written summary of research carried out to date and an outline of the proposed thesis research. The 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:

- *Total units.* Completion of a minimum of 135 units of courses numbered 100 or greater, including M.S. thesis research (CS 180).
- *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.
- *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.
- *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.
- *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:

- complete 18 units of research in his or her field of interest.
- 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 the next requirement may be included in this total. Courses taken to fulfill the requirements for the Master of Science degree may be included also.
- 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.

- pass a qualifying oral examination covering broadly the 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 interested in subjects that form the core of new "interdisciplinary" sciences. These branches of science provide the basis for the growth of 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:

- complete 12 units of research;
- 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;
- 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 the previous requirement, and shall not be counted toward any minor requirements.
- 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 and the option representative. The program should be well-balanced, with courses in several areas of concentration to avoid narrow specialization.

The M.S. program must include 3 units of Env 150 abc (seminar) and at least 105 units of graduate level courses from at least three of the following five subject areas (with a minimum of 18 units in each selected area):

- air quality
- water quality
- applied and environmental biology
- fluid mechanics and transport
- applied mathematics

At least 63 units must be in Env courses (including joint-listed courses but excluding reading and research course units). Students who have not had AMa 95 abc or its equivalent are required to include AM 113 abc or AM 114 abc as part of the applied mathematics group. Students are encouraged to take social science and humanities courses as all or part of the 27 elective units included in the total of 135 units.

Suggested courses in the various areas are:

Air quality: Env 116, Env 170, ChE/Env 157, ChE/Env 158, ChE/Env 159, Ge 103 c.

Water quality: Env 142 ab, Env 143, Env 146, Env 147, Env 242 abc, Bi/Ch 110 abc, Bi/Ch 132 ab, ChE 101, ChE 161, ChE 162, ChE/Ch 164, ChE 165, Ch 117, Ch 118 ab, Ge 103 ac, Ge 140 a.

Applied and environmental biology: Env 144, Env 145 ab, Env 147, Env 166, Env 168, Env 206, Env 208, Env 210, Bi/Ch 110 abc, Bi 122, Bi 180, ChE 163, Ge 111 ab.

Fluid mechanics and transport: Env 112 abc, Env 214 abc, ChE 103 abc, ChE 173 ab, Ge 103 ab, Hy 101 abc, Hy 111, Hy 113 ab, Hy 121, Hy 213.

Applied mathematics: AMa 101 abc, AMa 104, AMa 105 ab, AMa 181 abc, AM 113 abc, AM 114 abc, AM 125 abc, EE/ChE 170 ab, Ma 112 abc.

Social science: Ec 115, Ec 118, Ec 122, SS 132, SS 222 abc.

If a student has already earned a master's degree at another university, he or she may not enroll for a master's degree in environmental engineering science, unless the previous field of study was significantly different.

If a Ph.D. student completes all the requirements for the M.S. degree as part of the Ph.D. program and does not already have an M.S. degree in this field (or closely related field), he or she will be awarded the M.S. degree if an M.S. candidacy form is submitted to the option representative.

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 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 thesis adviser will act as chairman of the three-member counseling committee appointed for each student.

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 as soon as a research area has been chosen.

Areas of Specialization. Students may undertake thesis research in the following areas: air pollution, aerosol physics and chemistry, atmospheric chemistry, aquatic chemistry, applied microbiology, 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:

- 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.
- pass at least 27 units of course work in advanced mathematics in one of the following courses or sequences as recommended by the thesis adviser: AMa 101 abc; AMa 104, 105 ab, and AM 110; AM 125 abc; Ph 129 abc; Ma 112 abc; or a satisfactory substitute.
- pass the oral candidacy examination.

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 four areas: air quality; water quality; applied and environmental biology; and fluid mechanics and transport. Major courses will normally be selected from the lists given above for the M.S. degree, 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 is 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 or AM 114 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 test the student on course work and general knowledge of the field.

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. Three copies of the thesis are required of the graduate, one of which is deposited in the Institute library, one in the departmental 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 astronomy, biology, chemistry, mathematics, and physics, as well as in geochemistry, geology, and geophysics. 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. Students are encouraged to explore work in interdisciplinary areas both within and outside the division. Although financial support is not guaranteed, all students making normal progress have in the past been supported by a combination of fellowships, research assistantships, and teaching assistantships.

Admissions and Entrance Procedures

Only students who intend to work full time toward the doctor of philosophy (Ph.D.) degree are admitted. The admission process follows Institute regulations. Applicants are strongly urged to submit Graduate Record Examination (GRE) scores for the aptitude tests and the advanced test in their field of undergraduate specialty. Applicants from non-English-speaking nations are required to submit Test of English as a Foreign Language (TOEFL) scores.

Based on their applications and interests, students enter one of the major subject options of the division and are given an academic adviser who is a professorial faculty member associated with the option. The four options are geology, geochemistry, geophysics, and planetary science. Students may later change options, but must first obtain approval by the new option. Each student must plan to satisfy the requirements for the Ph.D. degree in one option.

Entering students take a placement exam in the week preceding the beginning of instruction for the first term. The exam covers basic mathematics, physics, and chemistry. Afterward, the student meets with his or her adviser prior to registration and selects courses based in part on the results of the placement exam.

Students are encouraged to register for at least 9 units of research (Ge 297) in each of two out of the first three terms of residence. Each of these terms of research should be under the direction of different faculty members. The primary objective is to communicate to the students the excitement of discovery based on original investigations and to provide a broad scope of research aims. An important by-product can be formulation of propositions for the Ph.D. oral examination or orientation toward Ph.D. research.

Master's Degree

Students enrolled in the Ph.D. program may be awarded a master's degree when they have satisfied the basic Institute requirement of 135 units. These courses must be numbered 100 or higher, and must be part of those used to satisfy the Ph.D. requirement in one of the options of the division. Specifically required are Ge 101, 102, 103, and 109. More advanced courses may be substituted for Ge 101, 102, or 103, subject to approval by the instructor and the division faculty.

Doctoral Degree: Division Requirements

For a Ph.D. degree the student must 1) pass the qualifying oral examination, 2) satisfy course requirements of the division and of an option, and 3) complete a thesis and successfully defend it in a final oral examination. Admission to candidacy occurs after the student has satisfied the first two requirements and has been accepted for thesis research by a division faculty member, who then becomes the student's thesis adviser. The student will continue to have a separate academic adviser.

The qualifying examination is the oral defense of two research propositions, each supported by a succinct statement of the problem and of the candidate's specific approach to it. Students are encouraged to consult with various staff members concerning their ideas on propositions, but the material submitted must represent the work of the student. There must be a different faculty member associated with each of the two propositions. The exam is administered by the qualifying examination committee, which has members from the four options of the division, and is normally taken early in the first term of the second year of residence. A more detailed outline of the qualifying examination is available in the chairman's office.

The basic divisional course requirement includes 45 units within the division but outside the area of the student's option. The required 45 units of courses outside the major field may be used to satisfy a subject minor in another option of the division. An average grade of B or better is required for these courses. Ge 101, 102, and 103 are specifically required and must be taken during the first two years. Students may petition to drop one of these courses, with approval of the division faculty, if they already have substantial academic training in that field. Oral presentation, Ge 109, is required of all degree candidates but does not count for the units listed above. Students are expected to attend departmental seminars and seminar courses led by visiting scientists throughout their graduate careers. Students may submit a petition to their option to substitute appropriate graduate courses taken at other institutions corresponding to no more than 27 units.

The division encourages students to engage in research early in their graduate careers. A student making normal progress will have submitted a paper, in which the student is senior author, by the end of the third academic year. The paper will be submitted to a refereed scientific journal and will have the approval of a faculty member of the division. Doctoral candidates must complete a thesis 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 April 1. The final oral examination for the doctorate will be scheduled following submission of the thesis and, in conformity with Institute regulations, it must be scheduled at least two weeks before the degree is to be conferred.

Candidates are expected to publish the major results of their thesis work. A manuscript should be reviewed by the member of the staff supervising the major research and should be ready for submission to a refereed scientific journal at the time of the final exam. The student should be principal author. 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. Published papers may be included in the thesis.

The student's progress toward meeting these requirements will be monitored annually by the faculty. Satisfactory progress includes meeting the following schedule:

End of first academic year (third term): submission by the student 1) of tentative titles of propositions for review by the qualifying examination committee; and 2) of courses planned to satisfy the Ph.D. requirement for review by the option.

End of second academic year: 1) passing oral exam; 2) approval by the option of courses planned to satisfy candidacy requirements; 3) submission of a tentative thesis topic and adviser.

End of third academic year: 1) satisfactory completion of course requirements; 2) satisfactory completion of other requirements including selection of thesis topic and adviser, 3) admission to candidacy.

End of fourth academic year: satisfactory progress toward completion of thesis.

After completing the fifth academic year, the student must formally petition to register for each subsequent year. Financial aid will normally not be extended beyond the sixth year.

The student's program and progress will be reviewed annually by his or her option. In cases where in the opinion of the faculty in the option the student is clearly not showing adequate progress, they may recommend an evaluation by the full faculty. The faculty may deny permission to continue in the Ph.D. program based upon their overall assessment of the student's performance.

Requirements of the Major Subject Options

Geology and Geobiology. In addition to the general Institute and basic division requirements, which include taking at least 45 units within the division in subjects other than their own major subject, 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. Courses that cannot be used to satisfy these requirements include languages, research and reading courses, and certain courses constituting basic preparation in their field, as follows: Ge 101, Ge 105, Ge 106, Ge 107, Ge 114, and Ge 115. At least 36 of the 90 units must be taken outside the Division of Geological and Planetary Sciences (with a grade of C or better). It is possible for these to be used to satisfy part of the requirements of a minor. Also, 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 general Institute and basic division requirements, the candidate for a Ph.D. degree in geochemistry shall acquire at least a minimum graduate background in each of three categories of course work: 1) geology, geophysics, and planetary sciences; 2) chemistry, physics, astronomy, mathematics; and 3) geochemistry and cosmochemistry. This option assumes a basic knowledge of chemistry at the level of Ch 21 abc as a prerequisite for admission. These requirements may be met by successful completion (normally B average or higher for courses within the division) of at least 45 units of suitable course work at the 100 level or higher in each category. The requirements in the first category coincide with the basic division requirement except that one term of field geology must be included. Reading and research courses may not be used, although students are expected to take such courses and to devote each summer to research.

Students completing the geochemistry academic program are required to submit a tentative proposal for their research no later than May 1 of the third year in residence. This proposal should document the scientific importance of the project relative to previous work, feasibility of completion within an allowable graduate student tenure and, if any, preliminary results. The proposals will be reviewed by the geochemistry faculty.

Geophysics. In addition to 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 two categories below. At least 36 units must be completed from each group. Courses with less than five units per term in these groups will not be accepted.

Group A. Courses in mathematics, applied mathematics, physics, applied physics, and chemical physics. A minimum proficiency in basic mathematical methods at the level of AMa 101 and in basic physics at the level of Physics 106 is required.

Group B. Courses in geophysics.

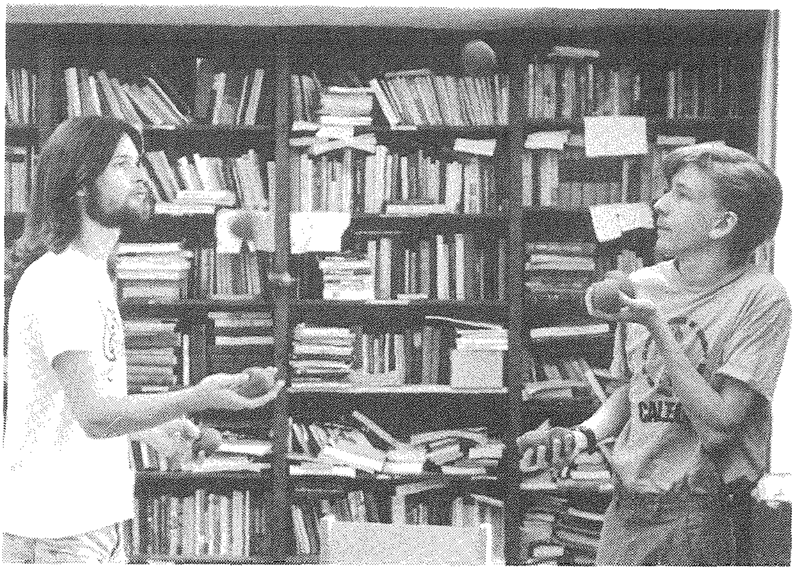
Students with an exceptionally strong background in one or more of the areas represented by these groups may, upon petition to the option representative, be excused from up to 18 units of the overall 90-unit requirement. Research and reading courses cannot be used to satisfy these requirements but are 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 (essentially, those courses taught by the planetary science faculty). These requirements may be met by successful completion (normally B average or higher) of at least 45 units of suitable course work at the 100 level or higher in each category. The requirements in the first category coincide with the basic division requirement, except that Ge 103 is considered a planetary science course. 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 by satisfactory completion of a subject minor. Courses used to satisfy this secondary requirement may also be used to satisfy the requirements in one of the 45-unit categories.

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 in courses at the 100 level or higher. 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. Students interested in terminating their graduate study at the Master's level are not normally admitted. The graduate program is designed to give students a deep understanding of issues fundamental to synthesis-structure-property relationships in materials. The program for all graduate students begins with a set of core courses. After meeting the requirements for the M.S. degree, students continuing for the Ph.D. degree are required to pass an oral candidacy examination, complete a thesis describing original research in materials science or a related field, and publicly defend their thesis work.

Master's Degree in Materials Science
Each student is assigned to a member of the faculty, who will serve as the student's adviser. The adviser and two other faculty members will approve his or her course of study. Study for the degree of Master of Science in Materials Science ordinarily will consist of three terms of courses chosen from the following list, totaling at least 138 units. Completion of these courses within two years with no grade less than a C constitutes the academic requirements for the M.S. degree.

Required Courses

a. APh 110 abc (6 units) or E 150 abc (3 units), seminar

b. 1. MS 120, MS 121, APh/MS 122, Kinetics of Crystal Imperfections, Phase Transformations in Solids, Diffraction Theory and Applications, 27 units

2. APh 105 abc, States of Matter, 27 units
3. APh 114 ab, Solid State Physics, 18 units
4. Either AM 114 abc, or AM 125 abc, or AMa 101 abc, or Ph 129 abc, Mathematical Methods, 27 units
5. At least 9 units chosen from:
   MS 123, Transmission Electron Microscopy Laboratory
   MS 131, Crystal Defects Laboratory
6. At least 27 units chosen from:
   AM 135 abc, Mathematical Elasticity Theory
   APh 114 c, Solid State Physics
   Ph 125 abc, or Ch 125 abc, Quantum Mechanics

Degree of Doctor of Philosophy in Materials Science

Work towards the degree of Doctor of Philosophy in Materials Science requires a minimum of three years following the completion of the bachelor's degree or equivalent. Approximately two years of this time are devoted to research work leading to the doctoral thesis.

Language Requirement. There is no language requirement for the Ph.D. degree.

Minor. No minor is required for the Ph.D. degree. Students are, however, encouraged to take advanced courses appropriate to their particular interests.

Counseling. A faculty member, normally the student's research adviser, is assigned to advise the student on a suitable course program.

Admission to or Continuation in Ph.D. Status. To be advanced to candidacy for the doctor's degree the student must satisfy three requirements:

a. Courses. Successful completion of an equivalent course program to that required for the M.S. degree. Alternatively, if the student has taken equivalent courses elsewhere, he or she must prove competence in these areas through an oral examination in each subject.

b. Oral Candidacy Examination. The student will prepare a brief presentation on a topic in his or her proposed area of research. The examination will be based on the student's course work and how it is related to the subject of the presentation.

This examination should be taken in the first term of the second year, and no later than the end of the student's second year of residence.

c. Research Competence. The student must have a doctoral research adviser, and must have completed at least 18 units of MS 300.

Thesis and Final Examination. The candidate is required to take a final oral examination covering the doctoral thesis and its significance in and relation to his or her major field. 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 its 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 Materials Science

A student majoring in another option at the Institute may elect a subject minor in materials science. He or she must obtain approval from the materials science faculty of a course of study containing at least 54 units of advanced courses in materials science. Normally a member of the materials science faculty will participate in the candidacy examination in the student's major department.

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 55. 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 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.

Each student must participate actively in seminars for a total of at least three terms. Students are strongly encouraged to do this within the first two years of graduate studies, but must complete this before advancement to candidacy. The department will help to make seminars accessible to students. Guidelines will be distributed to the students at the beginning of each academic year.

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. The committee will consist of three members, including the student's adviser. It is the student's responsibility to arrange the formation of this committee in consultation with the adviser. 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 student must demonstrate a good knowledge of one of three foreign languages—French, German, and Russian. This requirement is satisfied by passing a written test consisting of translating a passage of a mathematical work chosen by an examiner, who is a member of the mathematics faculty. A list of the examiners in each language will be distributed to the students at the beginning of each academic year.

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 118, ME 126.

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,

[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 or AM 114 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.

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:

- complete 12 units of research;
- 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;
- 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 the second requirement above, and shall not be counted toward a minor;
- 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

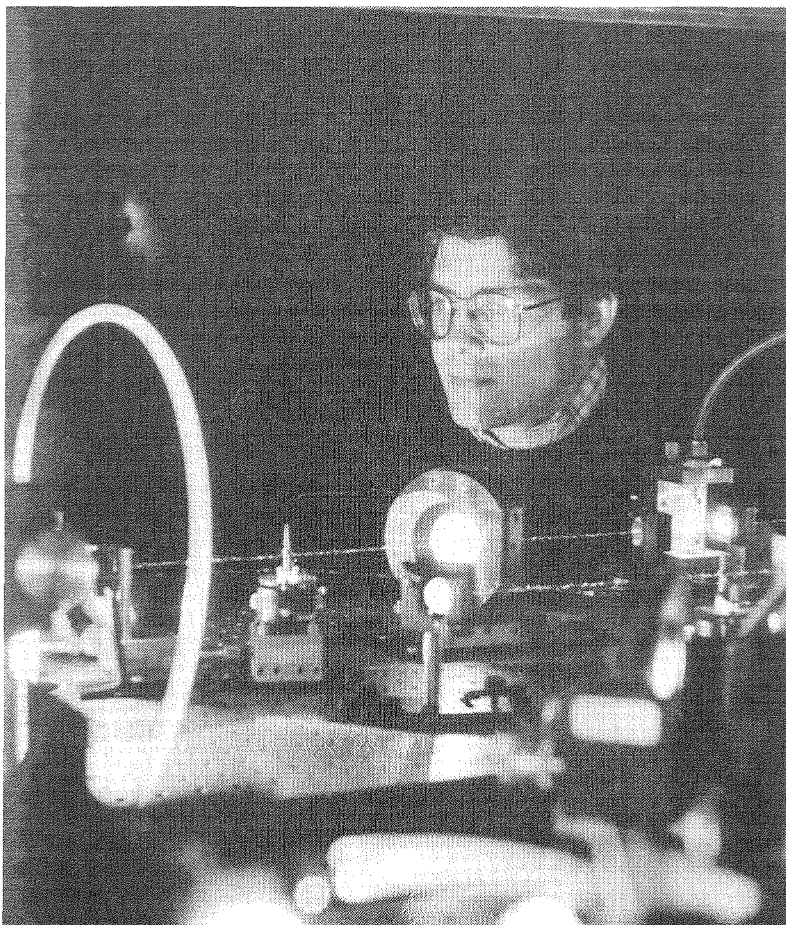
A student majoring in another branch of engineering or another division of the Institute may, with the approval of the faculty in mechanical engineering and the faculty in his or her major field, elect mechanical engineering as a subject minor. The group of courses shall differ markedly from the major 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 101, Ph 118, Ph 127, Ph 129, Ph 135, Ph 136, Ph 176, 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 101, Ph 118, Ph 127, Ph 176, 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.

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

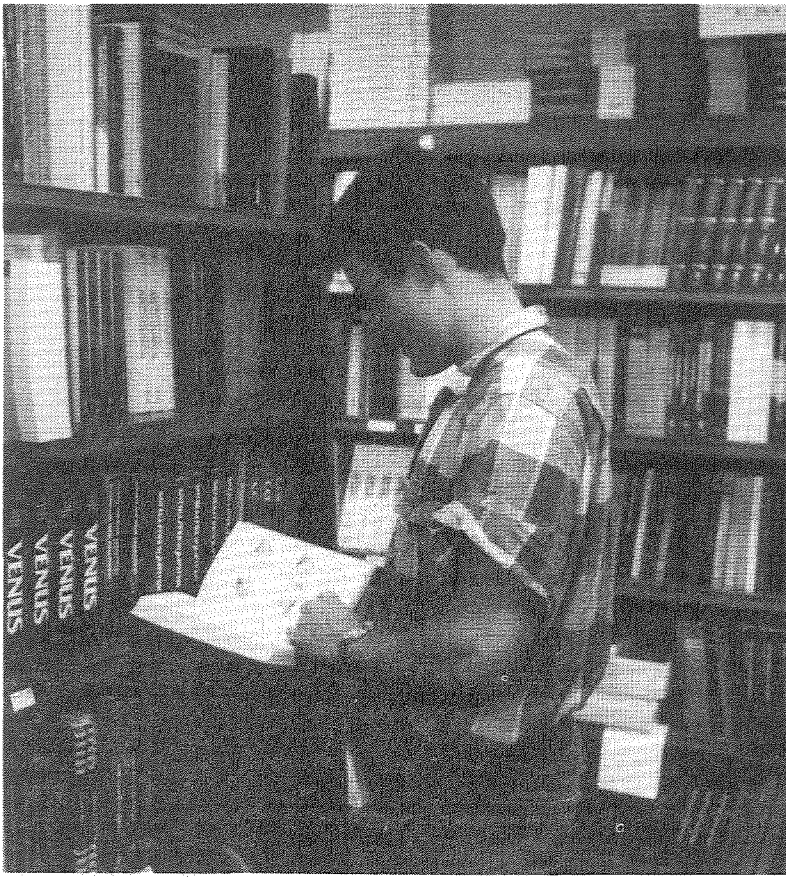
Business and government are confronted with problems of growing complexity. In addressing these problems, decision-makers have come to place increasing value upon social scientific analysis. The graduate program in social science is designed to produce scholars who can apply both the theoretical perspectives 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 must provide Graduate Record Examination scores and 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.

- 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 222 a, 222 b, 222 c (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.

- 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.
- 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 multi-disciplinary 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

5

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

AW	Adjunct Writing
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
CNS	Computation and Neural Systems
CS	Computer Science
Ec	Economics
EE	Electrical Engineering
E	Engineering
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

ADJUNCT WRITING

A number of one-term Adjunct Writing courses (2-0-1 units) giving formal instruction and practice in writing are offered each year in conjunction with regularly scheduled courses. Freshmen who need special help with writing will be directed to the Adjunct Writing courses, each linked to a particular Freshman Humanities course. (In such cases, but in no other, the regular courses will have their units reduced from 3-0-6 to 2-0-4.) An Adjunct Writing course offered in conjunction with an upper class course may, at the discretion of the instructor, be required of all students enrolling, or it may be an elective. Credit for an Adjunct Writing course will be assigned to the discipline of the linked course(s).

Whether a particular Adjunct Writing course is graded pass/fail depends on the particular course with which it is linked. Students taking such courses may take any number of them for credit.

(**Note:** The 3 Adjunct Writing units count toward the 18-unit Freshman Humanities requirement when taken with a Freshman Humanities course. An Adjunct Writing course in Social Sciences receives credit toward the 36-unit requirement in Social Science.)

AW/Hum. Adjunct Writing for Humanities. *3 units (2-0-1); first, second, or third terms.* Given in conjunction with certain Humanities courses.

AW/SS. Adjunct Writing for Social Sciences. *3 units (2-0-1); first, second, or third terms.* Given in conjunction with certain Social Science courses.

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. Credit is based on the satisfactory completion of a substantive research report which must be approved by the Ae 100 adviser and by the option representative.

Ae/APh 101 abc. Fluid Mechanics. *9 units (3-0-6); first, second, third terms.* Begins with study of one-dimensional flows, then moves to consideration of flows with progressively more complex dimensionality. Third term: viscous flows. 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: Knauss.

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: Aaron.

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. Grades are based on student projects and attendance (no more than three unexcused absences). 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. Not offered 1988–89.

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: Kubota.

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 1988–89.

Ae/AM 213 abc. The Mechanics of Fracture. *9 units (3-0-6); first, second, third terms. Prerequisites: Ae/AM 102 abc or equivalent and instructor's permission.* Currently practiced analytical and experimental techniques used in the study of fracture in metallic and nonmetallic solids. Topics include: mechanics of brittle and ductile fracture in structural materials, 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, establishment of relevant fracture criteria. Transitional behavior, rate sensitivity, running cracks. Static and dynamic fracture testing and structural design considerations. Not offered 1988–89.

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 1988–89.

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 1988–89.

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. Not offered 1988–89.

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: free and wall-bounded flows; discussion of vortex methods in two and three dimensions; spectral methods. Problems discussed: 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 discovering unstable modes. Laminar boundary layer stability and dual role of viscosity; effects of pressure gradient, suction and heat transfer in liquids and gases. Recent work on control of laminar oscillations by utilizing "feedback." Axisymmetric and three-dimensional disturbances. Unresolved problems of response of laminar shear flows to "external" disturbances. Not offered 1988–89.

Ae 234. Hypersonic Aerodynamics. *9 units (3-0-6); first 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); third 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 238. Sources of Vorticity. *9 units (3-0-6); second term.* Torque exerted on element of fluid by stress distribution. Conditions at a solid boundary. The baroclinic torque, compressibility, stratification. Effects of viscoelasticity and turbulence. Accelerated reference frames, body forces. Unorthodox boundary conditions. Vorticity production due to discretization errors in numerical computations. Instructor: Hornung.

Ae 239. Turbulent Shear Flows. *9 units (3-0-6); first 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 1988–89.

Ae 240. Special Topics in Fluid Mechanics. *9 units (3-0-6); third term.* Subject matter changes depending upon staff and student interest. Instructor: Narasimha.

Ae 241. Special Topics in Experimental Fluid and Solid Mechanics. *9 units (3-0-6). Prerequisites: Ae/APh 104 or equivalent or instructor's permission.* Selected topics, to be announced, subject matter depending on current interests. Not offered 1988–89.

ANTHROPOLOGY

An 22. Introduction to the Anthropology of Development. *9 units (3-0-6); first term.* Introduction to the study of social change in contemporary tribal and peasant societies. Emphasis on the impact of modernization, especially through urbanization, industrialization, and the intensification of agriculture. Instructor: Scudder.

An 101. Selected Topics in Anthropology. *9 units (3-0-6).* Not offered 1988–89. Instructors: Staff and visiting lecturers.

An 123. The Anthropology of Rapid Social Change. *9 units (3-0-6); second 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).* General history of the development of anthropological theory and practice. Examines developing concerns and professionalization of the discipline, methods of field work, and some possible implications and applications of anthropological knowledge. Instructor: Dirks.

An 126. The Anthropology of South Asia. *9 units (3-0-6).* With village ethnographies 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: Meiron, Saffman.

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: Franklin.

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. Instructor: Lorenz.

AMa/CS 132 ab. Concurrent Scientific Computing. *9 units (3-3-3); second, third terms. Prerequisites: basic knowledge of numerical methods and some programming experience.* A course on the application of computers to scientific computing problems. A variety of numerical methods and their implementation on several architectures will be discussed. Homework assignments will include a project on a concurrent computer. Topics: linear algebra computations, fast Fourier transform, multigrid, conjugate gradient, vortex and Monte Carlo methods; vector processors, parallel machines with local and shared memory. Instructor: Van de Velde.

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: Cohen.

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 1988–89.

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. Not offered 1988–89.

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. Not offered 1988–89.

AMa 161. Applied Functional Analysis. *9 units (3-0-6). Prerequisites: AMa 104, Ma 108, Ma 110, or equivalent.* Introduction to Hilbert and Banach spaces. Linear functions, dual spaces, linear operators. Fredholm theory, spectral theory. Frechet derivatives, Newton's method, pseudoinverses, bifurcation theory. Applications to differential equations, integral equations, and numerical analysis. Not offered 1988–89.

AMa 181 abc. Mathematical Programming and Game Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 104 or equivalent.* Computer algorithms for linear programming: simplex, Khachian, Karmarkar. Duality; peturbation theory; combinatoric optimization by integer programming: Gomory's method; multi-objective programming; two-person games. Fixed-point theorems of Brouwer, Kakutani, and Schauder. Nash's theorem for *n*-person games. Kuhn-Tucker theory; quadratic and geometric programming; computer algorithms for nonlinear programming. Not offered 1988–89.

AMa 190. Reading and Independent Study. *Units by arrangement.* Graded pass/fail only.

AMa 204 abc. Numerical Solution of Partial Differential and Integral Equations. *11 units (3-2-6); first, second, third terms. Prerequisites: AMa 95, 104, and 105, or equivalent.* Finite difference, finite element, and spectral methods for numerical solution of partial differential equations. Discussion of numerical consistency, accuracy, and stability. Explicit and implicit methods of linear and nonlinear time-dependent problems. Multigrid and iterative methods for solution of elliptic partial differential equations. Integral equation formulations; continuation and bifurcation; application to problems in different areas, such as fluid dynamics and geophysics. Computer assignments will be given. Not offered 1988–89.

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. Not offered 1988–89.

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. Instructor: Keller.

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 261 a. Special Topics in Nonlinear Wave Propagation. *9 units (3-0-6); first term. Prerequisites: AMa 101 and instructor's permission.* Inverse scattering and related techniques for the study of nonlinear waves. Solitons and their interactions. Multiphase nonlinear waves. Recent developments in these areas. Instructor: Whitham.

AMa 290. Applied Mathematics Colloquium. *Units by arrangement.*

AMa 300. Research in Applied Mathematics. *Units by arrangement.*

Other courses particularly suited to a program in applied mathematics include Ma 191, Ma 142, Ma 144, Ma 147, AM 135, AM 136, AM 151, AM 175, AM 176, APh 156, Ph 125, Ph 209, and Ph 236.

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. Instructors: Staff.

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 1988–89.

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 1988–89.

Ae/AM 102 abc. Mechanics of Structures and Solids. *9 units (3-0-6).* For course description, see Aeronautics. Instructor: Knauss.

Ae/AM 108 abc. Finite Element Methods. *9 units (3-0-6).* For course description, see Aeronautics. Not offered 1988–89.

AM 113 abc. Introductory Engineering Mathematics. *12 units (4-0-8); first, second, third terms. Prerequisite: elementary calculus.* Alternative to AM 114 abc, including review of concepts and techniques from calculus and ordinary differential equations. Introduction to complex variables and applications. Illustrative examples of boundary-value problems for the Laplace equation, the heat equation, and the wave equation. Instructor: Knowles.

AM 114 abc. Engineering Mathematics. *12 units (4-0-8); first, second, third terms. For graduate students who have not had the equivalent of AMa 95 abc. Prerequisite: Ma 1 abc, Ma 2 abc, or equivalent.* Includes: basic theory of complex variables and applications, such as conformal mapping, linear differential equations, and special functions; Fourier series and

Fourier integrals; solution of boundary-value problems for partial differential equations by separation of variables and by integral transforms. Instructor: Beck.

AM 125 abc. Engineering Mathematical Principles. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 abc, AM 113 abc, or AM 114 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: Caughey.

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. Not offered 1988–89.

AM 141 abc. Wave Propagation in Solids. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 abc, AM 113 abc, or AM 114 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 1988–89.

AM 151 abc. Dynamics and Vibrations. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 abc, AM 113 abc, or AM 114 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: Iwan.

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 include linear and nonlinear vibrations of discrete and continuous systems, stability and control of dynamical systems, and stochastic processes with applications to random vibrations. Not offered 1988–89.

AM 176 abc. Nonlinear Dynamical Systems and Chaos. *9 units (3-0-6); first, second, third terms. Prerequisites: AM 125 abc, or instructor's permission.* Basic ideas from dynamical systems theory. One-dimensional maps, circle maps, rotation numbers, kneading theory, strange attractors, structural stability, hyperbolicity, symbolic dynamics, invariant manifolds, Poincare maps, the Smale horseshoe. Techniques of local bifurcation theory are developed with emphasis on center manifolds and normal forms, global bifurcations, chaos, homoclinic and heteroclinic motions. Applications will be taken from a variety of areas, including fluid mechanics, structural mechanics, control theory, circuit theory, orbital mechanics, condensed matter physics, and classical field theory. Instructor: Wiggins.

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).* For course description, see Aeronautics. Not offered 1988–89.

Ae/AM 223 abc. Plasticity. *9 units (3-0-6).* For course description, see Aeronautics. Not offered 1988–89.

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/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 construction and performance. The 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. Instructors: Staff.

APh 9 ab. Solid-State Electronics for Integrated Circuits. *6 units (2-2-2); first, second terms; six units credit for the freshman laboratory requirement.* Introduction to solid-state electronics, including physical modeling and device fabrication. Topics: semiconductor crystal growth and device fabrication technology, carrier modeling, doping, generation and recombination, pn junction diode, MOS capacitor and MOS transistor operation, and deviations from ideal behavior. Laboratory includes computer-aided layout, and fabrication and testing of light-emitting diodes, transistors, and inverters. Students learn photolithography, and use of vacuum systems, furnaces, and device-testing equipment. Instructor: Atwater.

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. 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); second term. Prerequisite: Ph 1 abc.* Nine lectures cover fundamentals of optics with emphasis on modern optical applications, 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 to be selected from optical communications and radar, adaptive optical systems. Instructor: Bridges.

APh 24. Introductory Modern Optics Laboratory. *6 units; third 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 on acceptance by the instructor of a suitable proposal.* A non-structured project laboratory designed for original experiments in applied physics. Emphasis is on 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 arranged to meet the needs of students wishing to do advanced work. Primarily for undergraduates. Students should consult with their advisers before registering. 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 first term; 1-3-5 second and third terms).* For course description, see Aeronautics.

APh 105 abc. States of Matter. *9 units (3-0-6); first, second, third terms. Prerequisite: APh/ME 17 abc 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; noise. Instructor: Johnson.

APh 107. Advanced Dynamics. *9 units (3-0-6); third term. Prerequisite: Ph 106 a, b, or equivalent.* Lectures on advanced topics in classical mechanics, such as conservative vs. dissipative systems, integrable systems, the KAM Theorem, "stochasticity and chaos." Examples will be drawn from statistical mechanics, plasma physics, and 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 98 abc or equivalent.* Introductory lecture and problem course dealing with experimental and theoretical problems in solid-state physics. 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/MS 122. Diffraction Theory and Applications. *9 units (3-0-6); second term. Prerequisite: instructor's permission.* Principles of electron and x-ray diffraction, and applications in characterizing materials. Topics include: Scattering and absorption of electrons and x-rays by atoms, anomalous scattering. The transmission electron microscope (TEM) and the x-ray diffractometer. Kinematical theory of diffraction: mathematical and graphical treatments; effects of strain, size, disorder, and temperature; bright field and dark field TEM imaging of crystal defects. Dynamical theory of diffraction: Darwin's theory; Bethe's theory; defect contrast in TEM. Special topics in TEM. Instructor: Fultz.

APh/EE 130. Introduction to Optoelectronics. *9 units (3-0-6); first term. Prerequisites: APh 23, 24 or instructor's permission.* Introduction to phenomena, devices, and applications in optoelectronics. Gaussian beam propagation; basic laser theory and discussion of selected lasers; modulation, optical detectors, and noise; system design considerations, with examples from optical communication, radar, and other applications. Instructor: Bridges.

APh/EE 131. Optoelectronic Devices. *9 units (3-0-6); second term. Prerequisite: APh/EE 130 or instructor's permission.* Propagation of light in crystals; electro-optic effects and their use in the modulation of light; an introduction to non-linear optics; harmonic generation. Semiconductor lasers. Design examples of practical interest. Offered in alternate years; not offered 1988–89.

APh/EE 132. Fourier Optics. *9 units (3-0-6); second term. Prerequisite: AMa 95 abc.* Fourier transform techniques are used to describe light propagation through homogeneous media and thin optical elements (lenses, gratings, holograms); applications to modern optical systems. Topics: scalar diffraction theory; the lens as a Fourier transforming element; coherent and incoherent imaging; optical information processing systems; holography. Instructor: Psaltis.

APh 150. Topics in Applied Physics. *Units and term to be arranged.* Content will vary from year to year, but at a level suitable for advanced undergraduate or beginning graduate students. Topics are chosen according to the interests of students and staff. Visiting faculty may present portions of this course. Instructors: Staff.

APh 154. Advanced Modern Optics Laboratory. *9 units (0-4-5); first 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. Instructors: Staff.

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: Gould.

EE/APh 180. Solid-State Devices. *9 units (3-0-6).* For course description, see Electrical Engineering.

APh 181 ab. Physics of Semiconductors and Semiconductor Devices. *9 units (3-0-6); first, second 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. 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.* Course in experimental and theoretical solid-state physics. Topics: phonons; electronic excitation in solids; electron-phonon interactions; optical transport and magnetic properties; superconductivity; ferroelectricity. Emphasis will be mainly theoretical with frequent comparison between theoretical predictions and experimental results. Not offered 1988–89.

APh 250. Advanced Topics in Applied Physics. *Units and term to be arranged.* Content will vary from year to year; topics chosen according to 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 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 108. Italian Renaissance Art. *9 units (3-0-6).* A basic study of the greatest achievements of Italian painting, sculpture, and architecture in the 15th and 16th centuries. Masterpieces by a succession of artists such as Giotto, Masaccio, Brunelleschi, Donatello, Alberti, the Bellini, Leonardo da Vinci, Michelangelo, Raphael, Titian, Veronese, and others will be examined for their formal beauty and power, and studied as manifestations of individual genius in the context of their time and place: Italy, fragmented politically, yet at the peak of its cultural dominance. Instructor: Howard.

Art 110. Baroque Art. *9 units (3-0-6); first term.* A survey of the arts of painting, sculpture, and architecture from the late 16th century to the late 18th century. A confident and optimistic age, the Baroque fostered the rise of national schools that produced artistic giants like Bernini, Caravaggio, Rubens, Rembrandt, Velasquez, Claude, Poussin, Tiepolo, and Guardi. The masterpieces of these and other artists reflect the wide variety of Baroque art and will be studied within the context of certain commonly held ideals and of the differing economic, political, and religious systems that characterized the period. Instructor: Howard.

Art 112. British Art of the Georgian Period.* *9 units (3-0-6); first term.* Introduction to visual arts and vocabularies of analysis for the study of painting through an in-depth study of British art of the Georgian period in the Huntington Art Gallery collection. Instructor: Wark.

Art 115. Art of the Nineteenth Century. *9 units (3-0-6).* A survey of nineteenth-century art with an emphasis on French painting created between 1780 and 1880. The lectures will focus on issues such as the new image of the artist, the tension between public and private statements in the arts, the rise of landscape painting, the development of the avant-garde, and paintings of modern life during this period. Instructor: Bennett.

Art 118. Art of the Twentieth Century. *9 units (3-0-6).* A survey of European and American painting, sculpture, and architecture of the twentieth century. The lectures will focus on issues such as the ways in which artists tried, succeeded, or failed to fit together personal and public meaning in their art, the problems facing architects in an industrial society, the claims and strategies of the avant-garde, why art became abstract, and what is meant by the claim during this period that "art is dead." Discussion will center on the relationship between art and politics, technology, and individual artistic expression. Instructor: Bennett.

ASTRONOMY

Ay 1. Introduction to Astronomy. *9 units (3-1-5); third term.* Primarily for freshmen; surveys astronomy and astrophysics, emphasis on application of physics in astronomy. Graded pass/fail. Instructor: Schmidt.

Ay 20. Basic Astronomy and the Galaxy. *11 units (3-2-6); second 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. Instructor: Readhead.

Ay 21. Galaxies and Cosmology. *9 units (3-0-6); third term. Prerequisite: Ay 20.* The extragalactic distance scale. Clusters of galaxies. Introduction to cosmology. Balance of matter and radiation in the universe. Instructor: Sargent.

Ay 22. Solar System. *9 units (3-0-6); first 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: Zirin.

Ay 30. Current Trends in Astronomy. *3 units (2-0-1); second term.* Weekly seminar designed for sophomore astronomy majors only, held in faculty homes in the evening, to introduce students to the faculty and their research. Graded pass/fail. Instructor: Zirin.

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.

*Advanced courses with credit toward the 36-unit Humanities requirement. Other advanced courses receive credit toward the 36-unit H&SS requirement. See page 84.

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: Scoville.

Ay 110. Senior Seminar in Astrophysics. *6 units (2-0-4); third term.* Designed for Ay seniors. Seminar on astrophysical topics of current interest. Lectures given by the students. Emphasis on topics requiring a synthesis of previous formal course work. Instructor: J. Cohen.

Ay 134. The Sun. *9 units (3-1-5); second 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 1988–89.

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 by 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 by 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: Libbrecht.

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: Mould.

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: Kulkarni, 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: Djorgovski.

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. Instructors: Readhead, Djorgovski.

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. Instructors: Scoville, Kulkarni.

Ay 211. Extragalactic Astronomy. *9 units (3-0-6); third term.* Course for graduate students in astronomy, including discussion of recent research in extragalactic astronomy and cosmology. Given in alternate years. Not offered in 1988–89.

Ay 212. Topics in Astronomy. *9 units (3-0-6); second term.* A course for graduate students in astronomy. Topic for 1988–89 will be quasars. Instructors: Sargent, Schmidt.

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. 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 covered vary from year to year. The topic for 1988–89 will be the physics of accretion and active galactic nuclei. Black holes, accretion disks, radiation processes, acceleration and propagation of relativistic jets, emission lines, and the cosmological evolution and significance of active galaxies. Given in alternate years. Instructor: 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 1988–89.

BIOLOGY

Bi 5. Introduction to Modern Biology. *6 units (3-0-3); first term.* A course designed as a survey of modern biology including such areas as developmental biology and cell physiology, which will be examined from biochemical, genetic, and evolutionary viewpoints. Although designed for non-majors, may be taken by potential biologists, but not for credit toward biology option requirements. Graded pass/fail. Instructors: Revel, Anderson.

Bi 8. 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 necessary for understanding biological systems at the molecular level, Bi 8 emphasizes cellular processes involved in organization and expression of genetic information, including what is commonly called molecular biology, and introduction to topics in developmental biology and immunology. Graded pass/fail. Instructors: Staff.

Bi 9. Cell Biology. *9 units (3-0-6); third term.* Continues coverage of biology at the cellular level begun in Bi 8. Topics: cytoplasmic structure, membrane structure and function, cell motility, and cell-cell recognition. Emphasis on both the ultrastructural and biochemical approaches to these topics. Instructors: Lazarides and staff.

Bi 10. Cell Biology Laboratory. *6 units (0-4-2); third term. Prerequisite: Bi 8; designed to be taken concurrently with Bi 9.* 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: Staff.

Bi 11. Organismic Biology. *9 units (3-3-3); first term. Prerequisite: Bi 9.* Survey of the principal kinds of organisms and problems they solved in adapting to various environments. Instructor: Brokaw.

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 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.* Intended to extend 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. 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 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 on 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 1988-89. 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 8 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, Kennedy, Parker, 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 8, Bi 9.* Introduction to the chemistry and biology of viruses. Emphasis on replication strategies of animal viruses, with consideration also given to epidemiology of viruses, nature and control of virus diseases, evolution of viruses, and some aspects of bacterial and plant virus replication. Given in alternate years; not offered 1988-89. Instructor: Strauss.

Bi 122. Genetics. *9 units (3-0-6); second term. Prerequisite: Bi 8 or Bi 9, or instructor's permission.* Lecture and discussion course covering basic principles of genetics. Instructor: Meyerowitz and staff.

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: Lipshitz.

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.* 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 1988–89. 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. Instructor: Chan.

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 formation and maintenance of the hierarchy of tissues and organs in multicellular organisms. Topics 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 1988–89. 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 152. Behavioral Biology. *6 units (2-0-4); second term.* Introduction to ethology and behavioral genetics. Topics: 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 biochemistry and molecular biology of processes fundamental to nervous system function. These include neurotransmitter/neuropeptide synthesis and release, neurite outgrowth, receptor and ion channel function, and myelination. Other topics include neurotrophic factors and putative cell surface recognition molecules. The relationship of these subjects to mental illness and learning will be considered. Given in alternate years; not offered 1988–89. Instructors: Anderson and 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 1988–89. Instructor: Allman.

Bi 158. Primatology. *9 units (3-1-5); third term.* Evolutionary and behavioral biology of primates. Topics include fossil primates, comparative anatomy, physiology and ethology of primates, and tool invention and symbolic communication in primates. Given in alternate years; not offered 1988-89. Instructor: Allman.

Bi 161. Cellular Neurobiology Laboratory. *6 units (0-4-2); second term. Prerequisite: Bi 150 or instructor's permission.* Principles of cellular neurobiology and membrane biophysics illustrated using favorable preparations, such as frog nerve-muscle synapse and cultured nerve and muscle tissue. Students conduct all aspects of 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 1988-89. Instructor: Lester.

Bi 162. Central Nervous System Laboratory. *6 units (0-4-2); second term. Prerequisite: Bi 150 or instructor's permission.* Physiological properties of individual neurons and multi-neural circuits explored in mammalian cerebral and cerebellar cortices. Both *in vitro* and *in vivo* experimental techniques used. Students instructed in all aspects of 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 1988-89. Instructor: Bower.

Env/Bi 166. Microbial Physiology. *9 units (3-0-6).* For course description, see Environmental Engineering Science.

Env/Bi 168. Microbial Diversity. *9 units (3-0-6).* For course description, see Environmental Engineering Science.

Bi 180. Methods in Molecular Genetics. *12 units (2-8-2); first term. Prerequisites: Bi 122 and instructor's permission.* An introduction to current research tools of molecular genetics. Students perform a series of structured experiments to familiarize them with basic genetic approaches, including mutant selection, genetic mapping, gene cloning and gene product analysis. Students then confront an unresolved research problem in biology to be addressed by both designing and executing their own experiments. Graded pass/fail. Instructors: Emr, Simon.

CNS/Bi/Ph 185. Collective Computation. *9 units (3-0-6).* For course description, see Computation and Neural Systems.

CNS/Bi 186. Vision: From Computational Theory to Neuronal Mechanisms. *9 units (4-0-5); second term.* For course description, see Computation and Neural Systems.

Bi 190. Advanced Genetics. *6 units (2-0-4); third term. Prerequisite: Bi 122.* Lectures and discussions covering advanced principles of genetic analysis. Emphasis on genetic approaches to the study of development in *Saccharomyces, Caenorhabditis, Drosophila,* and *Arabidopsis.* Instructors: Sternberg, Lipshitz, Meyerowitz.

Bi/Ch 202 abc. Biochemistry Seminar. *1 unit; all terms.* A seminar on selected topics and on recent advances in the field. Instructors: 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 1988-89. 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 1988-89. 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 1988-89. 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. Individual cellular elements and synaptic interactions responsible for generating each behavior are examined in detail. Other topics include modulation of motor output by sensory input and experience. Given in alternate years; not offered 1988-89. 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: proliferation, migration, differentiation, and death of neurons; role of trophic factors, cell surface molecules, and hormones. Emphasis on generation of specific synaptic connections and molecular basis underlying it. Given in alternate years; offered 1988-89. 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 1988-89. 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.* Reading and discussion illustrating recent applications of biochemical and molecular biological techniques to the study of signalling in the nervous system. Topics will include structure and regulation of ion channels and receptors; biochemistry of second messenger pathways; and structural and functional studies of synapses. The course will emphasize reading and evaluation of current research papers. Given in alternate years; offered 1988-89. 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; offered 1988-89. 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. Underlying theory of simple stochastic processes will be developed as needed. Not offered 1988-89. Instructors: 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 basic principles of computer hardware, operating systems, and 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 C; CCO 1 b will cover PASCAL; 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. Instructors: 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.* A comprehensive course in classical thermodynamics with engineering and chemical applications. First and second laws; equations of state; thermochemical calculations. Thermodynamic cycles; multicomponent systems, excess properties, fugacities, activity coefficients, and models of nonideal solutions. Chemical reaction equilibria; phase equilibria and applications; thermodynamics of ionic solutions and electrode processes. Equilibrium stage separations. 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. 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); second term. Prerequisites: Ch 21 a, ChE 103 a.* 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. Instructor: Arnold.

E/ChE 102 abc. Systems Analysis and Control. *9 units (3-0-6).* For course description, see Engineering.

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 105. Process Control. *9 units (3-0-6); first term. Prerequisite: AMa 95 abc or AM 113 abc, or concurrent registration in either.* Review of Laplace transforms and linear algebra. Feedback control of linear systems. Frequency response. Sampled-data systems. Introduction to multivariable control. Instructor: Morari.

ChE 110 ab. Optimal Design of Chemical Systems. *12 units (3-0-9); second, third terms. Prerequisites: ChE 63, ChE 101, ChE 103, 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); first, second terms.* Projects illustrative of problems in transport phenomena, unit operations, chemical kinetics, process control, and reactor design are performed. Instructors: Morari, Arnold.

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. Not offered 1988–89.

ChE/Env 157. Combustion and Air Pollution Sources. *9 units (3-0-6); third term. Open to graduate students and seniors with instructor's permission.* Principles necessary to understanding the sources and control of air pollutants; generation of pollutants in combustion systems; the internal combustion engine; control techniques for particulate and gaseous pollutants. Instructors: Flagan, Seinfeld.

ChE/Env 158. Air Pollution Aerosols. *9 units (3-0-6); second term. Open to graduate students and seniors with instructor's permission.* Fundamentals of particulate air pollutants; aerosol physics and chemistry; gas-to-particle conversion processes; pollutant effects on visibility. Instructors: Cass, Flagan, Seinfeld.

ChE/Env 159. Atmospheric Chemistry and Physics of Air Pollution. *9 units (3-0-6); first term. Open to graduate students and seniors with instructor's permission.* Principles necessary to understanding the atmospheric behavior of air pollutants; atmospheric gas- and aqueous-phase chemistry; atmospheric diffusion; removal processes and residence times; statistical distributions of pollutant concentrations. Instructors: Cass, Seinfeld.

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. Instructors: Arnold, Bailey.

ChE/Ch 164. Introduction to Statistical Thermodynamics. *9 units (3-0-6); second term. Prerequisite: Ch 21 abc or equivalent.* Ensembles and statistical mechanical formulation of the laws of thermodynamics. Classical statistical mechanics; quantum statistics; translational, rotational, vibrational, and electronic partition functions. Chemical equilibria. Real gases and distribution functions; other interacting systems; liquids and solids. Instructor: Marcus.

ChE 165. Applied Chemical Thermodynamics. *9 units (3-0-6); second 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 1988–89.

ChE 167. Advanced Polymer Science. *9 units (3-0-6); second term. Prerequisite: ChE 166 ab or equivalent.* Science of synthetic macromolecules: characterization and properties. Emphasis on understanding of polymer properties in terms of molecular structure. Not offered 1988–89.

EE/ChE 170 ab. Control System Synthesis. *9 units (3-0-6).* For course description, see Electrical Engineering.

EE/ChE 171. Nonlinear Systems. *9 units (3-0-6).* For course description, see Electrical Engineering.

EE/ChE 172. System Identification and Adaptive 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 mechanics of non-Newtonian liquids; selected topics in hydrodynamic stability theory; transport processes in turbulent flows. Other topics may be discussed, depending on class needs and interests. 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: electronic structure of atoms, periodic properties, ionic substances, covalent bonding, Lewis representations of molecules and ions, shapes of molecules, Lewis acids and bases, Bronsted acids and bases, chemical equilibria. Second term: oxidation and reduction, systematics of reaction chemistry, theories of bonding, chemistry of the transition metals. Third term: special topics selected from contemporary chemical research emphasizing chemical reactivity, stereochemistry and physical methods of characterization of molecules, solids and surfaces. Graded pass/fail. Instructors: Bercaw, Gray, Lewis.

Ch 2 ab. Advanced Placement in Chemistry. *9 units (3-0-6); first, second terms. Prerequisite: instructor's permission.* Structure of molecules with an introduction to the structure of condensed phases. Algebraic methods are used to quantify symmetry of molecular geometrical, vibrational, and electronic structure. Quantum mechanical and modern experimental techniques of structural determination will be covered. Graded pass/fail. Not offered 1988–89.

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.* 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: Dervan, Grubbs.

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.* 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 1988–89. 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. Instructors: Anson, 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, Parker.

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: Baldeschwieler, Chan, McKoy.

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 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 1988–89.

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: Dougherty, Myers.

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 technical reports before groups. Graded pass/fail. Instructors: Anson, Dougherty.

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. Not offered 1988–89.

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: Lewis.

Ch 117. Introduction to Electrochemistry. *6 units (2-0-4); third term.* Discussion of the structure of electrode-electrolyte interface, the mechanism by which charge is transferred across it, and experimental techniques used to study electrode reactions. Topics change from year to year but usually include diffusion currents, polarography, coulometry, irreversible electrode reactions, the electrical double layer, and kinetics of electrode processes. Not offered 1988–89.

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. Not offered 1988—89.

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. Overview of methods for force fields and molecular dynamics simulations. 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 quantum chemistry 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: Baldeschwieler, Marsh.

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: McKoy, Weitekamp, Zewail.

Ge/Ch 127. Nuclear Chemistry. *9 units (3-0-6); first term. Prerequisite: Consent of instructor.* For course description, see Geology.

Ge/Ch 128. Cosmochemistry. *9 units (3-0-6); first term. Prerequisite: Consent of instructor.* For course description, see Geology.

Ch 130. Spectroscopy. *9 units (3-0-6); third term.* Discussion of various topics in modern spectroscopy. Group theory with applications to molecular structure and spectroscopy. Instructor: 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 1988–89.

Bi/Ch 132 ab. Biophysics of Macromolecules. *9 units (3-0-6).* For course description, see Biology.

Ch 135. Chemical Dynamics. *9 units (3-0-6); third term. Prerequisites: Ch 21 abc and Ch 41 abc or equivalent, or consent of instructor.* Detailed considerations of cross sections, rates, energetics, and mechanisms of chemical reactions. Emphasis on theoretical models used to interpret gas-phase reactions studied with molecular beam and laser techniques. Not offered 1988–89.

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. Not offered 1988–89.

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 1988–89.

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 1988–89. Instructor: Dervan.

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. Not offered 1988–89.

Ch 147 ab. Polymer Chemistry. *9 units (3-0-6); second, third terms. 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. Instructor: 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.* General treatment of 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 1988–89.

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 21 abc or equivalent.* Transport processes in dilute gases; Boltzmann equation; Brownian Motion; Langevin and Fokker-Planck equations; linear response theory; time-correlation functions and applications; nonequilibrium thermodynamics. 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.* Topics in modern inorganic chemistry. Not offered 1988–89.

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. Instructor: Kupperman.

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 1988–89.

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. NMR basics and applications, 1988–89.

Ch 242 a. Chemical Synthesis. *9 units (3-0-6); first term. Prerequisite: Ch 41 abc.* An integrated approach to synthetic problem solving featuring an extensive review of modern synthetic reactions with concurrent development of general strategies for synthesis design. Instructor: Myers.

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 1988–89.

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. 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 1988–89.

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. Not offered 1988–89.

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. Not offered 1988–89.

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 examination of its chemical, physical, and mechanical properties. Classification and identification of soils, surface chemistry of clays, interparticle reactions, soil structure. Linear constitutive relations for soils, including steady state and transient water flow. Second term: 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. Instructors: 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 forming the foundation for structural analysis and design are covered. 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, concepts in design. Special consideration is given to 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 on engineering for earthquakes. Instructor: Hall.

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; magnitude, intensity, frequency of occurrence; engineering implications of geological phenomena, including earthquake mechanisms, faulting, fault slippage, and effects of local geology on earthquake ground motion. Not offered 1988–89.

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 1988–89.

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.

COMPUTATION AND NEURAL SYSTEMS

CNS/EE 124. Pattern Recognition. *9 units (3-0-6); second term. Prerequisite: Ma 2.* Covers classic results from pattern recognition and discusses in this context associative memories and related neural network models of computation. Discriminant functions, 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.

CS/CNS 174 abc. Computer Graphics Laboratory. *9 units (3-3-3).* For course description, see Computer Science.

CNS 179. Reading in Computation and Neural Systems. *Units by arrangement; first, second, third terms. Permission of instructor required.*

CNS 180. Research in Computation and Neural Systems. *Units by arrangement with faculty. Offered to pre-candidacy students.*

CNS/CS/EE 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 designing large-scale CMOS analog systems. MOS transistor above and below threshold; current mirrors; 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 and control system examples from feedback control, vision, and auditory processing. In addition to laboratory work on elementary circuits, each student will design a modest system-level project and submit it for fabrication. Third-term laboratory is reserved for testing and evaluating these projects. Instructor: Mead.

CNS/CS/EE 184 abc. Analog Integrated Circuit Projects Laboratory. *Units by arrangement; second, third, first terms. Prerequisite: CNS 182 abc; may be taken concurrently with CNS 182 bc.* Design projects in large-scale analog integrated systems. Each student, or pair of students, is expected to define, design, verify, and submit for fabrication a system of their choice. The project definition and simulation must be finished by the end of the second quarter (184a), and the final design must be verified and submitted for fabrication by the end of the third quarter (184b). Testing and characterization of the fabricated circuits will be done in the first quarter of the following year (184c). A two-term version of the course can be made available by arrangement with the instructor. Graded on a pass/fail basis. Instructor: Mead.

CNS/Bi/Ph 185. Collective Computation. *9 units (3-0-6); first term. Background: EE 14 and CS 10 or equivalent.* Model neural networks; differential equations and circuits for a neural net; energy functions that compute; associative memory, analog decoding, combinatorial problems, sequences; neural nets for speech and image processing; systems that learn; self-organizing maps. Course work will include a short hardware or software project. Instructor: Hopfield.

CNS/Bi 186. Vision: From Computational Theory to Neuronal Mechanisms. *9 units (4-0-5); second term. Prerequisites: Bi 150 or instructor's consent.* Lecture and discussion course aimed at understanding visual information processing in both biological and artificial systems. The course will emphasize an interdisciplinary approach aimed at understanding vision from several levels: computational theory, algorithms, psychophysics, and a study of the hardware (neurophysiology and/or circuit theory). Consideration will be given to a number of distinct processes in early vision (e.g., binocular stereo, motion analysis, edge detection, color). Students will be required to complete one project (mathematical analysis, computer modeling, or hardware). Instructors: Koch and Van Essen.

CNS 221. Computational Neurobiology. *9 units (4-0-5); third term. Prerequisites: Bi 150, CNS 185; or instructor's consent.* Lecture, discussion, and laboratory aimed at understanding computational aspects of information processing within the nervous system. 1988–89: Methods in Computational Neuroscience. The course will teach how to simulate neuronal structures at various scales, from extracting the relevant neurobiological data to computer modeling. Single channel models; compartmental models; calcium dynamics; small invertebrate model systems; visual and olfactory systems in mammals; connectionist networks; numerical solutions of differential equations; electronic circuit simulators; graphical tools; numerical versus analytical approaches; neural networks; and parallel computers. Students are expected to complete one simulation project on the Neural Network Simulator in the CNS lab. Instructors: Koch and Bower.

CNS 256. Methods of Multineural Recording. *6 units (2-0-4); third term. Prerequisite: Bi/ Ph 50 or Bi 150.* Reading and discussion course, topics to include multielectrode recording *in vitro* and *in vivo*; optical detection of activity; event-related electric potentials and magnetic fields; activity-related measures using 2-deoxyglucose autoradiography and positron emission tomography. Engineering aspects as well as underlying biophysics will be studied. Instructor: Pine.

CNS 280. Research in Computation and Neural Systems. *Hours and units by arrangement. For graduate students admitted to candidacy in computation and neural systems.*

COMPUTER SCIENCE

CS/EE 4. Introduction to Digital Electronics. *6 units (2-0-4); first term.* An introduction to modern digital design techniques. Boolean algebra and the formulation of logic equations. Hardware realization of combinational and sequential logic circuits. The building blocks and operation of a computer: binary arithmetic, the ALU, and random-access memory. Graded pass/ fail. Instructor: Goodman.

CS/Ma 6 abc. Introduction to Discrete Mathematics. *9 units (3-0-6); first, second, third terms.* For course description, see Mathematics.

CS 10. Introduction to Programming. *6 units (1-4-1); first, second terms.* Structured programming methods and high-level programming. Control structures, data manipulation, elementary data structures, recursion, and interactive graphical input and output. Weekly laboratory exercises programming personal computers in PASCAL. Graded pass/fail. Instructors: Staff.

CS/EE 11. Digital Electronics Laboratory. *6 units (0-3-3); second 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 12. Introduction to Data Structures and Algorithms. *9 units (2-4-3); third term. Prerequisite: CS 10.* Problem solving, top-down program design, and invariants. Time and space complexity of algorithms. Data structures including stacks, queues, heaps, priority queues, and trees. Sorting, searching, and hashing methods. The laboratory involves several small programming exercises followed by an assigned project. Graded pass/fail. Instructors: Staff.

CS 51. Principles of Microprocessor Systems. *9 units (3-3-3); first term. Prerequisite: CS/ EE 4 or permission of instructor.* 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.* Supervised research in computer science by undergraduates. Topic must be approved by the supervisor, and a formal final report must be presented on completion of 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 1988–89.

CS/EE/Ma 129 abc. Information and Complexity. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 2c 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. Not offered 1988–89.

CS 131. Parallel Programs. *9 units (3-0-6); first term.* Systematic development of programs for a variety of applications and computer architectures. Applications include combinatorics problems such as sorting, searching and graph problems, matrix computations, operating systems problems and fault tolerant algorithms. Architectures include parallel synchronous machines, asynchronous shared-memory multiprocessors, message-passing or distributed systems and VLSI processor arrays. The goal is to derive programs from formal specifications, prove them correct and evaluate their complexity. Not offered 1988–89.

AMa/CS 132 ab. Concurrent Scientific Computing. *9 units (3-3-3).* For course description, see Applied Mathematics.

CS 136. Functional Programming. *9 units (3-3-3); first term.* Introduction to 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 1988–89.

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 1988–89.

CS 139 ab. Concurrency in Computation. *9 units (3-0-6); first, second 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. Decision Support Systems. *9 units (3-3-3); first, second, third terms. Prerequisite: CS 10 or programming experience using PASCAL.* 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; not offered 1988–89.

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 third term. Given in alternate years. 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/CNS 174 abc. Computer Graphics Laboratory. *9 units (3-3-3); 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 interactive modeling, physically based modeling, surface rendering, ray tracing and lighting models. Students will implement several medium-scale projects; there will be an opportunity for independent projects third term. Instructor: Barr.

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.

CNS/CS/EE 182 abc. Analog Integrated Circuit Design. *9 units (3-3-3).* For course description, see Computation and Neural Systems.

EE/CS 183 abc. Integrated Digital Communication. *9 units (3-0-6).* For course description, see Electrical Engineering.

CNS/CS/EE 184 abc. Analog Integrated Circuit Projects Laboratory. *Units by arrangement.* For course description, see Computation and Neural Systems.

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. 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. Not offered 1988–89.

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.*

CS 286 abc. Seminar in Computer Science. *9 units (3-0-6). Permission of the instructor required.*

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. Not offered 1988–89. Instructors: Staff.

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. For description, see Humanities and Social Sciences.

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 114. Economics of Crime. *9 units (3-0-6). Prerequisite: Ec/SS 11 or equivalent.* This course studies the economic approach to criminal behavior and its application to various related policy issues, such as the deterrent effects of capital punishment, the optimal allocation of social resources to law enforcement, and tax evasion. Both theoretical and empirical analyses will be utilized. Instructor: Wilde.

Ec 116. Contemporary Socioeconomic Problems. *9 units (3-0-6); second 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. Instructor: Wilde.

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. Not offered 1988–89. Instructors: Staff.

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, Kim.

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.

Ec 123. Forecasting Economics Time Series. *9 units (3-0-6); third term. Prerequisite: Ec 122.* Various forecasting techniques; application to business and economics. Instructors: Staff.

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.* Economic and political factors influencing 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 U.S. is analyzed in some detail. This course emphasizes theory less than does Ec 120. Not offered 1988–89. Instructors: Staff.

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: Border, Dubin.

Ec 127. Problems in Economic Theory (Seminar). *Units by arrangement; first, second, third terms. Prerequisite: Ec 121.* Consideration of selected topics in economic theory. Instructors: Staff and guest lecturers.

Ec/SS 129. Economic History of the United States. *9 units (3-0-6); second 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.* Modern theory of labor markets. Uses empirical evidence to supplement theoretical results. Instructor: Wilde.

Ec/PS 134. The Political Economy of Urban Areas. *9 units (3-0-6); first 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 135. Economics of Uncertainty. *9 units (3-0-6). Prerequisite: Ec/SS 11, Ma 2.* An analysis of the effects of uncertainty on economic decisions. Included among the topics are individual and group decision making under uncertainty, expected utility maximization, insurance, financial markets and speculation, product quality and advertisement, value of information, and equilibrium. Instructor: Palfrey.

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. Instructor: Border.

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. Instructor: Palfrey.

Ec/SS 145. Public Finance. *9 units (3-0-6). Prerequisite: Ec/SS 11 or equivalent.* An intermediate-level course on the economics of the public sector. Material is chosen from welfare economics, public expenditure theory and practice, taxation theory and practice, federalism, and public choice theory. Instructor: Ledyard.

Ec 147. Altruism and Fairness in Economics. *9 units (3-0-6). Prerequisite: Ec/SS 11.* A study and discussion of altruism and fairness and their congruence with standard economic models. The emphasis will be on class discussion and short papers or problems. Instructor: Ledyard.

ELECTRICAL ENGINEERING

CS/EE 4. Introduction to Digital Electronics. *6 units (2-0-4); first 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 1988–89.

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, Kirchhoff's laws, transient and steady-state network solutions, phasor notation, Thevenin and Norton theorems, piece-wise linear analysis, power considerations, distributed systems, introduction to Laplace transform and the pole-zero description of network characteristics. Principles of silicon diodes, FETs 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 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, state-space representations, and stability analysis. Special emphasis will be placed on transform techniques (Fourier, Laplace, and Z-Transforms). Instructor: Abu-Mostafa.

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 include a written report based on actual laboratory experience. Topic selection and final report must be approved by the Electrical Engineering Undergraduate Committee. Not offered on pass/fail basis. Instructors: Staff.

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 include a written report based on work performed. Topic selection and 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. Instructors: Staff.

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: BJTs, FETs, 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 1 12, 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 analog, 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 ab. Digital Signal Processing Principles. *9 units (3-0-6); first and second terms. Prerequisites: EE 32 ab and AMa 95 abc or equivalents.* Advanced discrete-time linear systems concepts, stability-test procedures, DFTs and Fast Fourier Transforms, FIR and IIR digital filter design and implementation, structural passivity and losslessness with applications to low round-off noise, low sensitivity and limit-cycle free structures, digital signal processing structures suitable for VLSI implementation, periodically time varying systems, multirate concepts including block filtering, quadrature mirror filtering, and unconventional sampling theorems. 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.

CNS/EE 124. Pattern Recognition. *9 units (3-0-6).* For course description, see Computation and Neural Systems.

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: Abu-Mostafa.

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. Instructor: McEliece.

EE 128. Multirate Signal Processing. *9 units (3-0-6); third term. Prerequisite: EE 32 ab, AMa 95 abc, or equivalent.* Course deals with multirate signals and systems. Instead of a singular sampling rate, as in conventional systems, multiple sampling rates are involved in these systems. Applications of such systems include speech and image coding, voice privacy systems, signals and system coding, and system optimization. Topics: periodically time-varying systems, bi-frequency descriptions, decimation and interpolation filters, quadrature mirror filter banks, unconventional sampling theorems, and error-free signal reconstruction. Not offered 1988–89.

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.

APh/EE 131. Optoelectronic Devices. *9 units (3-0-6).* For course description, see Applied Physics.

APh/EE 132. Fourier Optics. *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. Engineering Electromagnetics. *12 units (3-1-8); second term. Prerequisite: EE 14.* Foundations of circuit theory, and guided-wave and radiating systems. Statics, Maxwell's equations, plane waves, guided waves, resonators, and antennas. Instructor: Rutledge.

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, optical fibers and integrated circuits, and opto-electronic systems. Scattering matrix; discontinuities in waveguides. Selections from periodic propagating structures, coupled mode devices, electronic waveguides. Instructor: Bridges.

EE 153. Microwave Circuits. *12 units (3-2-7); first term. Prerequisite: EE 14.* The fundamentals of very high-speed circuits. Students design microstrip circuits using computer-aided design techniques, and fabricate and test them in the lab. Topics include transmission-line discontinuities, branch-line couplers, filters, coupled lines, network analyzers, Schottky-diode mixers, noise, and gallium-arsenide field-effect transistor amplifiers and oscillators. Instructor: Rutledge.

EE 154. Antennas. *9 units (3-0-6); third term. Prerequisite: EE 151.* Fundamentals of radiating systems in communications and radar. Dipoles and slots, horn and lens antennas, travelling-wave antennas, integrated-circuit antennas, and arrays. Instructor: Rutledge.

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 for Communication and Signal Processing. *9 units (3-0-6); first term. Prerequisite: Ma 100 or equivalent.* 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; intersymbol interference and synchronization considerations; signal-to-noise ratio and error probability; optimum demodulation and detection in analog and digital baseband and carrier communication systems. Instructor: Simon.

EE 164. Adaptive Filters, Linear Prediction, and Optimal Filters. *9 units (3-0-6); third term. Prerequisites: EE 112 ab and EE 162 or equivalents.* Adaptive FIR and IIR filters, adaptation algorithms, convergence analysis, adaptive FIR lattice filters and other orthogonalizing techniques, recursive least squares techniques, fast-Kalman techniques, stable IIR adaptive filtering, adaptive filtering in sub-bands, Weiner and matched digital filters, linear predictive coding, normal equations, Levinson's recursion, and associated lattice structures. Some applications from the following areas will be used as motivators: speech compression, spectral factorization, channel equalization, echo and noise cancelation, interference minimization, and antenna arrays. Instructor: Vaidyanathan.

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. Instructor: Edwards.

EE/ChE 170 ab. Control System Synthesis. *9 units (3-0-6); second, third terms. Prerequisites: E/ChE 102 or equivalent.* Matrix fraction descriptions (MFDs) of linear systems. Spectral factorization and Riccati equations, Wiener-Hopf optimal control. Linear quadratic (LQ) optimal control, robustness and other properties of LQ regulators, stochastic optimal control. H_∞ optimal control. Instructors: Doyle, Staff.

EE/ChE 171. Nonlinear Systems. *9 units (3-0-6); first term. Prerequisites: E 102 or equivalent.* Methods for analysis and design of nonlinear control systems. Describing functions, small gain theory, Lyapunov theory, conic sectors, geometric methods, input-output methods, μ-analysis, robustness of nonlinear feedback systems. Instructor: Sideris.

EE/ChE 172. System Identification and Adaptive Control. *9 units (3-0-6); second term. Prerequisites: EE/ChE 171 or equivalent.* Parametric and nonparametric identification, spectral analysis, least squares, maximum likelihood estimation. Model reference adaptive control, self-tuning regulators, instability mechanisms, universal stabilizers, robustness of adaptive control schemes. Instructor: Sideris.

EE/APh 180. Solid-State Devices. *9 units (3-0-6); third term. Prerequisite: EE 151 or Ph 106 (may be taken concurrently).* With the phenomenological statement of physical principles, the performance of a device and its representation in terms of an equivalent circuit is derived from the device's materials and design. Subjects include the motion of charge carriers in solids, equilibrium statistics, the electronic structure of solids, doping, nonequilibrium states, pn junction, junction transistor, Schottky diode, and field-effect transistor. Instructor: Nicolet.

CS/EE 181 abc. VLSI Design Laboratory. *12 units (3-6-3).* For course description, see Computer Science.

CNS/CS/EE 182 abc. Analog Integrated Circuit Design. *9 units (3-3-3).* For course description, see Computation and Neural Systems.

EE/CS 183 abc. Integrated Digital Communication. *9 units (3-0-6); first, second, third terms. Prerequisite: At least one term of communications or signal processing.* Concepts and systems used in digital transmitting, synchronizing, and switching voice, data and images digitally in communication networks, with emphasis on common-carrier and computer communication networks. Digital representation, multiplexing, traffic theory, queueing theory, circuit switching, protocol hierarchy, packet switching, local area networks, integrated services, cellular radio, and analysis and design of large-scale circuit switches and switched digital networks. Emphasis is on the changes in communication concepts being wrought by the digital revolution. Instructor: Posner.

CNS/CS/EE 184 abc. Analog Integrated Circuit Projects Laboratory. *Units by arrangement.* For course description, see Computation and Neural Systems.

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 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 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.)* Guidance and practice in organizing and preparing topics for presentation and in speaking with the help of visual aids, including blackboard, overhead projector, and slide projector. Instructors: McDonough, staff.

E 101. Introduction to Automatic Control. *9 units (3-0-6); third term. Prerequisite: EE 32, ChE 105, or equivalent.* Feedback control design, stability and performance analysis in frequency and time domain. Loop shaping for performance and robustness. Examples from aeronautics, electronics, and chemical engineering. Instructors: Staff.

E/ChE 102 abc. Systems Analysis and Control. *9 units (3-0-6); first, second, third terms. Prerequisites: E 101 or equivalent.* Analysis of linear multivariable systems, using state space, frequency domain and stochastic techniques. Unified treatment using linear operator theory. Extension of classical control design techniques to multivariable systems, stressing robustness and (structured) singular value analysis. Sampled-data control theory. Examples from electrical, chemical, mechanical, and aerospace systems. Instructors: Doyle, Morari.

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 *(see Mechanical Engineering)*

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.* Instructors: Staff.

ENVIRONMENTAL ENGINEERING SCIENCE

Env 1. Engineering Problems of the 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 impacts 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 (3-0-6); first, 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); third term. Prerequisite: ChE/Env 157, 158, 159 (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 models; properties of colloids in natural water systems; 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 may 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); first 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), first term; 9 units (3-0-6); second term.* An exposition of basic biological principles concerning interrelations between organisms, particularly those directly affecting humans and their 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 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 1988–89. 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 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, microbiology of metals. Not offered 1988–89. 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. Combustion and Air Pollution Sources. *9 units (3-0-6); third term. Open to graduate students and seniors with instructor's permission.* Principles necessary to understanding the sources and control of air pollutants; generation of pollutants in combustion systems; the internal combustion engine; control techniques for particulate and gaseous pollutants. Instructors: Flagan, Seinfeld.

ChE/Env 158. Air Pollution Aerosols. *9 units (3-0-6); second term. Open to graduate students and seniors with instructor's permission.* Fundamentals of particulate air pollutants; aerosol physics and chemistry; gas-to-particle conversion processes; pollutant effects on visibility. Instructors: Cass, Flagan, Seinfeld.

ChE/Env 159. Atmospheric Chemistry and Physics of Air Pollution. *9 units (3-0-6); first term. Open to graduate students and seniors with instructor's permission.* Principles necessary to understanding the atmospheric behavior of air pollutants; atmospheric gas- and aqueous-phase chemistry; atmospheric diffusion; removal processes and residence times; statistical distributions of pollutant concentrations. Instructors: Cass, Seinfeld.

Env/Bi 166. Microbial Physiology. *9 units (3-0-6); second term. Recommended prerequisite: one year of general biology.* A lecture and discussion course on growth and functions in the prokaryotic cell. Topics covered: growth, transport of small molecules, protein excretion, membrane bioenergetics, energy metabolism, motility, chemotaxis, global regulators, and metabolic integration. Instructor: Lidstrom.

Env/Bi 168. Microbial Diversity. *9 units (3-0-6); third term, alternate years. Recommended prerequisite: one year of general biology.* A lecture and discussion course on the metabolic diversity of prokaryotic microorganisms. Each of the major metabolic groups of prokaryotes will be discussed in terms of their biochemistry, genetics, and ecology. The course will comprise a comprehensive survey of the known microbial groups, their capabilities, and their importance in geochemical cycling and industrial applications. Not offered 1988–89. Instructor: Lidstrom.

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 208. Special Topics in Microbiology. *6 units (2-0-4); third term alternate years. Prerequisite: instructor's permission.* A lecture and discussion course to cover topics of current interest in the field of microbiology. As the topics will vary from year to year, it may be taken any number of times. Potential topics: genetics in unusual microorganisms; risk assessment and the release of genetically engineered organisms to the environment; environmental molecular biology. Not offered 1989–90. Instructor: Lidstrom.

Env 210. Advanced Seminar in Microbiology. *3 units (1-0-2); first term. Prerequisite: instructor's permission.* A seminar course for advanced graduate students and staff to discuss current research and technical literature in the field of microbiology. As the topics will vary, it may be taken any number of times. Instructor: Lidstrom.

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. 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. Not offered 1989–90. 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.

For other closely related courses see listings under Chemistry, Chemical Engineering, Biology, Geology, Hydraulics, Economics, and Social Science.

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.* Broad, up-to-date view of the earth, focusing on geological items of current interest: paleomagnetism, mid-oceanic rises, sea-floor spreading, plate tectonics, continental drift, evolution of continental plates, the earth's interior, and environmental geology. Topics vary with the individual instructor and class interests. Classes are limited in size and individually handled by full-time faculty members. All students must be prepared to devote six weekend days to field trips. Instructors: Wyllie, staff.

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: Burnett.

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. Given in alternate years; offered 1989–90. 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.

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. Geology. *9 units (3-3-3); first term. Prerequisites: Ch 1 or 2, Ma 1, Ph 1.* The constitution of the solid earth and the history of its development based on the record preserved in the rocks and observation of ongoing 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. Field trips. Instructor: Staff.

Ge 102. Geophysics. *9 units (2-1-6); second term. Prerequisites: Ma 2, Ph 2.* 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.

Ge 103. Planetary Science. *9 units (3-0-6); first term. Prerequisites: Ma 2, Ph 2.* 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: Stevenson.

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 and Tectonics. *9 units (3-3-3); second term. Prerequisite: Ge 101.* 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. Mechanics of rock deformation. Structural analysis by geometrical and graphical techniques. Structure of major tectonic features of the earth's crust; tectonics of mountain building and sea-floor spreading. Field trips for study of structural features. Instructor: Saleeby.

Ge 107. Geologic Field Mapping. *9 units (0-9-0); third term. Prerequisites: Ge 101, Ge 106.* Introduction to the rationale and techniques of geologic field mapping. Emphasis on construction of a geologic map in a terrain 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: Allen.

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: 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 109. 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: Murray.

Ge 110. Sedimentary Geology. *9 units (3-3-3); third term. Prerequisite: Ge 101.* 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 common groups of lower invertebrates; emphasis on evolution and adaptive modifications; consideration of higher invertebrate groups; preparation of fossils; and problems of invertebrate paleontology. Not offered 1988–89.

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. Not offered 1988–89. Instructor: Wyllie.

Ge 114. Mineralogy. *12 units (3-6-3) or 9 units (3-4-2); first term. Prerequisite: Ge 101.* Atomic structure, composition, physical properties, occurrence, and identifying characteristics of the major mineral groups. The laboratory work involves characterization and identification of important minerals by physical and optical properties. The 12-unit course is required for geology majors, and includes additional laboratory studies on optical crystallography and use of the petrographic microscope. Instructor: Rossman.

Ge 115 ab. Petrology and Petrography. Systematic study of rocks and rock-forming minerals with emphasis on 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); first, second, third terms. Prerequisites: Ge 101, 106, and 107, or consent of instructor.* Field mapping and supporting laboratory studies in topical problems related to Southern California tectonics and petrogenesis. Each year the sequence offers a breadth of experience in igneous, metamorphic, and sedimentary problems. Instructor: Staff.

Ge 123. Summer Field Geology. *15 units (3 weeks, including transportation). Prerequisites: Ge 101, 106, and 107, or consent of instructor.* Advanced field studies in a topical problem during summer break in a remote area of western North America. May be taken in lieu of one quarter of Ge 121 for geology majors, or may be taken in addition to the Ge 121 sequence and applied to requirements for divisional elective units. To be arranged. Instructor: 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 1988–89. Instructor: Kirschvink.

124 a. *9 units (3-3-3); second term. Prerequisites: Ge 101, 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); third term. Prerequisite: Ge 124 a.* A field trip to the southwest U.S. to study the physical stratigraphy and magnetic zonation, followed by lab analysis.

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 1988–89. Instructor: Sieh.

Ge/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 1988–89. Instructor: Burnett.

Ge/Ch 128. Cosmochemistry. *9 units (3-0-6); first term. Prerequisite: Consent of instructor.* The chemistry of the interstellar medium, of protostellar nebulae, and of primitive solar system objects with a view towards establishing the relationship of the chemical evolution of atoms in the interstellar radiation field to complex molecules and aggregates in the early solar system. Emphasis will be placed on identifying the physical conditions in various objects, time scales for physical and chemical change, chemical processes leading to change, observational constraints, and various models which attempt to describe the chemical state and history of cosmological objects in general and the early solar system in particular. Offered 1988–89. Instructor: Blake.

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 1988–89. Instructor: Stevenson.

Ge 135. Regional Geology of Southern California (Seminar). *6 units (3-0-3); second term. Prerequisites: Ge 101, 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 101 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. *second term.* 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. *third term.* 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. Instructors: Wasserburg, Epstein.

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.

Ge 151. Planetary Surfaces. *9 units (3-0-6); third term.* Review of processes responsible for formation and modification of the surfaces of the terrestrial planets, icy satellites, and small bodies, and 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 1989–90. Instructors: Murray and staff.

Ge 152 abc. Atmospheres and Oceans. *9 units (3-0-6); first, second, third terms.* Physical and chemical processes in atmospheric fluid envelopes. First term: dynamics of large-scale motions in atmospheres and oceans, physical and chemical oceanography. Second term: atmospheric radiative transfer and remote sensing, atmospheric temperatures and radiative equilibrium, weather and climate. Third term: atmospheric chemistry, numerical modeling, planetary atmospheres. Instructors: Ingersoll (first and second terms), Yung (third term).

Ge 153. Planetary Radio Astronomy. *9 units (3-0-6); second term. Prerequisite: instructor's permission.* Investigates the atmospheres and surfaces of the planets and their satellites using microwave techniques. Information from the literature and current observations in millimeter and submillimeter spectroscopy, thermal microwave emission, radio and visual occultations, and radar astronomy will be discussed from the standpoint of the physics and chemistry of solar system objects. Given in alternate years; offered 1989–90. Instructor: Muhleman.

Ge 154. Planetary Atmospheres. *9 units (3-0-6); third term. Prerequisites: Ma 2, Ph 2, Ge 152 abc, 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. Given in alternate years; offered 1988–89. 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 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 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 1988–89. 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 Advanced Atmospheres and Oceans. *9 units (3-0-6); first term. Prerequisite: Ge 152 or equivalent.* Advanced topics pertaining to the dynamics, thermodynamics and chemistry of atmospheres and oceans. Theory of radiative transfer in planetary atmospheres. Offered 1988-89. Instructor: Yung.

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 1988–89. 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 1988–89 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 1989–90. 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 1989–90. 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. Given in alternate years; offered 1989–90. Instructor: Albee.

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 (3-3-3); first 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. Observing experience will be required at the telescope. Given in alternate years; offered 1988–89. Instructor: Brown.

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.* 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; chemistry of meteorites as a clue to initial conditions in the solar nebula; 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 1989–90. Instructor: Burnett.

Ge 240. Advanced Isotope Geochemistry. *9 units (3-0-6); offered by announcement only. 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 1989–90. 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 1989–90. Instructors: Saleeby, Silver.

Ge 248. Geodynamics. *9 units (3-0-6); third term.* Application of continuum mechanics to geologic problems of mass and heat transfer; 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 1989–90. 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.* 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. 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, Suppe.

Ge 282 abc. Geological Sciences Seminar. *1 unit; first, second, third terms.* Presentation of papers by invited investigators. In charge: Ingersoll, 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)*

HISTORY

Courses above H 20 are open only to students who have fulfilled the freshman humanities requirement.

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 instructor and student. Course subject matter varies according to individual needs. Normally taken 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 instructor and student. Normally taken 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

*Advanced courses with credit toward the 36-unit Humanities requirement. Other advanced courses receive credit toward the 36-unit H&SS requirement. See page 84.

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. Not offered 1988–89. Instructors: Hoffman, Searle.

H 106 abc. Topics in Medieval and Renaissance History.* *9 units (3-0-6).* 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 instructor or Registrar. Instructor: Searle.

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 1988–89. 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." Not offered 1988–89. Instructor: Fay.

H 110. Early Modern Europe.* *9 units (3-0-6); first 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.

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).* Public issues, social trends, and cultural developments of special interest in Europe today. While the setting will be historical, particular emphasis will be placed on 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. Emphasis on the evolution of social and political institutions and attitudes. Not offered 1988–89. Instructors: Staff.

H 114. European Intellectual History.* *9 units (3-0-6).* 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. Science, Weapons, and National Security.* *9 units (2-0-7).* The history of the arms race since 1945, with particular attention to its domestic sources, including defense R & D, the scientific community, the national security bureaucracy, Congress, and the president. Instructor: Kevles.

H 116. Russia. *9 units (3-0-6).* The major developments and characteristics of Russian history during the Muscovite and Imperial periods, from the 16th century to the Revolution of 1917. Not offered 1988–89. Instructors: Staff.

H 117. The Soviet Union Since the Revolution. *9 units (3-0-6).* Selected episodes of Soviet political, economic, and social history from the Revolution to the present. Emphasis on the continuity of Russian history. Not offered 1988–89. 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 84.

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. Not offered 1988–89. 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. Not offered 1988–89. Instructor: Fay.

H 121. South Asian Civilization.* *9 units (3-0-6).* 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 1988–89. Instructor: Dirks.

H 122. Gandhi.* *9 units (3-0-6).* Readings will include Gandhi's *Autobiography,* biographies and memoirs, detailed studies of his political role in the Indian nationalist movement and of the traditional roots of his charisma, and several conflicting assessments of the significance of his political style and ideology for modern India and the world. Not offered 1988–89. 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. Not offered 1988–89. Instructor: Dirks.

H 124. Population and Family History in Premodern Societies.* *9 units (3-0-6).* Four aspects of population and family history in China and Europe: demographic, establishing the parameters of birth, marriage, and death; economic, treating the family as a unit of production as well as consumption; social, analyzing the evolving structure of various kin groupings—lineage, clan, household, and family; cultural, identifying and interpreting the symbolic forms and meanings of the "family." Instructor: Lee.

H 125. History and Anthropology.* *9 units (3-0-6).* 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. Not offered 1988–89. 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. Not offered 1988–89. Instructors: Staff.

H/Hum 131. History on Film.* *9 units (2-2-5).* An investigation into the variety of ways history has been and can be represented on the screen. Some terms the focus will be a specific historical period or nation; other terms the focus will be the nature of film as a medium for history and biography. The class will include weekly screenings of films as well as weekly discussion sections. 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. Not offered 1988–89. Instructor: Rosenstone.

*Advanced courses with credit toward the 36-unit Humanities requirement. Other advanced courses receive credit toward the 36-unit H&SS requirement. See page 84.

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).* 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).* Main events of 19th- and 20th-century China, with various interpretations of their historical significance. Focus: modern roots of the Chinese revolution beginning with Sun Yat-Sen. 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).* The development of the Supreme Court, its doctrines, and its role in U.S. history through analyses of selected cases. Instructor: Kousser.

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. Not offered 1988–89. Instructor: Kousser.

H 152. America in the Era of Roosevelt and Truman.* *9 units (3-0-6).* Topics in the history of the Depression, World War II, and the origins of the Cold War. Instructors: Kevles, Moore, 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.

*Advanced courses with credit toward the 36-unit Humanities requirement. Other advanced courses receive credit toward the 36-unit H&SS requirement. See page 84.

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; emphasis on their critiques of American life, role in society, and contributions. Not offered 1988–89. 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 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

All courses numbered 1 through 20 are freshman humanities courses. Courses numbered above 20 are open only to students who have fulfilled the freshman humanities requirements.

AW/Hum. Adjunct Writing for Humanities. *3 units (2-0-1); first, second, or third terms.* Given in conjunction with certain Humanities courses, which then count as 6 units (2-0-4).

Hum 1 ab. Greek Civilization. *9 units (3-0-6); first and second or second and third terms.* Introduction to Greek culture from Homer to Aristotle. Hum 1 a is a prerequisite for Hum 1 b. Instructors: philosophy and literature staff.

Hum 2 ab. Traditional Europe: Society, Material Life and Values before 1800. *9 units (3-0-6); first and second terms.* Introduction to patterns of life and thought in pre-industrial Europe, stressing the structure of economic, political, and cultural life. First quarter: 300 A.D.-1400 A.D.; second quarter: 1300-1800. Instructors: history and philosophy staff.

Hum 3 ab. Early European Literature. *9 units (3-0-6); first and second or second and third terms.* Critical exploration of selected literature, chiefly English, from the Middle Ages, the Renaissance, or the Restoration. Depending on the instructor, continental authors such as Dante, Rabelais, or Molière may also be covered. Instructors: literature staff.

Hum 4 ab. The Romantic Age in the Arts in Europe. *9 units (3-0-6); first and second or first and third terms.* First quarter: masterpieces of English poetry of the Romantic (1770s-1830) period and, in translation, selected works from Germany, France and Russia. Second quarter: introduction to music and visual arts of the Romantic period. In both quarters due attention will be paid to the classical background and classical counter-tendencies evident in the arts in the Romantic period. Not offered 1988–89. Instructors: literature, art history, and music staff.

Hum 5 ab. The Arts in Nineteenth Century Europe. *9 units (3-0-6); first and second or first and third terms.* First quarter: masterpieces of fiction from England, France, and Russia (the latter two in translation) roughly from the fall of Napoleon in 1815 to World War I. Second quarter: European music and the history of art in the same period (1815-1918). Not offered 1988–89. Instructors: literature, art history, and music staff.

Hum 6 ab. The Modern Age. *9 units (3-0-6); first and second or first and third terms.* Since the middle of the 19th century, historical, economic, and cultural pressures have redefined Western society. Using a variety of artistic, literary, philosophical, and historical works, this two-quarter sequence will introduce students to aspects of the history, politics, thought, literature, art and culture of modernity. Instructors: literature and history staff.

Hum 7 ab. American Society and Politics. *9 units (3-0-6); first and second or second and third terms.* An introduction to the major events and forces that shaped the American past, and

*Advanced courses with credit toward the 36-unit Humanities requirement. Other advanced courses receive credit toward the 36-unit H&SS requirement. See page 84.

the way historians and biographers have analyzed them. Depending on the instructor, topics covered may include: the Revolution and the Constitution, the Civil War and Reconstruction, the New Deal, immigration, industrialization, technological change and twentieth-century political movements and culture. Instructors: history staff.

Hum 8 ab. American Literature and Culture. *9 units (3-0-6); first and second and second and third terms.* Studies in American ideas, styles, and general culture from the colonial period to the present. Emphasis on those characteristic features of American experience that have influenced and continue to affect our culture and character. Students may take two quarters of either element or one quarter of each. Instructors: literature and history staff.

Hum 9 ab. Introduction to Asia. *9 units (3-0-6); first and second or second and third terms.* Asia contains a variety of civilizations and cultures whose only common property is that they have been defined in opposition to what is "European." Using religious and philosophical texts, anthropological and demographic studies, narrative histories and biographies, novels and films, this two-quarter sequence will introduce students to the thought, society, art, religion, history, politics, and economy of some of these civilizations, particularly the Indian and Chinese. Instructors: history staff.

Hum 10 ab. Morality, Society, and Politics. *9 units (3-0-6); first and second or first and third terms.* Theories of morality and politics have generally been shaped not only by the broader intellectual climate of their time, but also by the perceived virtues and defects of the social and political conditions of the time. This two-quarter sequence will provide an introduction to the moral and political theories which helped shape Western societies, with the emphasis on the seventeenth century to the present. The first quarter will concentrate on moral theory and the second quarter on political theory. Each theory will be presented in historical context but will also be assessed for its relevance to contemporary life and politics. Instructors: philosophy staff.

Hum 11 ab. Literature and Psychology. *9 units (3-0-6); first and second terms.* Introduction to literature and psychology considered as parallel investigations of such essential human issues as development of a sense of self, the nature of dreams, levels (conscious and unconscious) of communication. Readings in psychology, psychoanalysis and in the creative writing of (among others): Dostoevsky, Mann, Coleridge, R. L. Stevenson. Instructors: literature and psychoanalytic studies staff.

Hum 12 ab. Belief, Truth, and Knowledge. *9 units (3-0-6); first and third terms.* Introduction to philosophical theories of rational belief formation. Among issues discussed will be the following: How do we tell which of our beliefs are true? How do our beliefs and the concepts in which they are expressed influence our interpretations of reality? How much control do we have over our beliefs? Depending on the instructor, the following topics will be covered in this two-quarter sequence: the application of formal logic and/or informal argument analysis to moral and scientific reasoning; theory of knowledge; philosophy of language; philosophy of science; ethical theory. Readings will include both historical and contemporary philosophical texts. Instructors: philosophy staff.

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. Instructors: Staff.

Hum 119. Selected Topics in Humanities. *9 units (3-0-6).* Advanced courses to be determined on a course-by-course basis by the instructor. Instructors: Staff and visitors.

H/Hum 131. History on Film.* *9 units (2-2-5).* For course description, see History.

*Advanced courses with credit toward the 36-unit Humanities requirement. Other advanced courses receive credit toward the 36-unit H&SS requirement. See page 84.

HUMANITIES AND SOCIAL SCIENCES

HSS 99. Humanities-Social Science Tutorial Program. Upon application and screening by the tutorial committee (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 undergraduates, 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 every year. 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 107 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 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. Instructor: 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. Instructors: Staff.

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 study of combustion processes, including theoretical and experimental treatment of laminar and turbulent flames; acoustic and detonation waves; volatilization and combustion of liquid droplets and solid particles; combustion problems of air-breathing engines and liquid and solid propellant rockets; flame stability; aspects of gas, oil, and coal combustion. 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. For course description, see Humanities and Social Sciences.

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. Writing is emphasized in the third quarter. Instructors: Staff.

L 105. French Literature. *9 units (3-0-6). Prerequisite: L 103 abc or equivalent. Advanced humanities credit will be determined by the instructor.* A body of French literature is treated from the standpoint of a dominant theme. Conducted in French. Instructors: Staff.

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: Staff.

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, aural and oral drill and exercise, expansion of vocabulary, and practice in reading, writing, and conversational skills. Third quarter will emphasize written expression and technical/scientific translations. Students who have studied German elsewhere must consult with the instructor before registering. Instructors: Staff.

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.) Not offered 1988–89. 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. Writing is emphasized in the third quarter. Instructors: Staff.

L/Lit 154. French Literature in Translation: The French Novel. *9 units (3-0-6); first 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. Instructor: A. Smith.

L/Lit 160 ab. German Literature in Translation.* *9 units (3-0-6).* First term: Middle Ages through the Classic/Romantic Age. Second term: 19th and 20th centuries, stressing Kafka, Hesse, T. Mann. Third term: exiled writers. 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 84.

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.* Major Latin authors, usually one per term. Instructor: Pigman.

LINGUISTICS

Lin 101 a. Introductory Linguistics. *9 units (3-0-6).* 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).* 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). 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. Instructors: B. Thompson, F. Thompson.

LITERATURE

Courses above Lit 20 are open only to students who have fulfilled the Freshman Humanities requirements.

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.*

*Advanced courses with credit toward the 36-unit Humanities requirement. Other advanced courses receive credit toward the 36-unit H&SS requirement. See page 84.

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. For course description, see Humanities and Social Sciences.

Lit 100. Introduction to Poetry. *9 units (3-0-6).* What is poetry? Why and how should one read it? What "weapons" does the good poem deploy in order to give pleasure? How does an inexperienced reader develop into an expert and sensitive one? To answer these and other basic questions, a substantial range of poems, from simple to complex, will be read and discussed. Instructor: Mandel.

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 ab. Seminar in Creative Writing. *9 units (3-0-6).* Students will develop their writing skills chiefly through their own creative efforts and class discussions of their work and that of their fellow students. Through outside readings and discussions with the instructor, they will also be exposed to alternate styles and techniques. In odd-numbered years, both terms will be devoted to fiction-writing. In even-numbered years, poetry, playwriting, or essay-writing will be the subject of 108 b. Instructors: Staff.

Lit 112 ab. English Renaissance Literature.* *9 units (3-0-6).* 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 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. Not offered 1988–89. 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. 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 84.

Lit 122 abc. The English Novel.* *9 units (3-0-6); third 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. Instructors: Staff.

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, British, 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 ab. James Joyce and Modern Literature.* *9 units (3-0-6).* Joyce's major works, along with selected poetry and fiction from his modernist contemporaries (Eliot, Yeats, Pound, Lawrence, Woolf, etc.). First term: through the opening chapters of *Ulysses*. Second term: the rest of *Ulysses* and selections from *Finnegans Wake*. Instructor: Bush.

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. 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, including the Confessional Poets , the New York school, Beat poetry, Deep Image work, and the Language poets. Instructors: Staff.

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. Instructors: Staff.

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. Not offered 1988–89. 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 84.

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.

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.

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: 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: theater from Ibsen to the present. Not offered on a pass/fail basis. Not offered 1988–89. 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 1988–89. 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.

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 5 a). MS 5 bc not offered 1988–89.

*Advanced courses with credit toward the 36-unit Humanities requirement. Other advanced courses receive credit toward the 36-unit H&SS requirement. See page 84.

MS 15 ab. Principles of Materials. *9 units (3-0-6); first term.* 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. Instructors: Fultz (MS 15 a), Freise (MS 15 b).

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.* Mechanical behavior of metals for engineering applications. Elastic behavior of anisotropic materials and polycrystalline aggregates. Yielding, plastic flow, and strengthening mechanisms; 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. Not offered 1988–89.

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. Phase Transformations in Solids. *9 units (3-0-6); third term. Prerequisites: APh/ME 17 abc and MS 15 a, or graduate standing.* Diffusion from atomistic and continuum viewpoints. Thermodynamics and kinetics of first- and second-order phase transformations, decomposition, and ordering reactions. Role of strain energy in solid-solid phase transformations. Diffusionless transformations. Microstructural morphologies. Instructor: Fultz.

APh/MS 122. Diffraction Theory and Applications. *9 units (3-0-6).* For course description, see Applied Physics.

MS 123. Transmission Electron Microscopy Laboratory. *(0-7-2); third term. Prerequisite: APh/MS 122.* Techniques of using the transmission electron microscope (TEM) for the characterization of materials. Operation and alignment of the TEM. Bright field, dark field, and diffraction techniques with specimen tilting. Specimen preparation. Experiments include studies of crystal defects and solid-state precipitation reactions by diffraction contrast methods, and an introduction to high-resolution TEM. Instructor: Ahn.

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. Not offered 1988–89.

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 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*. Not offered 1988-89.

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 1 bc, 2a. Freshman Mathematics, Advanced Placement. *9 units (4-0-5); first, second, third terms.* Instructor: Apostol.

Ma 2 abc. Sophomore Mathematics. *9 units (4-0-5); first, second, third terms.* A continuation of the topics introduced in Ma 1 including linear algebra, calculus of several variables, and probability. Instructor: Luxemburg.

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. Instructors: Aschbacher, S. Katok.

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: Wilson, Woodin.

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. Not offered 1988-89.

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 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 supervised reading course 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 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. Not offered 1988–89.

Ma 104 a. Introduction to Complex Variables. *9 units (3-0-6); second term. Prerequisite: Ma 2 ab.* Topology of plane regions, Cauchy-Riemann equations, Cauchy integral formula, series expansions, analytic continuation, Laurent expansions, and residue calculus. Instructor: Flaminio.

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: Flaminio, Howland, Sadun.

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: A. Katok, Wolff.

Ma 112 abc. Statistics. *9 units (3-0-6); first, second, third terms.* The first term is an introductory course in the basic techniques of probability theory, hypothesis testing, and regression analysis. The second and third terms include analysis of variance, estimation, nonparametric inference, sequential analysis, decision theory, and exploratory data analysis. Instructor: Lorden.

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: Kechris.

CS/Ma 117 abc. Computability Theory. *9 units (3-0-6).* For course description, see Computer Science. Not offered 1988–89.

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 noncommutative rings, lattices, and fields. Instructor: Wales.

Ma 121 abc. Combinatorial Analysis. *9 units (3-0-6); first, second, third 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. Instructors: Van Lint, Wilson.

Ma 122 a. Topics in Group Theory. *9 units (3-0-6); third term. Prerequisite: Ma 5 abc or consent of instructor.* 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. Not offered 1988–89.

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. Instructor: Sadun.

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 1988–89.

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: Flaminio, A. Katok.

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. Instructors: Christy, Gabai, Klassen.

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. Instructor: Ramakrishnan.

Ma 191 abc. Lie Groups and Symmetric Spaces. *9 units (3-0-6); first, second, third terms.* Instructor: Kanai.

Ma 191 d. Fuchsian Groups. *9 units (3-0-6); second term.* Instructor: S. Katok.

Other Ma 191 titles may be announced.

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. Instructors: Woodin, Kechris.

Ma 218 abc. Advanced Complex Analysis. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 104 a or Ma 110 a or equivalent.* Topics will be selected from: linear spaces of analytic functions, conformal mapping, algebraic functions, Riemann surfaces, linear and non-linear potential theory, extremal length, functions of several complex variables, approximation in the complex plane and singular integrals. Instructor: Hamenstadt.

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 390. Research. *Units by arrangement.*

Ma 392. Research Conference. *Three terms.*

See also the list of courses in Applied Mathematics.

MECHANICAL ENGINEERING

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: Brennen.

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 mechanical, thermal, solar, and nuclear power generation. Instructors: Acosta, Cass.

ME 70. Engineering Graphics. *4 units (2-2-0); first term.* Fundamental aspects of projective geometry and graphical techniques used by the scientist and engineer as an aid in spatial visualization, communication, and creative design. Emphasis on effective use of freehand sketching, orthographic projections, and basic descriptive geometry solutions helpful in computer-augmented design or graphics systems. Introduction to 3-D geometric modeling using the CADRE facility. Instructors: Staff. Offered every year in the first term.

ME 71 ab. Introduction to Design. *9 units (1-6-2); second and third terms. Prerequisite: ME 70 or instructor's permission.* Introduction to design through a coordinated series of problems and short design projects emphasizing physical concepts. Use of graphical techniques and elementary analysis for rapid engineering approximation in preliminary design. Application of engineering drawing practice and computer-aided design. Selection of materials, standard components, manufacturing methods; function and economics will be considered. Some projects will involve the use of shop tools and instruction in the construction of simple working models. Instructors: Staff.

ME 72. Engineering Design. *9 units (3-4-2); first term. Prerequisites: AM 35 abc 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 graphical communication. Techniques in analysis of engineering systems learned previously will be applied. An engineering design contest will be held and will include the design, fabrication, and operation of a device to compete with similar devices designed by other students. Instructor: Antonsson.

ME 73 ab. Machine Component Design. *9 units (3-4-2); second, third terms. Prerequisites: AM 35 abc or permission of instructor.* Basic machine components including: bearings, seals, shafts, gears, belts, chains, couplings, linkages, and cams. Analysis and synthesis of these devices, as well as their use in the design of larger engineering systems will be examined. The laboratory section makes use of contemporary mechanical hardware to provide students with "hands-on" experience with the components discussed in class. Instructor: Antonsson. Not offered 1988–89.

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 115. Introduction to Kinematics. *9 units (3-0-6). Prerequisites: some understanding of linear algebra.* Introduction to the study of planar, rotational, and spatial motions with applications to mechanism analysis and design. Topics in kinematic analysis will include screw theory, rotational representations (such as quaternions and matrix groups), and dual number theory. These analytical techniques will be applied to the study of mobility in mechanisms and to the synthesis of both closed and open chain mechanisms, such as four bar linkages and robot manipulators. This course is intended to provide the student with tools for solving useful problems while laying a foundation for future study and research in the area of kinematics. Instructor: Burdick.

ME 117. Case Studies in Thermal Systems. *9 units (3-0-6); first term. Prerequisite: ME 22 or equivalent, or permission of instructor.* Case-study approach to the role of heat transfer and fluid flow in design and analysis of engineering systems. Cases for examination are drawn from engineering practice. May include guest lecturers. Not offered 1988–89.

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. Instructor: Hunt.

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 basic measurement techniques and phenomena in 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, and turbomachines. Instructors: Staff.

ME 130 abc. Introduction to Robotics. *9 units (3-2-4); first, second, 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 135 ab. Vehicle Design for Mars Surface Exploration. *9 units (2-0-7); second and third terms.* Design project course supervised in collaboration with personnel of JPL. Purpose: design vehicle(s) suitable for proposed Mars missions to be flown by NASA in the 1990s. Access to JPL facilities and personnel arranged as required. No prerequisites; open only to seniors and graduate students. Instructors: Culick, Burke.

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 generation of the governing differential equations of state can be accomplished readily using the technique of Bond Graph modeling, particularly useful for nonlinear 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.* Fundamentals of computing analysis and problem solving and graphics are brought together with 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 abc. Engineering Two-Phase Flows. *9 units (3-0-6). 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. Not offered 1988–89.

ME 230. Advanced Robotics. *9 units (3-0-6). Prerequisites: ME 130 abc, ME 115, EE/ChE 170 ab, or permission of instructor.* This course will focus on the analysis, design, and control of robotic mechanisms. The topics (which can change with the interests of the class participants) will include redundant manipulators, multi-arm cooperative manipulation, force control, multifingered dextrous manipulation, and walking machines. Class lectures will be divided between a review of analytical techniques that can be applied to the study of these mechanisms, and a survey of current research literature. Coursework will include an independent research/development project chosen by the student. Instructor: Burdick.

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 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 1988–89. Instructor: Britton.

Mu 31. Medieval and Renaissance Music History.* *9 units (3-0-6); first term, alternate years.* Development of Western music from the ancient Greeks through medieval monasteries

*Advanced courses with credit toward the 36-unit Humanities requirement. Other advanced courses receive credit toward the 36-unit H&SS requirement. See page 84.

and cathedrals to the chapels, courts, and countryside of the high Renaissance. Includes listening and discussion of style of representative music. Instructor: Britton.

Mu 32. Music History of the Baroque Era.* *9 units (3-0-6); second term, alternate years.* 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. Instructor: Britton.

Mu 33. Music of the Age of Enlightenment.* *9 units (3-0-6); third term, alternate years.* Music of the so-called "pre-Classic" and "Classic" periods (ca. 1750–1825), with emphasis on C.P.E. Bach, Haydn, Mozart, and the early works of Beethoven. Instructor: Britton.

Mu 34. Music History of the Early Romantics.* *9 units (3-0-6); first term, alternate years.* Examines concepts of Romanticism found in other ages, and a wealth of music from late Beethoven, Schubert, Mendelssohn, Schumann, Chopin, and others to Franz Liszt. Instructor: Britton.

Mu 35. Music History of the Late Romantics.* *9 units (3-0-6); second term, alternate years.* Explores the music of the late-19th century Nationalists as well as the forward-looking works of Liszt, Wagner, Mahler, Strauss, and others. Instructor: Britton.

Mu 36. The New Music: Music History of the 20th Century.* *9 units (3-0-6); third term, alternate years.* 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. Instructor: Britton.

Mu 50. Introduction to the Music of Asia. *9 units (3-0-6), first term.* This course will survey the music and related performance traditions of South, Southeast, and East Asia. Each musical tradition will be discussed, using the techniques of ethnomusicology, history, anthropology, and organology (the study of musical instruments). The cultural significance of musical performances in court, village, tribal, urban, and religious contexts will be explored, based on readings and class lectures. These will be illustrated by recordings, live demonstrations by Asian musicians, and videotapes and films of actual performances. For final reports, students will be encouraged to attend local Asian events involving music. A music background is not required. Instructors: Staff.

Mu 51. Music of East Asia. *9 units (3-0-6), third term.* This course will explore the music and related performance traditions found in China, Mongolia, Japan, and Korea. Ancient sources on music in China will be discussed, followed by a study of the forms of Chinese opera, chamber music, and modern developments during and after the Cultural Revolution. A wide variety of traditional Japanese forms such as Noh, Kabuki, Bunraku, Gagaku, and Sankyoku will lead to a study of contemporary Japanese art music involving indigenous and Western instruments, as well as modern popular forms such as Shigin, and the uses of music in Japanese Buddhist ritual. Readings from Chinese and Japanese literature will enhance the discussions of social and cultural patterns governing musical performance. Tibetan Buddhist ritual music and dance, opera, and folk forms will be explored. No music background required. Instructors: Staff.

Mu 52. Music of Southeast Asia. *9 units (3-0-6).* This course will explore the musical traditions of mainland and insular Southeast Asia: Burma, Thailand, Laos, Cambodia, Vietnam, the hill tribes of the Southeast mainland, Malaysia, the Philippines, and Oceania. The various gong-chime ensembles (such as the gamelan) will be compared and contrasted from musical and

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cultural points of view. The uses of music in conjunction with language will be explored through examples from syncretic theatrical forms involving poetry, puppetry, and dance. The relationship of tonal languages to music will be discussed. The construction of musical instruments, particularly gong-making, will be a focus of the course. No music background required. Instructors: Staff.

Mu 53. 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. Not offered 1988–89. Instructor: Rao.

Mu 101. Selected Topics in Music. *Units to be determined by arrangement with 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. Instructors: Staff.

PA 20 abc. Debate. *3 units (1-0-2); first, second, third terms.* Study and discussion of the annual intercollegiate debate topic. Instructor: Cain.

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. Instructor: Cain.

PA 30 abc. Choral Music. *3 units (0-3-0); first, second, third terms.* Instruction in choral ensembles, such as men's and women's glee clubs. Instructors: Staff.

PA 31 abc. Chamber Music. *3 units (0-3-0); first, second, third terms.* Instruction in performing chamber music. Instructors: Staff.

PA 32 abc. Orchestral Music. *3 units (0-3-0); first, second, third terms.* Instruction related to participation in a symphony orchestra. Instructors: Staff.

PA 33 abc. Instrumental Music. *3 units (0-3-0); 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. Instruction in playing the sitar. Instructor: Rao.

PA 35. Music for Piano Ensemble: History, Analysis, Performance. *9 units (3-0-6); second, third 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. Not offered 1988–89. 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: Staff.

PA 60 abc. Studio Arts. *3 units (0-3-0); first, second, third terms.* Instruction in "hands-on" art—currently sculpture and painting/drawing.

PHILOSOPHY

Courses above Pl 20 are open only to students who have fulfilled the freshman humanities requirements.

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).* Selected current issues involving conflicts about moral right and wrong will be studied, and the various sources of those conflicts investigated. The issues studied will vary but will include some of the following: medical experimentation and the allocation of medical resources; the alleged "right to life," and its bearing upon abortion, capital punishment, and euthanasia; political liberty and the prohibition of certain minority activities under criminal sanctions (e.g., the use and sale of designated drugs, morally offensive publications, prostitution); civil disobedience and conscientious objection; majority and minority rights. If the course is oversubscribed, preference will be given to students who have successfully completed Hum 10 ab. Instructors: Staff.

HSS 99. For course description, see Humanities and Social Sciences.

Pl 102. Selected Topics in Philosophy. *9 units (3-0-6).* Instructors: Staff and visiting lecturers.

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.

*Advanced courses with credit toward the 36-unit Humanities requirement. Other advanced courses receive credit toward the 36-unit H&SS requirement. See page 84.

Pl 181. Democracy.* *9 units (3-0-6).* 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. Instructor: Cain.

Pl 182. Ethics and International Relations.* *9 units (3-0-6).* The course considers whether moral criteria can or should apply to the conduct of international affairs. The topics treated, which will vary with the instructor, include: war and morality; the special problems of nuclear war; disarmament; economic distribution; migration. Instructors: Staff.

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 *Political Economy.* The course will also follow some of the controversies these works have given rise to in the century or so since original publication. Not offered 1988–89.

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 1988–89.

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, Pine. Section leaders: Newman, Raab, Whaling, 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 classical waves, introductory quantum mechanics, thermodynamics, and statistical mechanics. Lecturers: Gomez, Politzer.

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. Instructors: Frautschi, 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. Instructors: Frautschi, 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. Instructors: Frautschi, Gomez.

*Advanced courses with credit toward the 36-unit Humanities requirement. Other advanced courses receive credit toward the 36-unit H&SS requirement. See page 84.

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. Mobility of ions in gases; precise measurement of the value of e/m of the electron. Instructors: Frautschi, 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. Instructors: Frautschi, 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 include: wave mechanics, interpretation of the quantum wave-function, one-dimensional bound states, scattering, and tunneling; thermodynamics, introductory kinetic theory, and quantum statistics. May be taken to fulfill the Institute Ph 2 requirement. Instructors: Filippone, McKeown.

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: Prince.

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.

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: Hitlin.

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 below.

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: Avron.

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 1988–89.

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. Students may register for any particular term or terms.

Ph 103 a. *First term.* Techniques of detection and spectroscopy in modern astronomy for both optical and far-infrared radiation. Instructors: Oke, Phillips.

Ph 103 b. *Second term.* The art of order-of-magnitude estimates using basic physics, with examples from biomechanics, materials, weather, and astrophysics. Instructors: Goldreich, Phinney.

Ph 103 c. *Third term.* Particle physics without accelerators, emphasizing neutrino physics and searches for new particles (e.g., axions), with applications in astrophysics and cosmology. Instructor: Vogel.

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 application of 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 Lagrangian and Hamiltonian formulations of mechanics, small oscillations and normal modes, boundary value problems, multipole expansions and various applications of electromagnetic theory. Instructors: Peck, Phillips.

Ph 118 abc. Electronic Circuits and Their Application to Physical Research. *9 units (3-0-6); first, second, third terms.* Fundamentals of electronics with emphasis on proven techniques of instrumentation for scientific research. Both the physical principles and properties of electronic components and circuits, with emphasis on analog systems. Common electronic instruments, computer interfaces, and typical control logic in scientific research used as examples. Typically given in alternate years. In 1988–89, offered second and third terms. Instructor: Drever.

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, nuclear, and elementary particle 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 1988–89.

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. Instructor: Chiu.

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. Typically one term each of three distinct areas. In 1988–89, condensed matter, elementary particle physics, and nuclear physics. Terms may be taken separately. Instructors: Cross, Schwarz, McKeown.

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. Instructor: Thorne.

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 supervision of an instructor. Approval of instructor and of 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 student's research supervisor and 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 student's research supervisor and departmental adviser or registration representative must be obtained before registering. Graded pass/fail.

Ph 176 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 in modern computer environments, e.g., PCs and concurrent processors. Not offered 1988–89.

CNS/Bi/Ph 185. Collective Computation. *9 units (3-0-6).* For course description, see Computation and Neural Systems.

Ph 203 abc. Nuclear Physics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 98 or Ph 125 or equivalent.* Fundamental structure and properties of nuclei from the nucleon to nuclear matter. Topics for the first two terms include: independent and collective aspects of nuclei; weak, electromagnetic, and hadronic interactions with nuclear systems. The third quarter will mainly treat applications of nuclear physics to astrophysics and will include universal and stellar nucleosynthesis and energy production. Instructor: Barnes.

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. In 1988–89, second and third terms only, with a prerequisite of Ph 135 a or equivalent. Instructor: Cross.

Ph 224 abc. Space Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 98, Ph 106, or equivalent.* Experimental and theoretical aspects of x-ray, cosmic ray, and gamma ray astrophysics, with emphasis on topics of current interest. Analysis of astronomical and technical aspects of the three great space observatories of the near future: the Hubble Space Telescope, AXAF, and SIRTF. Not offered in 1988–89.

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 1988–89.

Ph 229 abc. Advanced Mathematical Methods of Physics. *9 units (3-0-6); first, second, third terms.* Content changes from year to year.

Ph 229 ab. *First, second terms. Prerequisites: AMa 95, Ma 108, or Ph 129.* Novel computational techniques; parallel computer applications in geophysics, astrophysics, and particle physics; cellular automata applied to fluid dynamics; simulated annealing, neural networks, and genetic optimization algorithms; multiscale algorithms and relation to renormalization groups. Instructor: Fox.

Ph 229 c. *Third term. Prerequisite: instructor's permission.* Introduction to Riemann surfaces, with emphasis on topics relevant to string theory. Instructor: Schwarz.

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 emphasis on quantum chromodynamics, quark-gluon theory of strong interactions, including renormalization, confinement, chiral symmetry breaking, anomalies, perturbation theory for high energy, and lattice calculations. 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. Instructors: Porter, Telegdi.

Ph 234 abc. Topics in Theoretical Physics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 205 or equivalent.* In 1988–89, the course covers the standard model for strong, weak, and electromagnetic interactions based on the gauge group SU(3)xSU(2)xU(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's* Classical Mechanics, *or of Leighton's* Principles of Modern Physics. A systematic exposition of Einstein's general theory of relativity, with emphasis on applications to astrophysical and cosmological problems. Not offered in 1988–89.

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 1988–89.

Ph 240 abc. Current Theoretical Problems in Particle Physics. *6 units (2-0-4); first, second, third terms.* 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, the relation of physics to the other sciences, and the general notion of complex adaptive systems. Discussion and argument are encouraged. Graded pass/fail. Undergraduates admitted with permission of instructor. Only offered second term 1988–89. Instructor: Gell-Mann.

Ph 241. Research Conference in Physics. *No credit; first, second, third terms.* Meets weekly for a report and discussion of 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, 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: Neugebauer.

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 research leads directly toward the 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.

POLITICAL SCIENCE

HSS 99. See page 225 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 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 1988–89. 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 apply 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. Instructors: Cain, Wagner.

PS 118. Democratic Theory. *9 units (3-0-6); third 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? 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, Kousser.

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. Instructors: Cain, Kiewiet.

PS 121. Congressional Policy Formation and Legislative Process. *9 units (3-0-6); second term.* Decision making 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. Instructors: Staff.

PS/SS 122. Noncooperative Games in Social Science. *9 units (3-0-6); first term. Prerequisite: PS/SS 12 or equivalent.* Axiomatic structure and behavioral interpretations of game theory models in social science. Axiomatic utility theory and general noncooperative games. Instructor: McKelvey.

PS/SS 123. Cooperation and Social Behavior. *9 units (3-0-6). Prerequisite: PS/SS 122 or consent of instructor.* Game theoretic and evolutionary approaches to modeling various types of cooperative, altruistic, and social behavior. Emphasis on economic and political applications. Instructor: McKelvey.

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. Instructors: Hoffman, Tong.

PS 126. Bureaucratic Politics. *9 units (3-0-6); third 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. Instructors: Staff.

PS 127. Interest Groups in American Politics. *9 units (3-0-6); first term.* Survey of the literature on organized groups. Topics: who joins; internal politics of organizations; 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.* Axiomatic structure and behavioral interpretations of game theoretic and social choice models and models of political processes based on them. Instructors: Staff.

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. Not offered 1988–89. 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 1988–89. 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.* Written report 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 1988–89. 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.

RUSSIAN *(See Languages)*

SOCIAL SCIENCE

AW/SS. Adjunct Writing for Social Sciences. *3 units (2-0-1); first, second, or third terms.* Given in conjunction with certain Social Science courses.

Ec/SS 11. Introduction to Economics. *9 units (3-0-6).* For course description, see Economics.

*Advanced courses with credit toward the 36-unit Humanities requirement. Other advanced courses receive credit toward the 36-unit H&SS requirement. See page 84.

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. Instructor: 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 significant urban problems of contemporary America and alternative policies. Not offered 1988–89. Instructors: Staff.

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. Cooperation and Social Behavior. *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: Lowenstein. *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.

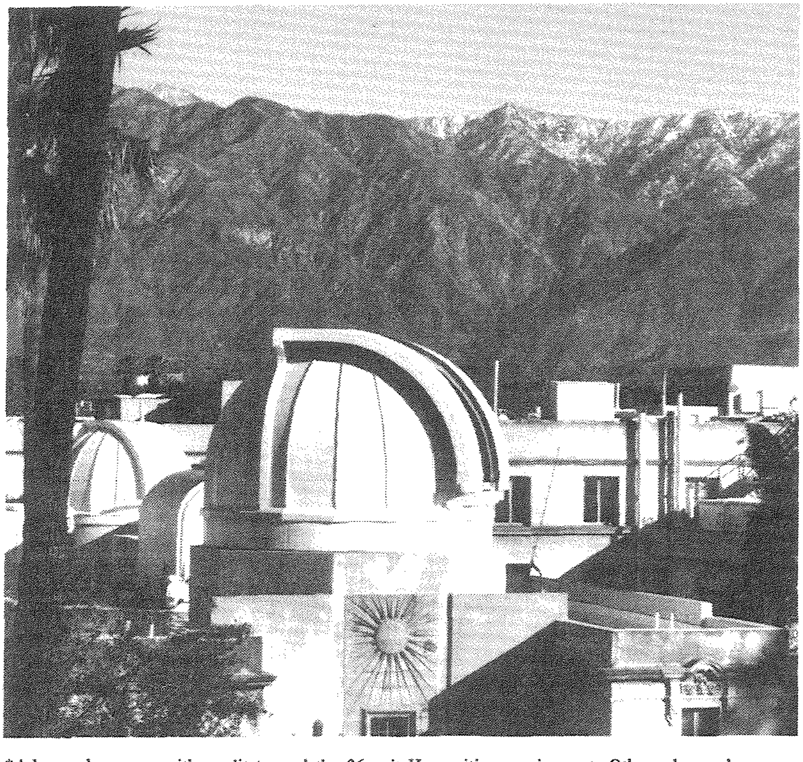
SS 200. Selected Topics in Social Science. *Units to be determined by arrangement with instructors.* Instructors: Staff and visiting lecturers.

SS 201. Game Theory. *9 units (3-0-6); second term. Prerequisite: Ma 112 a or equivalent.* Introduces utility theory, decision theory, and the theory of games, with emphasis on applications of the theory of games of incomplete information to modeling problems in the social sciences. Instructors: Border, Palfrey.

SS 202. Congress and the Executive. *9 units (3-0-6); third term.* Analysis of executive and congressional decision making. Emphasis on theory of committees and bureaucratic theory. Instructor: Kiewiet.

SS 203. American Electoral Processes. *9 units (3-0-6); first term.* An in-depth analysis of American electoral processes with emphasis on the application of new theory and quantitative techniques. Instructor: Kousser.

SS 204. Analytical Political Theory. *9 units (3-0-6); second term.* A survey of theoretical topics in social choice, voting, and electoral competition. Instructor: McKelvey.



*Advanced courses with credit toward the 36-unit Humanities requirement. Other advanced courses receive credit toward the 36-unit H&SS requirement. See page 84.

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, Palfrey, Plott, Wilde.

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: Border, Kim, Plott.

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. Instructors: Border, 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 decision making as well as construction of political economic processes consistent with stipulated ethical postulates, political platform formulation, the theory of political coalitions and decision making in political organizations. Instructors: Ledyard, McKelvey, Ordeshook.

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: Ledyard, McAfee, Palfrey.

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: Satterthwaite, Strnad, 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).* Relationship between 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. Instructors: Staff.

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, Grether.

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: Dubin, Grether.

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. Instructor: 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. Instructors: Cain, Kiewiet.

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.* Instructor: Cain.

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. Instructors: Staff.

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: Staff.

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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Robert R. Gagne, Ph.D.[1]
Chemistry
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Chemical Engineering
Paul C. Groves, B.S.[2]
Chemistry
William J. Kaiser, Ph.D.[1]
Chemistry
Keiko Kanamori, Ph.D.[1]
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Hasuck Kim, Ph.D.
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Pramod M. Lad, Ph.D.[1]
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Ronald R. Lagnado, Ph.D.[1]
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Bruno Lepetit, Ph.D.
Chemistry
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Chemistry
Ken-ichi Machida, D.Eng.
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Kikuo Okuyama, Ph.D.
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Barry D. Olafson, Ph.D.
Chemistry
Stanley H. Pine, Ph.D.[1]
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Lawrence Que, Jr., Ph.D.
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Mary F. Roberts, Ph.D.[2]
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Chemistry
Alfred P. Sattelberger, Ph.D.[2]
Chemistry
Jochem H. Schirmer, Ph.D.
Chemistry
Paul G. Schmidt, Ph.D.
Chemistry
Verner Schomaker, Ph.D.
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Kenneth L. Servis, Ph.D.[1]
Chemistry
C. Hunter Shelden, M.D.[1]
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Theodore B. Smith, Ph.D.
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Franz Stelzer, Ph.D.
Chemistry
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Chemistry
Incoronata Tritto, Ph.D.[2]
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Paolo Ugo, Ph.D.
Chemistry
Joan S. Valentine, Ph.D.
Chemistry
John C. Van Houten, Ph.D.
Chemistry
Wilton E. Vannier, M.D., Ph.D.
Chemistry
Kazunori Watari, Ph.D.
Chemistry
Fritz G. Widmer, Ph.D.
Chemistry

Members of the Professional Staff

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Chemistry
Jane G. Raymond, Ph.D.
Chemistry
James P. Yesinowski, Ph.D.
Chemistry

[1]Part-time
[2]In residence 1987–1988

Division of Engineering and Applied Science

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Norman H. Brooks, *Executive Officer for Environmental Engineering Science*
Hans G. Hornung, *Director of the Graduate Aeronautical Laboratories*
James K. Knowles, *Executive Officer for Civil Engineering and Applied Mechanics*
R. David Middlebrook, *Executive Officer for Electrical Engineering*
Donald S. Cohen, *Executive Officer for Applied Mathematics*

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Theodore von Kármán Professor of Aeronautics
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Engineering
Milton S. Plesset, Ph.D.
Engineering Science
W. Duncan Rannie, Ph.D.
Robert H. Goddard Professor of Jet Propulsion and Professor of Mechanical Engineering
Rolf H. Sabersky, Ph.D.
Mechanical Engineering
Eli Sternberg, Ph.D., D.Sc.
Mechanics
Homer J. Stewart, Ph.D.
Aeronautics
Vito A. Vanoni, Ph.D.
Hydraulics
J. Harold Wayland, Ph.D., D.Sc.
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Engineering Design
Charles H. Wilts, Ph.D.
Electrical Engineering and Applied Physics
David S. Wood, Ph.D.
Materials Science

Professors

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Mechanical Engineering
William B. Bridges, Ph.D.
Carl F Braun Professor of Engineering
Norman H. Brooks, Ph.D.
James Irvine Professor of Environmental and Civil Engineering
Thomas K. Caughey, Ph.D.
Applied Mechanics and Mechanical Engineering

Donald S. Cohen, Ph.D.
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Noel R. Corngold, Ph.D.
Applied Physics
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Mechanical Engineering and Jet Propulsion
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Thomas E. Everhart, Ph.D.
Electrical Engineering and Applied Physics
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Joel N. Franklin, Ph.D.
Applied Mathematics
Roy W. Gould, Ph.D.
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Wilfred D. Iwan, Ph.D.
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Paul C. Jennings, Ph.D.
Civil Engineering and Applied Mechanics
William L. Johnson, Ph.D.
Materials Science
Herbert B. Keller, Ph.D.
Applied Mathematics
Wolfgang G. Knauss, Ph.D.
Aeronautics and Applied Mechanics
James K. Knowles, Ph.D., D.Sc.
Applied Mechanics
Toshi Kubota, Ph.D.
Aeronautics
Anthony Leonard, Ph.D.
Aeronautics
E. John List, Ph.D.
Environmental Engineering Science
Frank E. Marble, Ph.D.
Richard L. and Dorothy M. Hayman Professor of Mechanical Engineering and Professor of Jet Propulsion
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Electrical Engineering
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Fletcher Jones Professor of Applied Physics
Carver A. Mead, Ph.D.
Gordon and Betty Moore Professor of Computer Science
R. David Middlebrook, Ph.D.
Electrical Engineering
James J. Morgan, Ph.D.
Marvin L. Goldberger Professor of Environmental Engineering Science
Marc-Aurele Nicolet, Ph.D.
Electrical Engineering
Wheeler J. North, Ph.D.
Environmental Science
Fredric Raichlen, Sc.D.
Civil Engineering
Anatol Roshko, Ph.D.
Theodore von Kármán Professor of Aeronautics
Philip G. Saffman, Ph.D.
Applied Mathematics
Ronald F. Scott, Sc.D.
Dotty and Dick Hayman Professor of Engineering
Charles L. Seitz, Ph.D.
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Bradford Sturtevant, Ph.D.
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Frederick B. Thompson, Ph.D.
Applied Philosophy and Computer Science
Thad Vreeland, Jr., Ph.D.
Materials Science
Gerald B. Whitham, Ph.D.[1]
Charles Lee Powell Professor of Applied Mathematics
Theodore Y. Wu, Ph.D.
Engineering Science
Amnon Yariv, Ph.D.
Thomas G. Myers Professor of Electrical Engineering and Professor of Applied Physics
Edward E. Zukoski, Ph.D.
Jet Propulsion and Mechanical Engineering

[1]On leave of absence second and third terms 1988–89

Associate Professors

James L. Beck, Ph.D.
Civil Engineering
Paul M. Bellan, Ph.D.
Applied Physics
Glen R. Cass, Ph.D.
Environmental Engineering and Mechanical Engineering
Slobodan M. Cuk, Ph.D.
Electrical Engineering
John C. Doyle, Ph.D.
Electrical Engineering
Rodney M. F. Goodman, Ph.D.
Electrical Engineering
James T. Kajiya, Ph.D.
Computer Science
Mary E. Lidstrom, Ph.D.
Applied Microbiology
Demetri Psaltis, Ph.D.
Electrical Engineering
Ares J. Rosakis, Ph.D.
Aeronautics and Applied Mechanics
David B. Rutledge, Ph.D.
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P.P. Vaidyanathan, Ph.D.
Electrical Engineering

Assistant Professors

Yaser S. Abu-Mostafa, Ph.D.
Electrical Engineering and Computer Science
Erik K. Antonsson, Ph.D.
Mechanical Engineering
Harry A. Atwater, Ph.D.
Applied Physics
Alan H. Barr, Ph.D.
Computer Science
Joel W. Burdick, Ph.D.
Mechanical Engineering
Brent Fultz, Ph.D.
Materials Science
David G. Goodwin, Ph.D.
Mechanical Engineering
John F. Hall, Ph.D.
Civil Engineering
Melany L. Hunt, Ph.D.
Mechanical Engineering
Christof Koch, Ph.D.
Computation and Neural Systems
Jens Lorenz, Dr.rer.nat., Habil.
Applied Mathematics
Daniel I. Meiron, Sc.D.
Applied Mathematics
Athanasios Sideris, Ph.D.
Electrical Engineering
Kerry J. Vahala, Ph.D.
Applied Physics
Stephen R. Wiggins, Ph.D.
Applied Mechanics

Instructor

Eric F. Van de Velde, Ph.D.[1]
Applied Mathematics

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Ronald F. Ayres, Ph.D.
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James Boyk, M.F.A.
Electrical Engineering/Music
James B. Breckinridge, Ph.D.
Applied Physics
Charles Elachi, Ph.D.
Electrical Engineering
Glen A. George, M.S.
Applied Science
Ilias Kastanas, Ph.D.
Applied Science
Taras Kiceniuk, M.S.
Mechanical Engineering

[1] von Kármán Instructor
[2] In residence 1987–88

David H. Lewis, Jr., Ph.D.
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Thomas R. McDonough, Ph.D.
Engineering
Frank J. Mullin, Ph.D.
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Steven J. Ostro, Ph.D.
Electrical Engineering
Charles B. Ray, M.S.
Computer Science
Edgar H. Satorius, Ph.D.
Electrical Engineering
Laif Swanson, Ph.D.
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Jeffrey W. Yu, Ph.D.
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Senior Research Fellows

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Peggy Jean Arps, Ph.D.
Environmental Engineering Science
Alan A. DiSpirito, Ph.D.
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Kai-Wei Nieh, Ph.D.
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Electrical Engineering
Dimitri Papamoschou, Ph.D.
Aeronautics
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Aeronautics

[1]Also Part-time Lecturer in Materials Science, 1987–88
[2]In residence 1987–88
[3]Also Part-time Lecturer in Aeronautics, 1987–88
[4]Chaim Weizmann Research Fellow
[5]IBM Research Fellow
[6]Also Part-time Lecturer in Electrical Engineering, 1987–88

Safiali Rouhi, Ph.D.
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Kemin Zhou, Ph.D.
Electrical Engineering

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James B. Rice, Ph.D.
Applied Mechanics and Applied Science

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Martin Rem, Ph.D.
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Colleen M. Cavanaugh, Ph.D.[2]
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Applied Physics
Chen-Chih Chu, Ph.D.
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Bruce M. Clemens, Ph.D.
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Bruno Crosignani, Lib.Doc.[2]
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Pierre Desre, These d'Etat[2]
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Steven J. Eisenreich, Ph.D.[2]
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Steven A. Gabriel
Computer Science
Philip M. Gschwend, Ph.D.[2]
Environmental Engineering Science
Chris Heegard, Ph.D.[2]
Electrical Engineering
Andrew T. Hunter, Ph.D.
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[1]Chaim Weizmann Research Fellow
[2]In residence 1987–88
[3]Also Part-time Lecturer in Mechanical Engineering, 1987–88

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Kimitaka Kawaguchi, B.S.E.E.[1]
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Yong Jig Kim, Ph.D.
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Tor Sverre Lande, M.Sc.
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Paulett C. Liewer, Ph.D.
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Sami F. Masri, Ph.D.
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Kazumasa Mitsunaga, Ph.D.[1]
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Hadis Morkoc, Ph.D.
Applied Physics
Ramarathnam Narasimhan, Ph.D.[1]
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Paul Pietrokowsky, Ph.D.
Materials Science
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Ricardo B. Schwarz, Ph.D.
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Vibeke Sorensen, M.A.H.
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Jawahar L. Tandon, Ph.D.
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John E. Tanner, Ph.D.
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Naresh Thadhani, Ph.D.
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John Wawrzynek, Ph.D.[1]
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Zhi Yuan Wu, B.S.E.E.[1]
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Stanley H. Bacon
Senior Engineer
James E. Broadwell, Ph.D.
Senior Scientist
Jonathan D. Melvin, Ph.D.
Senior Scientist
George T. Yates, Ph.D.
Senior Scientist

Division of Geological and Planetary Sciences

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Andrew P. Ingersoll, *Executive Officer for Planetary Science*
Hugh P. Taylor, *Executive Officer for Geology*
G. J. Wasserburg, *Executive Officer for Geochemistry*
Don L. Anderson, *Director, Seismological Laboratory*

[1]In residence 1987–88

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Paleoecology

Robert P. Sharp, Ph.D.
Robert P. Sharp Professor of Geology

Professors

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Arden L. Albee, Ph.D.
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Clarence R. Allen, Ph.D.
Geology and Geophysics
Don L. Anderson, Ph.D.
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Samuel Epstein, Ph.D., D.Sc., LL.D.
William E. Leonhard Professor of Geology
Peter Goldreich, Ph.D.
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David G. Harkrider, Ph.D.
Geophysics
Donald V. Helmberger, Ph.D.
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Andrew P. Ingersoll, Ph.D.
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Hiroo Kanamori, Ph.D.
Geophysics
Duane O. Muhleman, Ph.D.
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Jason B. Saleeby, Ph.D.
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Kerry E. Sieh, Ph.D.
Geology
Leon T. Silver, Ph.D.
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David J. Stevenson, Ph.D.
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Edward M. Stolper, Ph.D.
Geology
Hugh P. Taylor, Jr., Ph.D.
Robert P. Sharp Professor of Geology
G. J. Wasserburg, Ph.D., D.h.c., Sc.D.,
Crafoord Laureate
John D. MacArthur Professor of Geology and Geophysics
James A. Westphal, B.S.
Planetary Science
Peter J. Wyllie, Ph.D., D.Sc.
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Yuk L. Yung, Ph.D.
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Clair C. Patterson, Ph.D., D.Sc.
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Roger E. Bumgarner
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Spencer J. Cotkin, Ph.D.
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Patrick Dobson, Ph.D.
Geochemistry
Bjorn Gunnarsson, Ph.D.
Geology
Michael Gurnis, Ph.D.
Geophysics
Neil Humphrey, Ph.D.
Geophysics
Eric James, Ph.D.
Geology
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Dr. Chaim Weizmann Postdoctoral Fellow in Geology/Geophysics
Louise H. Kellogg
Bantrell Postdoctoral Fellow in Geochemistry/Geophysics
Glen Mattioli, Ph.D.
Dr. Chaim Weizmann Postdoctoral Fellow in Geochemistry
M. Meghan Miller
Postdoctoral Fellow in Geology
Jean-Paul Montagner, Doctorat d'Etat
Geophysics
Alain Prinzhofer, D.Sc.
Texaco Postdoctoral Fellow in Geochemistry
Allan Rubin, Ph.D.
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Henrik Skogby, Ph.D.
Geochemistry
Mordechai Stein, Ph.D.
Geochemistry
John Stone, Ph.D.
Texaco Postdoctoral Fellow in Geochemistry
Sieger R. van der Laan, Ph.D.
Experimental Petrology
Mark R. Wilson, Ph.D.
Geochemistry

Sherman Fairchild Distinguished Scholar

R. Keith O'Nions
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Robert H. Brown, Ph.D.
Planetary Science
Wesley T. Huntress, Ph.D.
Planetary Science
Philip D. Nicholson, Ph.D.
Planetary Science
John Suppe, Ph.D.
Geology

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Jay Banner, Ph.D.
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Jay Bass, Ph.D.
Geophysics
David Crisp, Ph.D.
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Michael J. DeNiro, Ph.D.
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Renata Dmowska, Ph.D.
Geophysics
Jonathon E. Ericson, Ph.D.
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Arthur Russell Flegal, Ph.D.
Geochemistry
Stephen H. Hartzell, Ph.D.
Geophysics
Thomas H. Heaton, Ph.D.
Geophysics
Lucile M. Jones, Ph.D.
Geophysics
Michael Malin, Ph.D.
Planetary Science

Yoshitsugu Nakagawa, D.Sc.
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John D. O'Keefe, Ph.D.
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Igor Ryabchikov, D.Sc.
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Kenji Satake, Ph.D.
Geophysics
David R. Scott, Ph.D.
Planetary Science
Hua Tan, Ph.D.
Geophysics
James Tyburczy, Ph.D.
Geophysics
John E. Vidale, Ph.D.
Geophysics
Ray J. Weldon, Ph.D.
Geology
Dorothy S. Woolum, Ph.D.
Geochemistry

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Glenn L. Berge, Ph.D.
Planetary Science
James H. Chen, Ph.D.
Geochemistry
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

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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
Robert W. Oliver, Ph.D.
Economics
Hallett D. Smith, Ph.D., L.H.D.
English
Alan R. Sweezy, Ph.D.
Economics

Associate Professors Emeriti

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History
Robert D. Wayne, M.A.
German

Lecturer Emeritus

Charles Newton, Ph.B.
English

Professors

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Psychoanalytic Studies
Ronald Bush, Ph.D.
Literature
Bruce E. Cain, Ph.D.
Political Science
Lance E. Davis, Ph.D.
Mary Stillman Harkness Professor of Social Science
Alan Donagan, B.Phil.
Philosophy
Peter W. Fay, Ph.D.[1]
History
David M. Grether, Ph.D.
Economics
Daniel J. Kevles, Ph.D.
J. O. and Juliette Koepfli Professor of the Humanities
J. Morgan Kousser, Ph.D.
History and Social Science
Jenijoy La Belle, Ph.D.
Literature
John O. Ledyard, Ph.D.
Economics and Social Sciences
Oscar Mandel, Ph.D.
Literature
Richard D. McKelvey, Ph.D.
Political Science
Edwin S. Munger, Ph.D.
Geography
Peter C. Ordeshook, Ph.D.
Political Science
Thomas R. Palfrey, Ph.D.
Economics and Political Science
Charles R. Plott, Ph.D.
Edward S. Harkness Professor of Economics and Political Science
Martin Ridge, Ph.D.[2]
History
Robert A. Rosenstone, Ph.D.
History
Thayer Scudder, Ph.D.
Anthropology
Eleanor M. Searle, D.M.S.
Edie and Lew Wasserman Professor of History
Annette J. Smith, Ph.D.
French
David R. Smith, Ph.D.
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

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Economics
Stuart A. Ende, Ph.D.
Literature
Philip T. Hoffman, Ph.D.
History and Social Science
D. Roderick Kiewiet, Ph.D.
Political Science
James Lee, Ph.D.
History
George W. Pigman III, Ph.D.
Literature
James F. Strnad II, Ph.D.[2]
Law and Economics
James F. Woodward, Ph.D.
Philosophy

Assistant Professors

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History
Taesung Kim, Ph.D.
Economics
Lawrence S. Rothenberg, Ph.D.
Political Science

[1]Leave of absence 1988–89
[2]Part-time

Caltech-Huntington Library Instructor

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Mellon Postdoctoral Instructors

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History
Scott Hamilton, Ph.D.
Literature
Lee Rowen, Ph.D.
Philosophy

Instructors

Leonard J. Moore, Ph.D.
History
Anthony Zielonka, Ph.D.
French

Lecturers

Andreas Aebi, Ph.D.
German
Shelley Bennett, Ph.D.
Art History
David J. Britton, D.M.A.
Music
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Education
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[1]Leave of absence 1988–89

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Astronomy
Stephen M. Schindler, Ph.D.
Physics
Stephen L. Scott, Ph.D.
Radio Astronomy

[1]Part-time

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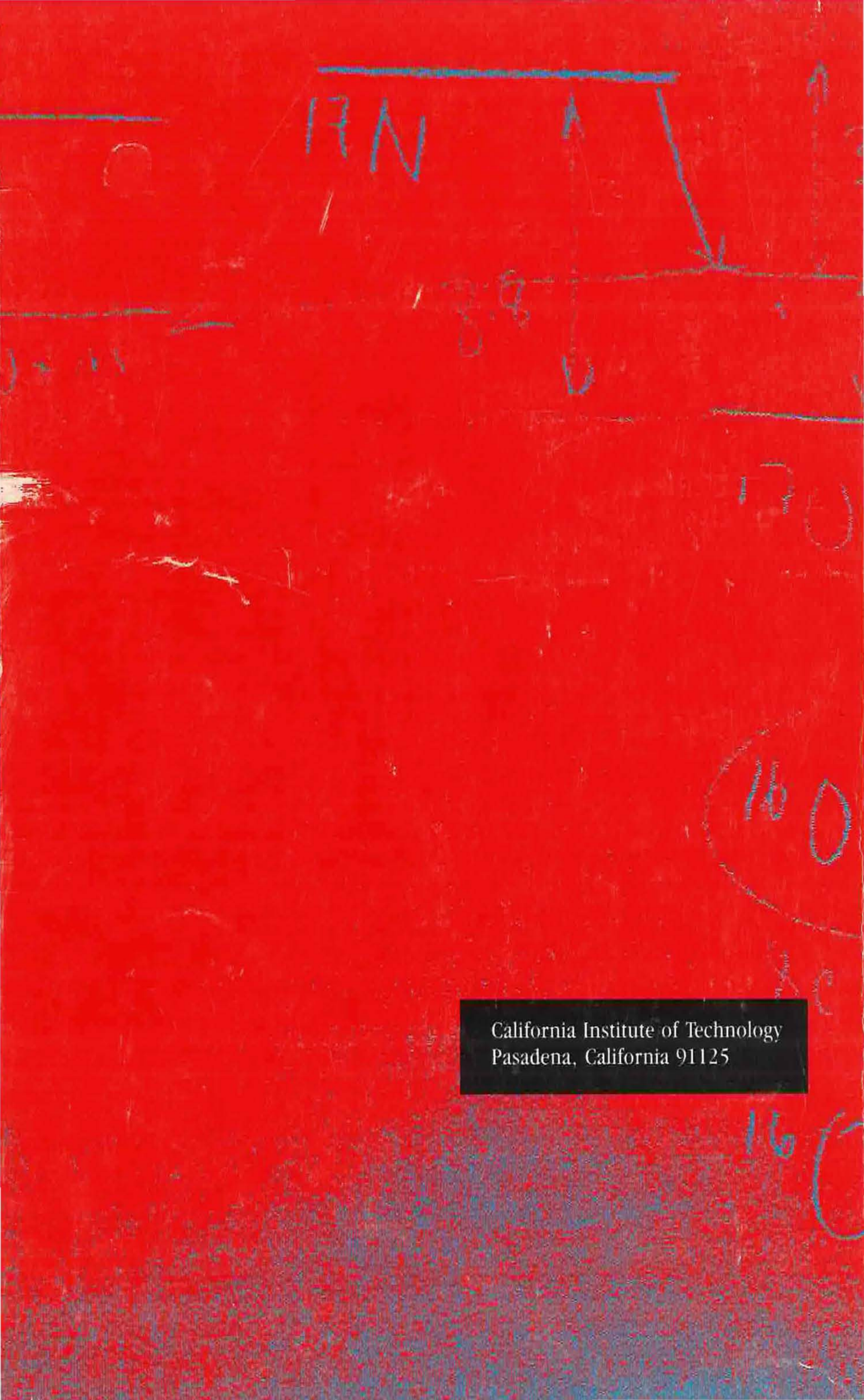

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