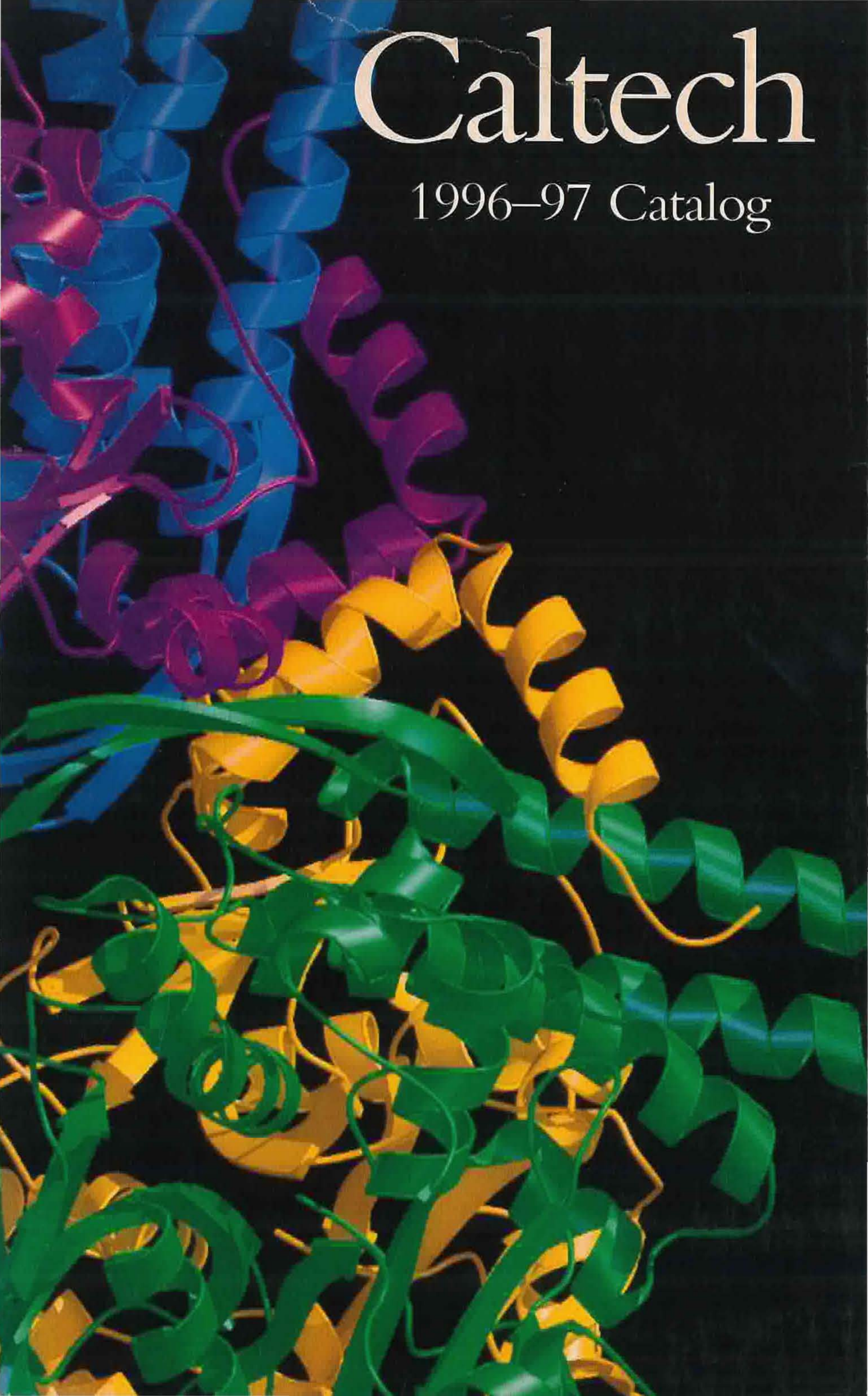
Caltech

1996–97 Catalog



1996–97

Caltech Catalog

California Institute of Technology
Pasadena, California 91125
818/395-6811

September 1996

On the cover:
The structure of Gal6, a protein found in organisms ranging from bacteria to humans—this version is from yeast. The protein consists of six identical subunits, each of which is shown in a different color. Gal6 is a protease—an enzyme that breaks down other proteins. The human form of Gal6 is named bleomycin hydrolase, because it can break down the anticancer drug bleomycin. (Its "real" target protein in the cellular machinery is unknown.) Tumor cells gain resistance to bleomycin by making increased levels of this enzyme. The structure of Gal6 may help in the design of inhibitors of bleomycin hydrolase that could overcome tumor cell resistance to bleomycin.
L. Joshua-Tor, S.A. Johnston, D.C. Rees

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Information for Graduate Students

Courses

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FIRST TERM 1996

September 24
Registration of new students: graduate students—8:30 a.m.–noon; undergraduate students—1:00–4:00 p.m.

September 25–27
New-Student Orientation for Undergraduates

September 26
New-Student Orientation for Graduates—2:30–4:00 p.m.
Graduate Welcome and Information Fair—4:00–7:00 p.m.

September 30
Beginning of instruction—8:00 a.m.
Undergraduate Academic Standards and Honors Committee—9:00 a.m.

October 18
Last day for adding courses and removing conditions and incompletes

October 30–November 5
Midterm examination period

November 11
Midterm deficiency notices due—9:00 a.m.
Last day for admission to candidacy for the degrees of Master of Science and Engineer

November 20
Last day for dropping courses and changing sections

November 25–December 6
Mail registration for undergraduate students, second term, 1996–97
Mail registration for graduate students, second term, 1996–97

November 28–29
Thanksgiving holidays

November 28–December 1
Thanksgiving recess

December 6
Last day of classes

December 7–10
Study period

December 11–13*
Final examinations, first term, 1996–97

**First due date for final examinations*

December 13
Last day for undergraduate and graduate students to register for second term, 1996–97, without a $50 late fee

December 14
End of first term, 1996–97

December 15–January 5
Winter recess

December 16
Instructors' final grade reports due—9:00 a.m.

December 23–25
Christmas holidays

January 1
New Year's holiday

SECOND TERM 1997

January 6
Beginning of instruction—8:00 a.m.
Undergraduate Academic Standards and Honors Committee—9:00 a.m.

January 24
Last day for adding courses and removing conditions and incompletes

February 5–11
Midterm examination period

February 17
Midterm deficiency notices due—9:00 a.m.

February 24–March 7
Mail registration for undergraduate students, third term, 1996–97
Mail registration for graduate students, third term, 1996–97

February 24
Instructional Recess Day—classes do not meet

February 26
Last day for dropping courses and changing sections

March 12
Last day of classes

March 13–16
Study period

March 14
Last day for undergraduate and graduate students to register for third term, 1996–97, without a $50 late fee

March 17–19*
Final examinations, second term, 1996–97

March 19
Last day for obtaining admission to candidacy for the degree of Doctor of Philosophy

March 20
End of second term, 1996–97

March 21–31
Spring recess

March 24
Instructors' final grade reports due—9:00 a.m.

THIRD TERM 1997

April 1
Beginning of instruction—8:00 a.m.
Undergraduate Academic Standards and Honors Committee—9:00 a.m.

April 21
Last day for adding courses and removing conditions and incompletes

April 30–May 6
Midterm examination period

May 12
Midterm deficiency notices due—9:00 a.m.

May 19–30
Mail registration for undergraduate students, first term, 1997–98
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May 21
Last day for dropping courses and changing sections

May 26
Memorial Day holiday

May 30
Last day for presenting theses for the degrees of Doctor of Philosophy and Engineer
Last day of classes—seniors and graduate students

May 31–June 3
Study period for seniors and graduate students

June 4–6*
Final examinations for seniors and graduate students, third term, 1996–97

**First due date for final examinations*

June 6
Last day of classes—undergraduates
Last day for undergraduate and graduate students to register for first term, 1997–98, without a $50 late fee

June 7–10
Study period for undergraduates

June 9
Instructors' final grade reports due for seniors and graduate students—9:00 a.m.

June 11–13*
Final examinations for undergraduates, third term, 1996–97

June 11
Undergraduate Academic Standards and Honors Committee—9:00 a.m.
Curriculum Committee—10:00 a.m.
Faculty meeting—2:00 p.m.

June 13
Commencement—10:00 a.m.

June 14
End of third term, 1996-97

June 16
Instructors' final grade reports for undergraduates due—9:00 a.m.

June 25
Undergraduate Academic Standards and Honors Committee—9:00 a.m.

July 3–4
Independence Day holidays

September 1
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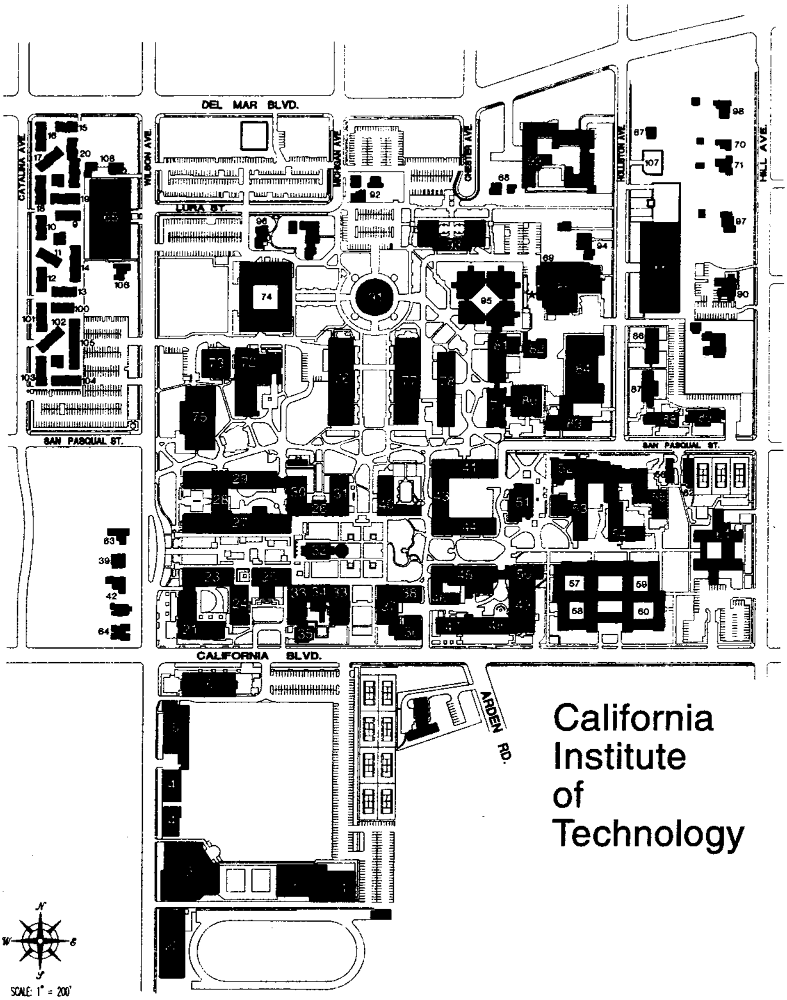
FIRST TERM 1997–98

September 23
Registration of new students: graduate students—8:30 a.m.–noon; undergraduate students—1:00–4:00 p.m.

September 25
New-Student Orientation for Graduates—2:30–4:00 p.m.
Graduate Welcome and Information Fair—4:00–7:00 p.m.

September 24–26
New-Student Orientation for Undergraduates

September 29
Beginning of instruction—8:00 a.m.
Undergraduate Academic Standards and Honors Committee—9:00 a.m.



California Institute of Technology

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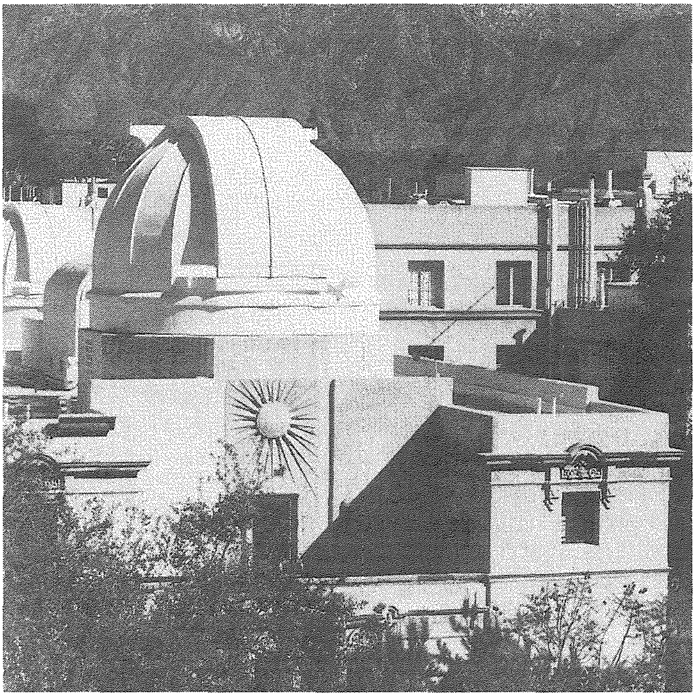
Section One

General Information



INTRODUCTION

The California Institute of Technology is an independent, privately supported university, whose educational mission has not changed since it was stated by the original trustees on November 29, 1921: "To train the creative type of scientist or engineer urgently needed in our educational, governmental, and industrial development."

Its mission in research was expressed by President Thomas E. Everhart in his 1988 inaugural address: "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."

Caltech conducts instruction at both the undergraduate and graduate levels and, including its off-campus facilities, is one of the world's major research institutions. Its mission to train creative scientists and engineers is achieved by conducting instruction in an atmosphere of research, accomplished by the close contacts between a relatively small group of students (approximately 900 undergraduate and 1,100 graduate students) and the members of a relatively large research staff (approximately 1,000 faculty members). "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. It is accredited by the Accrediting Commission for Senior Colleges and Universities of the Western Association of Schools and Colleges.

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; literature; mathematics; physics; planetary science; science, ethics, and society; 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, which are 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

Graduate students constitute approximately 55 percent of the total student body at Caltech. 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.

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 humankind, 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, biochemistry, biology, chemical engineering, chemistry, civil engineering, computation and neural systems, computer science, control and dynamical systems, electrical engineering, engineering science, environmental engineering science, geological and planetary sciences, materials science, mathematics, mechanical engineering, physics, and social science.

Postdoctoral and Senior Postdoctoral Scholars

Postdoctoral scholars form a vital part of the research community at Caltech and JPL. They advance knowledge by their research in science, technology, and scholarship; add to their own experience and education; and contribute to the education of Caltech undergraduates and graduate students. Postdoctoral scholars always work under the close supervision of one or more Caltech professorial faculty members. They must have an earned doctorate from a duly accredited institution in virtually all circumstances. Upon arrival at the Institute, postdoctoral scholars should check in immediately at the Faculty and Postdoctoral Scholars Office in Parsons-Gates.

HISTORICAL SKETCH

The California Institute of Technology developed from a local school of arts and crafts founded in Pasadena in 1891 by the Honorable Amos G. Throop. Initially named Throop University, it was later renamed Throop Polytechnic Institute. Known as the California Institute of Technology since 1920, it has enjoyed the support of the citizens of Pasadena, and as early as 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 discontinue the elementary school, the business school, the teacher-training program, and the high school, leaving only a college of science and 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 the kind of cultural scientific training that will make him and his fellows the matrix out of which you can occasionally develop a man like your great astronomer, George Ellery Hale."

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 from 1913 to 1919 as professor of general chemistry and as research associate; then, in 1919, 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 nine 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 900 undergraduates, 1,100 graduate students, and 1,000 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.

That 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 the 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 nonprofit 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 developed the first U.S. satellite, Explorer I, which was launched in 1958, and managed the Ranger, Surveyor, Mariner, Viking, and Voyager programs of lunar and planetary exploration for NASA, as well as Galileo, which is now orbiting Jupiter. The Infrared Astronomical Satellite (IRAS) provided a wealth of data on the infrared sky. The Laboratory also operates NASA's 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 the Institute added to its faculty several economists and political scientists who initiated theoretical and applied studies of interdisciplinary issues. 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 had 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 had received his B.S. at the 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 prestige, it has attracted a steady flow of gifts for buildings, endowment, and current operations. In addition, substantial grants and contracts from the federal government and private sources support many research activities.

Today Caltech has more than 19,000 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 N. 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
* Rudolph A. Marcus	chemistry	1992
* Edward B. Lewis, Ph.D. '42	physiology or medicine	1995

Caltech Crafoord Laureates

* Gerald J. Wasserburg	geochemistry	1986
Allan R. Sandage, Ph.D. '53	astronomy	1991
* Seymour Benzer	biosciences	1993

* *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 chair 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 chair, 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 chair, 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. He has been a member of the Board of Trustees since 1953, was chair of the Board from 1964 to 1974, and is now chair 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 chair of the Executive Council of the Institute, 1921–1945.

Arthur Amos 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 chair 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 chair 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., was 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. Various members of the Braun family have served on Caltech's 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. Renamed the **David W. Morrisroe Astroscience Laboratory,** 1995. Second-floor addition built with funds provided by Dr. Arnold O. Beckman, chair emeritus of the Board of Trustees.

Beckman Institute, 1989. Built with funds provided by the Arnold and Mabel Beckman Foundation and other private donors. Dr. Arnold O. Beckman is chair emeritus of the Board of Trustees.

Braun Athletic Center, 1992. Built with funds provided by the Braun family.

Parking Structure/Satellite Utility Plant, 1993.

The Gordon and Betty Moore Laboratory of Engineering, 1996. Built with funds provided by Dr. and Mrs. Gordon Moore. Dr. Moore is chair of the Board of Trustees.

Avery House, construction to be completed in 1996. Built with funds provided by Mr. R. Stanton Avery. Mr. Avery is chair emeritus of the Board of Trustees.

Sherman Fairchild Library of Engineering and Applied Science, dedication scheduled for January 1997. Built with funds provided by The Sherman Fairchild Foundation.

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.

W. M. Keck Observatory, Keck I–1991, Keck II–1996; Mauna Kea, Hawaii. Built with funds provided by the W. M. Keck Foundation. Site of two 10-meter Keck Telescopes.

Georgina and William Gimbel Building, Caltech Submillimeter Observatory, 1996. Built with funds provided by Mr. and Mrs. William Gimbel, members of the Associates.

Libraries

The Caltech Library System provides library resources and forward-looking information services of the highest quality in a timely, cost-effective manner to support and facilitate the research and educational programs of the Institute. The library system comprises the main collection in the Millikan Memorial; departmental libraries for astrophysics, geology, and public affairs; a management library in the Industrial Research Center; and the Sherman Fairchild Library of Engineering and Applied Science, due to open in January 1997. Collectively, the libraries subscribe to 3,338 journals, contain 536,913 volumes, and have extensive collections of technical reports, government documents, and maps.

The main library in the Robert A. Millikan Memorial includes the collections for biology, chemistry, mathematics, physics, and the humanities and social sciences. Circulation and reference services are on the first floor; microfilm and government documents collections are on the fifth floor, and photocopy service is in the basement. This 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 electronic catalog includes the records of books and journals held throughout the Caltech Library System. Also available on-line are the recent citations to articles in approximately 2,000 science and technology journals. Other special services that are available through the Caltech Libraries include computerized literature searches, document delivery, and interlibrary loans.

Beckman Institute

Opening its doors in 1990, the Beckman Institute represented a major new addition to Caltech. The mission of the scientists working there is to invent new methods, new materials, and new instrumentation for fundamental research in biology and chemistry. Their results will open the way for new applications of scientific discoveries to human needs.

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, consulting, and supplies.

The CCO supports educational computing. This support includes obtaining appropriate hardware and software and a large number of personal computers for student use, and assisting in the development of effective use of computers in the educational process. UNIX workstations, including a cluster of SUN computers, are available at no charge for student use.

The CCO manages and maintains CITnet, Caltech's campuswide local area network. This activity includes the support of high-speed connections to local, regional, national, and international networks, the development of shared network resources, and the maintenance of a campus electronic mail system and the Caltech World Wide Web "Home Page."

Four general-use microcomputer labs are available for the campus community. Computers from INTEL, APPLE, SUN, and NeXT are currently supported, as are color printers, scanners, and other peripherals. Each on-campus student house also has a computer lab that is maintained by students employed part time by the CCO.

The CCO's Media Integration Lab provides specialized tools and equipment for working with digital media and for producing multimedia products and presentations.

The CCO makes its documentation (newsletters, reference guides, and quick-reference sheets) available on the World Wide Web; the "URL" is: http://www.cco.caltech.edu/cco/ccohome.html

Industrial Relations Center

The Industrial Relations Center develops and offers programs on linking emerging technologies with management strategies and practices, improving the effectiveness of business operations, developing the leadership skills of technical professionals, and encouraging new business ventures. Courses and forums are presented on campus and are open to executives and managers in technology-based organizations, and 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 South Hill Avenue. The latest calendar of programs or more information may be obtained by calling extension 4041.

UNDERGRADUATE RESEARCH

The Institute provides three principal avenues for undergraduate research: the Summer Undergraduate Research Fellowships (SURF) program, research courses for academic credit and senior theses, and research for pay under a faculty member's grant or contract. Students may combine these options, but they may not receive both pay and credit at the same time for the same piece of work. Students registering for a research course during the summer do not have to pay tuition.

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 and awards granted by the members of the SURF administrative committee. The work is carried out during a ten-week period in the summer. Students may attend weekly seminars presented by members of the Caltech faculty and JPL technical staff and may participate in luncheon roundtable discussions with leaders in business, government, or academia. Students may also take part in 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, methods, and results of their work. On the third Saturday of 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 1996, SURF students were paid $3,600. Applications are available in January and are due in early March. Awards are announced in early April. To be eligible, students must be continuing undergraduates and have a cumulative GPA of at least 2.0. Students must complete the third quarter at Caltech (or at another school under a program approved by a dean). Students must be eligible for fall term registration as of the end of the June Undergraduate Academic Standards and Honors Committee (UASH) reinstatement meeting and must not be on medical leave or under disciplinary sanction. For further information regarding this program, contact the SURF Office, Room 137 Beckman Institute, (818) 395-2886, surf@starbase1.caltech.edu.

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 the Director of Residence Life.

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 of 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 mailboxes. Students should use their mailbox number, California Institute of Technology, Pasadena, CA 91126, to facilitate handling of mail at the campus post office.

Avery House

Made possible by a gift from trustee R. Stanton Avery, this innovative residential complex was designed by Moore, Ruble, Yudell and completed in September of 1996. Located at the north end of the campus, Avery House has rooms for about 100 undergraduates and 35 graduate students, in addition to four faculty apartments and a visitor's apartment. Its dining facilities, meeting rooms, lounges, and library are designed to encourage informal faculty–student interaction and to attract all members of the campus community to join in this interaction. Avery House hosts a regular series of lectures, performances, and social events open to the campus, and the house invites distinguished visitors to be in residence for varying lengths of time.

The Student Activities Center

The SAC is located in the basement of the south undergraduate housing complex and is open for student use 24 hours a day. Whether you are interested in music, art, publications, student government, gaming, photography, Ping-Pong, or simply finding a room for your group to meet in, the SAC will probably have what you need. The center also houses the South House Laundry Room, and has several study halls, a small library, a bike shop, an arcade, and a TV/VCR room—most are open 24 hours. The center also includes a coffeehouse. The SAC is open to all current members of the Caltech and JPL communities, though first priority is given to undergraduate and graduate students.

The SAC provides office space for the officers of the graduate and undergraduate student governments, working space for student publications, office and rehearsal space for musical activities, and space for many more student-oriented functions. It also offers an array of services to the community, including SAC and Winnett room reservations, and club mailbox distribution. The staff is also able to assist students who need help planning a program or coordinating a new club.

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 are 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 and 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 NCAA Division III and the Southern California Intercollegiate Athletic Conference, intercollegiate competition is carried out in nine men's sports and five women's sports with teams such as Claremont-Mudd-Scripps, LaVerne, Occidental, Pomona-Pitzer, Cal Lutheran, Redlands, and Whittier. Individual athletes and teams who distinguish themselves in conference competition earn the privilege of participating in NCAA regional and national championships.

Caltech also sponsors vigorous programs of club sports and intramural competition. Club sports include football, ultimate Frisbee, ice hockey, and women's soccer. Intramural competition consists of residence house teams battling for championships (and bragging rights) in flag football, soccer, swimming, ultimate Frisbee, basketball, volleyball, tennis, track and field, and softball. A full 33 percent of Caltech undergraduates participate in intercollegiate athletics, and over 80 percent participate in some form of organized athletic competition each year.

Outdoor athletic facilities include a football field, an all-weather running track, a soccer field, baseball and softball diamonds, eight tennis courts, and two 25-yard swimming pools. Indoor facilities include two full-size gymnasia for basketball, volleyball, badminton, and gymnastics; four racquetball courts; two squash courts; a 4,000-square-foot weight room; and a large multipurpose room for dance/aerobics, fencing, and martial arts. In addition, Caltech owns six Flying Junior sailboats that serve both instructional and competitive interests.

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 student 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 shop and the Students for the Exploration and Development of Space (SEDS).

The student government is active in campus affairs. The student members of each standing faculty committee ensure that undergraduate opinion is considered seriously. Excellent informal relations between students and faculty and between students and administration promote mutual concern and goodwill. Student-faculty conferences are held from time to time, 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, the American Society of Mechanical Engineers, and the Society of Women 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 Physical Plant complex. 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 the 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, business, and leadership activities.

Pluralistic and nonsectarian, 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 trips and backpacking adventures, subsidizes theater and sports tickets, administers the annual $3,000 Studenski travel award, has a copy machine and a TV/VCR, provides free outdoor campus concerts, runs a used-textbook exchange and the lost and found, provides a meeting room for campus organizations, rents camping equipment, sponsors guest speakers of national fame and local significance, plans many social and recreational activities, supports campus and community services, and coordinates the annual Leadership Institute. The Y offers a friendly atmosphere and a free cup of coffee with no membership lists, no fees, and no catches.

Ombudsperson

The Ombudsperson provides informal assistance in resolving intracampus conflicts, disputes, and grievances and promotes fair and equitable treatment within the Institute. Any member of the Caltech community (students, faculty, and staff) may receive confidential and independent assistance from the Ombuds Office.

Religious Life

In addition to several groups active on campus such as the Caltech Christian Fellowship, the Newman Club, and Hillel, houses of worship 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. Tickets, often with discounts available, are offered to Caltech students for all events in Beckman and Ramo Auditoriums. Under the auspices of the Office of Public Events are a ticket agency (handling tickets for Caltech 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 provides the following services for undergraduate and graduate students: (1) office consultation and treatment of most medical problems by physicians and nurse practitioners, physician visits by appointment only and at prescribed hours; (2) laboratory tests, X rays, and consultations as ordered by the medical staff; (3) routine medications, prescription drugs, and other supplies at cost; (4) dermatology and orthopedic clinic visits, which are available on a weekly and bimonthly basis and are by appointment only.

Staff and faculty are seen at the Health Center for on-the-job injuries only.

Student Counseling Service

A staff of mental health professionals provides individual, group, and crisis counseling to undergraduates and graduates at no cost. Students are seen at the center with various concerns, such as depression, stress, grief, relationship difficulties, and self-esteem issues, among others. The center also offers workshops and training on psychologically related topics, a substance-abuse prevention program, psychiatric consultation, and referrals to other professionals in the community. Counseling sessions are confidential.

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 (with a small deductible) hospital and surgical costs, as well as costs of outpatient treatment for injury or illness. Benefits continue for 12 months, on and off campus, provided that 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 to purchase 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 (CDC) provides assistance to students, research fellows, and alumni in the areas of career and

life planning and employment. Personal assistance is available in career choice, résumé preparation, interviewing, graduate school application, and job search strategies. Career and vocational interest tests can also be taken.

CDC On-line
The Career Development Center now has a home page on the World Wide Web with information about the center's programs and activities, as well as links to career, educational, and employment resources nationwide. The Web address is http://www.cco.caltech.edu/~gatti/cdc.html.

Premedical and Graduate School Advising
Students planning to apply to medical school can make use of many resources and individual counseling in the Career Center. Medical school catalogs and statistical information on successful Caltech medical school matriculants are among the materials available. Through the ASPIRE program, students can obtain relevant medical research experience, and there is a comprehensive list of available health-related volunteer opportunities. Counselors can help students throughout the process from freshman year to graduation, and will work closely with students to help ensure their success.

While students planning to apply to graduate school and other professional programs do not have to plan so far ahead, the Career Center provides many resources for these programs as well. Important to all students who will seek further education is the Letter of Recommendation service for application to graduate or professional school.

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., Eng., 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 Self-Help: Employment and Loans, under Financial Aid in Section Three.)

A Summer Program in Research or Engineering (ASPIRE)
The ASPIRE program provides opportunities for students at all levels to work in private industry, government laboratories, educational institutions, and other nonprofit agencies. Many of the advertised positions are with Caltech alumni. Students are encouraged to see a career counselor to receive individual help in defining their summer work interests, résumé preparation, and job search strategies. Application times for specific positions may be as early as December or as late as May. Many employers help students with transportation and summer housing. Students should come in during the fall term to get on the ASPIRE mailing list.

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.

CALTECH ALUMNI ASSOCIATION

The Caltech Alumni Association, an independent organization open to all former Caltech students, works worldwide to promote the Institute and to connect through ties of goodwill Caltech, its alumni, and current students. The Association supports on-campus student activities and organizations, sponsors activities that encourage contacts between alumni and students, and funds scholarships and undergraduate awards. Fifteen alumni chapters throughout the United States meet regularly, often with faculty speakers. The

Association also sponsors local, national, and international travel/study programs; Seminar Day, a day of lectures, exhibits, and social events held on campus; and class reunions. An alumni directory, e-mail and other on-line Internet services, a subscription to Caltech's *Engineering & Science* magazine, and an opportunity to participate in the Caltech Employees Federal Credit Union are some of the benefits of Association membership.

OFFICE OF INTERNATIONAL PROGRAMS

The Office of International Programs assists international students and their dependents in adjusting to life at Caltech and in the United States. The office develops programs and activities that encourage interaction among international and domestic students. All visa and immigration-related matters for international students are processed through the Office of International Programs. Visas for scholars and their dependents are available through the Faculty and Postdoctoral Scholars Office.

The staff of International Programs work closely with the graduate and undergraduate deans to address academic and personal concerns of international students. The office provides assistance with crosscultural adjustment, personal, financial, legal, career, and health-related needs of international students, in cooperation with other Institute departments and offices. International students with a legal or an Honor System grievance or concern may contact the director for assistance.

The Office of International Programs plans and promotes programs and activities that foster international and crosscultural awareness on campus. The New International Student Orientation Program is held each September to introduce international students to Caltech and the United States. In cooperation with the Graduate Student Council, other student governance groups, and various national and cultural organizations, International Programs staff assist individual students and clubs in planning multicultural events throughout the year. In addition, the office holds information seminars to update international students on immigration regulations, professional development, American values and work culture, and other appropriate topics.

The Office of International Programs issues international student and teacher ID cards for those traveling abroad. The office also assists students who are traveling abroad with crosscultural and adjustment information, obtaining State Department travel information, and securing visas. Information on short-term study and travel opportunities abroad, as well as travel guides, are available in the office.

In cooperation with the Dean of Graduate Studies, International Programs offers English-as-a-second-language classes for graduate students and visiting scholars throughout the year. More information on these classes is available in Section Five, the course listing of this catalog.

Further information about services, current programs, and immigration regulations can be obtained on the World Wide Web at http://www.cco.caltech.edu/~ispgroup/.

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 nonacademic 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.

GRADES AND GRADING

All permanent grades recorded for freshmen during the first and second terms they are enrolled 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 first-quarter or second-quarter 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 during the first and second quarter in which they are enrolled will be used in computing the cumulative grade-point average.

For all students beyond the first and second quarters of their 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. In any situation in which no grade is reported, the grade shall be assumed to be F.

At their discretion, instructors may give students who have not completed their work for a course by the end of the term a grade of E. The grade E indicates deficiencies that may be made up without repeating the course. If the instructor does not specify a date on the grade report sheet for completion of the work, students receiving an E will have until Add Day of the following term to complete their work for that course. Instructors may, however, require the work for the course to be completed by an earlier date. If a student receives an E and does not complete the work by the date specified by the instructor or by Add Day, the grade will be changed to an F. Adequate time must be afforded to instructors to grade the work and to submit the final grade to the Registrar. It is the responsibility of a student receiving an E to confirm that the Registrar has recorded the terms for satisfying the completion of the work in the course.

With the written permission of the instructor a student may extend the E grade past Add Day of the following term, but doing so will cause an additional E grade to be registered. Each additional extension of the E will be until the date specified by the instructor or until Add Day of the following term, but in each case will require the written permission of the instructor and the registering of an additional E grade.

After an undergraduate student has been awarded the grade of E six times, he or she is not eligible to receive E grades in any subsequent term. A petition for an E in a subsequent term may be approved by the Undergraduate Academic Standards and Honors Committee (UASH) in an exceptional case. Such a petition requires the support of the instructor and the Dean or Associate Dean of Students.

The grade I is given only in case of sickness or other emergency that justifies noncompletion of the work at the usual time, and its use must be approved by the Dean or the Associate Dean of Students or by the Dean of Graduate Studies. The time period within which the grade of I is to be made up should be indicated on the grade sheet, or students receiving an I will have until Add Day of the following term to complete their work for the course. As in the case of the E grade, the grade of I shall not be considered in calculating a student's grade-point average.

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 E's and I's 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:

- First-quarter and second-quarter 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.
- Required laboratory courses will be graded P or F regardless of when they are taken, but these courses must be taken during the freshman or sophomore years.
- 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 registration 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 registration.
- 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 90 may be in courses graded pass/fail because of the student's election.

NOTICES, AGREEMENTS, AND POLICIES

Accreditations and Authorizations

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

In specific degree programs the Engineering Accreditation Commission of 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, sexual orientation, parental or family or marital status, national or ethnic origin, or nondisqualifying disability; or (b) any other factor which is, in fact, irrelevant to student status or to the rendering of services, facilities, programs, or activities. In addition, the many Federal and State laws, and regulations issued thereunder, which bar discrimination in educational programs and related activities, are also applicable.

The grievance procedure described below is the Institute's official avenue for the redress of grievances of alleged discrimination or other issues. Informal assistance and consultation about possible discrimination or about grievance procedures may be obtained from the Assistant Vice President for Student Affairs, Dean of Students, the Associate Dean, the Dean of Graduate Studies, the Women's Center, the Director of Residence Life, or the Ombuds Office.

Americans with Disabilities Act (ADA)

Caltech is committed to full compliance with the Rehabilitation Act (Section 504) and the Americans with Disabilities Act (ADA). As part of the implementation of this law, Caltech has adopted a policy that assures continued reasonable accommodation will be provided for qualified individuals with disabilities, which includes learning disabilities. We also accommodate individuals with a record of disabilities or regarded as having a disability. Caltech's policy prohibits unlawful discrimination on the basis of disability in its programs, services, activities, and employment. It is the responsibility of the Caltech administration and faculty to ensure the Institute's compliance with this policy.

For information and services for accommodation of individuals with disabilities, please contact Dr. Sharyn Slavin, Assistant Vice President for Student Affairs, (818) 395-6321.

Sexual Assault Policy for Students

I. Basic Principles

Rape and other types of sexual assault, whether by a stranger or by an acquaintance, are violations of the law and the policy of the California Institute of Technology. Sexual assault includes but is not limited to rape, forced sodomy, forced oral copulation, rape by a foreign object, sexual battery, or threat of sexual assault. Caltech will not tolerate sexual assault, whether directed at males or females. The Institute will also provide assistance and support for survivors of such assault and will aid in the apprehension of assailants. To reduce the risk of sexual assault, the Institute provides education to increase awareness of this important issue.

Caltech views sexual assault, in any of its forms, as a very serious matter and is committed to responding promptly and thoroughly to investigate sexual assault charges leveled at a Caltech student by any other of its students.

A student who has been sexually assaulted by another student or any other member of the Caltech community is strongly encouraged to file a complaint with Caltech officials, as well as with any civil authorities the student deems appropriate. See section III of this document for details on filing a complaint with the police.

II. Procedures for Filing a Complaint on Campus
Students who wish to file a complaint against another student should do so as soon as possible after the assault, although complaints may be filed at any time. Undergraduates should contact the Dean or Associate Dean of Students. Graduate students should see the Dean or Assistant Dean of Graduate Studies.

If administrative changes are needed to protect the rights of either party, the dean shall see that they are made. Extensions to any time limits listed herein can be made if required for fairness or practical necessity. Such extensions will be made in writing and sent to the parties involved.

A. Initial Meeting
When a student files a complaint with one of the deans, the dean will:

- Ask the survivor questions to assess the situation for continuing threat to the survivor and/or other members of the community.
- Ensure that the survivor is given appropriate protection, if necessary, including protection from retaliation for the complaint. Such protection may include a temporary housing reassignment and other restrictions on the accused.
- Request a written statement of complaint from the survivor that includes as much detail as possible.
- Provide a copy of these procedures to the complainant.

B. Investigation
Within five working days of meeting with the respondent, the dean will form a two-person team to investigate the case. The dean may choose to be one of the members of that team. Both individuals involved in the investigation will respect the privacy of the students and that of all parties involved while they complete a thorough review of the situation. All participants will be required to keep the contents of the investigation confidential. The investigation should be completed within 21 days after the formation of the team. The Caltech investigation will occur independently from any *legal* proceedings that may take place.

The process will be the following:

- The respondent should be notified as soon as possible after a complaint is filed. The respondent will receive a verbal summary of the complaint.

•Both investigators will interview the survivor and will interview the respondent, and each will be allowed to have a friend present during his or her interview. The friend will serve as an observer and will not participate in the proceedings.

•The survivor and the respondent will be asked to suggest available witnesses. Others may be interviewed to obtain relevant information.

•The survivor will be kept informed of the status of the investigation.

C. Determination

The investigators will consult with Institute counsel and, when the dean is not a member of the team, make a recommendation to the dean regarding the charges and the appropriate consequences, including discipline up to expulsion for the respondent.

In addition, the investigating team shall prepare a summary record of the case for the dean. This record will be considered a confidential Institute document and will be available only to the Vice President for Student Affairs, the Provost, and the President in case of an appeal.

D. Resolution

The dean may consult with Institute counsel for aid in determining the Institute's legal duties and obligations before taking appropriate disciplinary action based on the team's findings.

The dean will inform both parties of the outcome of the investigation in writing within seven days after receiving the recommendation and completing consultation with counsel. The dean will carry out any disciplinary consequences if the accused is a student. Discipline for students can include, but is not limited to, the following: verbal counseling, probation, involuntary leave, and expulsion. If the complainant is found to have acted in bad faith in bringing the charges, disciplinary action may also be taken.

E. Appeal

Either the survivor or the accused may appeal the decision to the Vice President for Student Affairs. The appeals must be on the grounds of improper procedure or an arbitrary decision based on evidence in the record. The Vice President may interview both parties and consult with the investigators before deciding whether to accept the judgment of the dean or authorize further investigation or deliberations.

III. Filing a Complaint with Civil Authorities

If a student wishes to report a rape to the police, she is encouraged to seek support and guidance from the Caltech Women's Center.

They have experience in this area and can be very helpful. Their telephone number is (818) 395-3221. The telephone number for the Pasadena Police is (818) 405-4501.

Because sexual assault may involve physical trauma and is a crime, the survivor is encouraged to seek medical treatment at Huntington Memorial Hospital Emergency Room. This is necessary if the survivor wants evidence collected and is possible only if the assault occurred within the last 72 hours. The survivor also will be informed that because the assault is a crime, the hospital has an obligation to inform the police and that the police will conduct an interview at the hospital regarding the assault. The survivor can choose whether or not to disclose information to the police. The survivor's consent will be requested to allow collection of evidence and the survivor may choose to go forward with a criminal or civil prosecution.

To preserve evidence, the survivor should not shower, douche, or change clothes. The survivor should bring a fresh change of clothes to the hospital. If clothes have been changed, the clothes worn at the time of the assault should be put in a paper bag and brought to the hospital.

Survivors who do not wish to be interviewed by the police should seek medical assistance from the Caltech Health Center, a private physician, or other community resources. Health-care professionals may need to fulfill legally mandated reporting requirements.

IV. Community Resources

Verbal and written information about sources of support on campus and in the community will be provided to the survivor. Referrals to the following will be included:

Student Health Center	395-6393
Caltech Counseling Service	395-8331
Caltech Women's Center	395-3221
Office of the Dean of Students	395-6351 or
Dean of Graduate Studies	395-6367
Office of Residence Life	395-6194
Planned Parenthood	798-0706
Victim/Witness Assistance Program	356-5714
Pasadena Lawyer Referral Services	795-5641

V. Further Complaints

The complainant should notify the dean immediately if anyone associated with this matter is under continuing threat. In such cases, the complainant has the right to file another complaint.

On a "need-to-know basis," the following individuals at the Institute may also be informed of the fact that a sexual assault complaint has been made and that both parties are members of the Caltech community. The names of the individuals involved will not be released without their consent unless the release is essential to the health and safety of a student or to otherwise fulfill the legal obligations of the Institute. In such rare circumstances, the Vice President for Student Affairs is the only one authorized to make an exception to the rule of complete confidentiality regarding the names of those involved. If an exception is made to this rule, the parties will be notified as soon as possible.

The President
Vice President for Student Affairs
Assistant Vice President for Student Affairs
Dean of Students/Dean of Graduate Studies
Director of Residence Life/Master of Student Houses
Resident Associate
Director of the Women's Center
Director of the Student Counseling Services
Director of the Health Center
The Office of Public Relations
Campus Security

Sexual Harassment Policy for Students

It is the policy of the Institute to provide a work and academic environment free of unlawful harassment, including sexual harassment and all forms of sexual intimidation and exploitation. All students should be aware that the Institute will not tolerate any conduct that constitutes sexual harassment. Complaints of sexual harassment will be promptly and thoroughly investigated and appropriate action, including disciplinary measures, will be taken when warranted.

Management, faculty, students, and staff, at all levels, are responsible for maintaining an appropriate environment for study and work. This includes taking appropriate corrective action to prevent and eliminate harassment.

Sexual harassment is unlawful, violating Title VII of the Civil Rights Act of 1964, as amended, Title IX of the Education Code, and California state law. Sexual harassment is defined in the "Guidelines on Discrimination Because of Sex" under Title VII as follows:

> "Unwelcome sexual advances, requests for sexual favors, and other verbal or physical conduct of a sexual nature constitute sexual harassment when
>
> (1) submission to such conduct is made either explicitly or implicitly a term or condition of an individual's employment,
>
> (2) submission to or rejection of such conduct by an individual is used as the basis for employment decisions affecting such an individual, or

(3) such conduct has the purpose or effect of unreasonably interfering with an individual's work performance or creating an intimidating, hostile, or offensive working environment," even if it does not lead to tangible or economic job consequences.

The above principles also apply in an academic context under Title IX.

Some examples that may constitute harassment are:

- Unwanted sexual advances.
- Offering employment benefits in exchange for sexual favors.
- Making or threatening reprisals after a negative response to sexual advances.
- Making sexual gestures; displaying sexually suggestive objects, pictures, cartoons, posters, or calendars.
- Making or using derogatory comments, epithets, slurs, or jokes of a sexual nature.
- Verbal sexual advances or propositions.
- Verbal abuse of a sexual nature, graphic commentaries about an individual's body, sexually degrading words used to describe an individual, suggestive or obscene letters, notes, or invitations.
- Unwelcome, intentional and/or repeated touching of a sexual nature.

Even when relationships are consensual, care must be taken to eliminate the potential for harassment or other conflicts. Institute practice, as well as more general ethical principles, precludes individuals from evaluating the work or academic performance of those with whom they have amorous and/or sexual relationships, or from making hiring, salary, or similar decisions.

Upon learning about such a relationship, the supervisor or division chair has the authority to eliminate any direct administrative or academic relationship between the involved individuals.

When a consensual personal relationship arises and a power differential exists, consent will not be considered a defense in a claim that the Institute policy has been violated. The individual in the relationship with greater power will bear the burden of accountability.

Students have the legal right at any time to raise the issue of sexual harassment without fear of reprisal or retaliation. Any student who feels that he or she has been sexually harassed should immediately bring the matter to the attention of any of the individuals listed.

These individuals are available to members of the Institute community who seek information and counseling about the Institute's formal and informal mechanisms for resolving complaints. They will handle matters brought to their attention with sensitivity and discretion. They can also provide further information about Caltech's complaint investigation and resolution procedures, as described below.

Dean of Students, Parsons-Gates, 102-31, ext. 6351
Associate Dean of Students, Parsons-Gates, 102-31, ext. 6351
Dean of Graduate Studies, Parsons-Gates, 02-31, ext. 6346
Assistant Dean of Graduate Studies, Parsons-Gates, 02-31, ext. 3813
Master of Student Houses, Winnett, 115-51, ext. 6295
Director of Residence Life, Winnett, 115-51, ext. 6194

The Institute also offers members of the Caltech community the choice of seeking confidential personal counseling outside the Institute's formal mechanisms for resolving harassment complaints. These confidential counseling services are intended for the personal benefit of the individual and offer a setting where various courses of action can be explored. Those seeking this type of assistance should check with the Counseling Center, Young Health Center, 1-8, ext. 8331, or the Ombuds Office, Dabney, 4-40, ext. 6990.

Procedures for Investigating and Resolving Sex Discrimination and Sexual Harassment Complaints Involving Students

I. Basic Principles

It is Caltech's policy to provide a work and study environment for all members of the community that is free of sex discrimination, including sexual harassment. Copies of the Institute's Equal Employment Opportunity and sexual harassment policies are available from the Human Resources Office, Student Affairs, and the Provost's Office. The EEO policy prohibits unlawful discrimination based on sex and other protected characteristics. The sexual harassment policy, as cited above, contains definitions of sexual harassment and a general discussion of consensual relationships. Both policies identify appropriate people on campus to contact with complaints.

The most important test of any relationship between members of the Caltech community is respect for the rights of others. In the spirit of the Caltech Honor System, no member of the Caltech community should take unfair personal advantage of another member of the community. Thus, a position of trust or influence should never be exploited.

II. Procedures

A member of the Caltech community who believes he or she is being, or has been, subjected to sex discrimination, including sexual harassment, should review the Institute's definition and policies. There are at least three courses of action available to address the problem; each of these has different consequences and implications with respect to confidentiality and resultant action. These include:

(a) Talking personally with the offending individual, or writing a letter, and asking him/her to stop;

(b) Informally resolving the complaint with the help of a third party (see list below); and/or

(c) Reporting the offending conduct to the dean.

These options are described more fully in the following sections. They are not mutually exclusive. The complainant has the right to choose which course to follow.

Protection of complainant: Administrative changes may be needed in order to protect the rights of the complainant. The complainant should discuss any requested changes with the appropriate parties, as described below under each type of procedure. If the complainant desires, such protection might include a temporary housing reassignment for one of the parties, transfer of a student from a section, or other administrative or academic changes.

A. Informal Procedures

Options (a) and (b) above are considered informal procedures for resolving sex discrimination (including sexual harassment) complaints. In general, informal resolution of sex discrimination issues may be most appropriate if the goal is simply to stop the discrimination or harassment. If additional action is felt necessary (for example, if the complainant desires administrative changes), such actions should be discussed to ensure at the outset that the requested actions can be accommodated within the structure of the informal procedures.

Informal complaints against students may be in writing or may be oral.

Individuals who wish to explore informal resolution may take advantage of the Institute's counseling services, which are intended for the personal benefit of the individual. The Women's Center and the Ombuds Office offer information on various courses of action and personal support. The Institute Ombudsperson may be able to take informal steps to resolve issues and protect the complainant from retaliation. Mediation may be provided if both parties agree. The student Counseling Center provides personal counseling for students, and confidentiality is protected by statute. The Staff and Faculty Consultation Center provides counseling and the same confidentiality. For information on the legal limits of confidentiality that pertain to each informal resource, the complainant should contact the Ombuds Office, the Counseling Center, the Staff and Faculty Consultation Center, and the Women's Center.

B. Formal Procedures

In order to make a formal complaint, the complainant should meet with the Dean or Associate Dean of Students or the Dean of

Graduate Studies. If the complaint involves a dean or associate dean directly, the complainant should meet with the Vice President or Assistant Vice President (AVP) for Student Affairs, who will then perform the actions in this procedure assigned to the dean. The dean may offer to use informal procedures to resolve the complaint. However, the Institute must use formal procedures if requested to do so by either the complainant or the accused (hereafter referred to as the "respondent").

- If the complaint is against a faculty or staff member, the procedure of the respondent applies, but the dean shall assist in forming the investigative team and the AVP for Student Affairs will be apprised of the outcome of the process.
- If the complainant is a faculty or staff member, the procedure below applies, but Employee Relations (in the case of staff) or the division chair (in the case of faculty) shall aid in the selection of the investigative team and Employee Relations or the Provost (in the case of faculty) will be apprised of the outcome of the investigation.

If administrative changes are needed to protect the rights of either party, the dean shall see that they are made. Extensions to any time limits listed herein can be made if required for fairness or practical necessity. Such extensions will be made in writing and sent to the parties involved.

(1) Initial Meeting

During the initial meeting with the complainant, the dean shall request a written statement from the complainant which includes as much detail as possible. The dean shall inform the complainant of his/her rights and responsibilities, including the following: the right to choose not to cooperate with the investigation at any time (though once a formal complaint has been taken, the Institute has a legal duty to complete the investigation process); the requirement that all parties keep the content of the investigation confidential; and the right to bring a colleague from the Caltech community, excluding legal counsel and officers of the Institute, to provide personal support at any meeting during the process. This does not preclude any party's right to consult with an attorney outside of the meetings.

The dean shall provide a copy of the applicable procedures to the complainant.

(2) Student Respondents

If the complaint is against a student, the dean shall meet with the respondent within five working days. During this meeting, the dean shall provide a written summary of the complaint and a copy of this procedure to the respondent. In addition, the respondent shall be informed of his/her rights and responsibilities, including the confidentiality requirement and the right to accompaniment.

The dean shall also inform the AVP that a formal complaint has been filed.

(3) Investigation
Within five working days after meeting with the respondent, the dean receiving the complaint shall form a small team (usually two or three people) to investigate the complaint. The makeup of the team will take into account the status and needs of the parties involved. Students may serve as team members. Each team member will have received training on various aspects of sex discrimination and sexual harassment. Each party will be asked to comment on the suitability of the investigating team, and each party shall have up to two vetoes regarding its makeup.

All participants in the investigation will be required to keep the content of the investigation confidential. The team shall interview the complainant and respondent, and ask them to suggest witnesses that the team shall consider for interview. The team shall also interview others who might have pertinent information. Legal counsel (including that for the Institute) will not be permitted to attend the investigative hearing. All members of the team shall have equal access to evidence and testimony.

The investigation should be completed within 30 days of the formation of the team.

(4) Determination
The investigating team may consult with Institute counsel for aid in applying legal standards regarding sex discrimination and sexual harassment and in determining the Institute's legal duties and obligations. Within 10 working days after the interviews are completed, the team shall determine if there has been a violation of Institute policy and shall recommend appropriate consequences to the AVP for Student Affairs.

In addition, the investigating team shall prepare a summary record of the case for the AVP's files. This record will be considered a confidential Institute document and will be available only to the Vice President for Student Affairs in case of an appeal or the AVP for use in future cases involving either party.

(5) Resolution
The AVP for Student Affairs may consult with Institute counsel for aid in determining the Institute's legal duties and obligations before taking appropriate disciplinary action based on the team's findings. In cases where a violation of the Institute's EEO and/or sexual harassment policies is found, discipline can include, but is not limited to, the following: verbal counseling, probation, involuntary leave of absence, and expulsion. If the complainant is found to have acted in bad faith in bringing the charges, disciplinary action may also be taken.

Within five days of the team's recommendations, the AVP for Student Affairs shall inform the parties involved of the results in writing, and discuss any needed follow-up plans.

(6) Appeal
Appeals to the Vice President for Student Affairs on the grounds of improper procedures or an arbitrary decision based on the evidence in the record should be made within 15 days of the issuance of the decision. The vice president may interview the parties and consult with team members and others to determine whether to authorize further investigation.

(7) Further Complaints
The complainant should notify the dean immediately if the corrective action does not end the discrimination and/or harassment, or if any retaliatory action occurs. In such cases, the complainant has the right to file another complaint.

Distribution of These Procedures
These procedures will be distributed annually to continuing faculty, staff, and students, and upon arrival to new faculty, staff, and students. In the event that any significant revisions are made, revised versions will be distributed.

Student Grievance Procedure

Caltech provides a variety of routes, most of them informal, by which student complaints are brought to consideration and resolution. In academic matters, for example, they may begin with teacher-student conversations and may extend to the Deans, the Division Chairs, the Registrar, or to various committees having faculty and student members. Undergraduate housing matters are dealt with by house officers, the Resident Associates, the IHC, and the Director of Residence Life. The Dean of Graduate Studies is often of assistance in resolving graduate student matters. As the Institute officer responsible for the supervision of many Student Affairs offices, the Assistant Vice President for Student Affairs may be the appropriate person to appeal to in case of unresolved complaints involving those offices. The Ombudsperson, who acts as an ombudsman for the entire Caltech community, may be consulted confidentially about any problem. The Graduate Student Council and ASCIT may become involved in important complaints, and sometimes ad hoc groups are formed to make recommendations.

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

The first step in this procedure is to consult with the person appointed by the President of the Institute as mediator for student grievances. The mediator will assist the student in trying to work out the problem in an informal way. If the student is not satisfied with the results, he or she may appeal the case to the Student Grievance Committee. The members of the committee are undergraduates appointed by the ASCIT Board of Directors, graduate students appointed by the Graduate Student Council, faculty appointed by the faculty chair, and administrative staff appointed by the Vice President for Student Affairs. Two members and two alternates are appointed from each of the four categories. The Chair of the committee is appointed by the President and does not vote except in case of a tie. 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 following offices: Student Affairs, Dean of Students, Dean of Graduate Studies, Director of Residence Life, Women's Center, and the Ombuds Office.

Employment Experience of Recent Graduates

A survey was made at the end of June 1995 of the future plans of those students who had graduated at the commencement ceremony.

Of those receiving the B.S. degree about whom Caltech has definite information, 50 percent had been accepted for admission to graduate school for further education, 26 percent had accepted employment, 17 percent were uncommitted, and 2 percent had other plans. The average salary of those accepting employment was $3,156 per month. At the M.S. level, 78 percent were continuing in graduate school, 14 percent were employed at an average salary of $3,498 per month, 3 percent were uncommitted, and 4 percent had other plans. Of those receiving the Ph.D. degree, 36 percent were employed in industrial R&D with an average salary of $4,953 per month, 56 percent were employed as faculty or research fellows, 5 percent were uncommitted, and 1 percent had other plans.

Student Retention and Persistence Rates

Most undergraduates enter Caltech at the freshman level. Of the 231 freshmen enrolled during the 1994–95 academic year, 215 have reenrolled in the first term of the 1995–96 academic year and are progressing, yielding a persistence rate of 93 percent. Of the 216 freshmen enrolled during the 1989–90 academic year, 185 graduated by June 1995, yielding a graduation rate for this group of 86 percent. At the graduate level, 91 percent of entering students graduate with the degree of either Master of Science or Doctor of Philosophy or, occasionally, both.

Student Patent and Computer Software Agreement

Students at Caltech have many opportunities to work in laboratories, 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, databases, 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, nonexclusive license, with the right to grant sublicenses, for any purpose whatsoever.
3. I agree to notify the Institute promptly of any discovery, inno-

vation, or invention that 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

The following constitutes the policy of the California Institute of Technology regarding access to student records:

1. The Institute maintains educational records for each student that include name, address, student identification number (including Social Security 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 educational 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 Dean of Students, 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. Except as authorized by federal or state law or regulation, none of these educational 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 the written consent of that student. 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 educational 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 to the Dean of Students, or their deputies, as appropriate. A mutually convenient time will be arranged within 10 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 educational 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 cents for the first page copied and 12 cents for each additional page. All reasonable requests for explanations or interpretations of the educational records will be honored, and if inaccurate, misleading, or otherwise inappropriate data are found in these 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 the Dean of Students, or their deputies, do not agree on any item contained in the educational 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 chair 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 educational record, as determined by majority vote, will be in writing, will be rendered within 10 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 educational 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: a 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 if a member of an athletic team, dates of attendance, degrees and awards received, thesis title, home town, and most recently attended educational agency or institution. 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. A student will not be required to waive any rights regarding access to educational records. 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 educational 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, 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.

Academic Records of Veterans

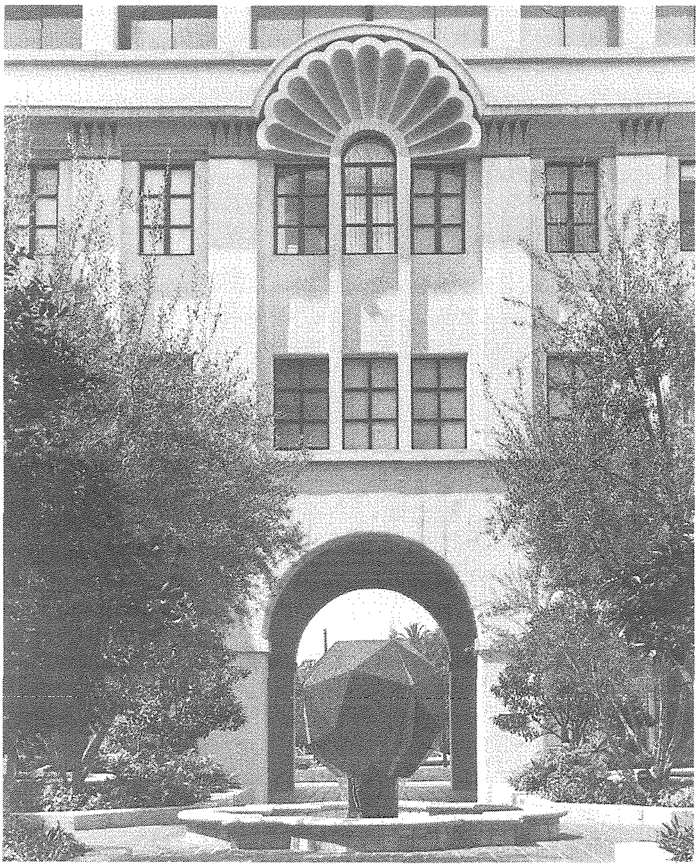
The Institute maintains a written record of a student's previous education. This is part of the student's permanent record card, and included on this is a summary of any prior college-level education. A true copy of a transcript of college-level work at other institutions is maintained as part of the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

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

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

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

Study and Research



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 this development. Work in fracture mechanics of polymers was initiated before composite materials became an important component of aerospace structures. This tradition places a high premium on an in-depth understanding of fields both closely and remotely related to the behavior of fluids and structures, such as physics, applied mathematics, geophysics, materials science, electronics, and even astrophysics. As a consequence, GALCIT students are known and sought after for their broad yet intense education and for their ability to deal with new and challenging problems.

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

Physics of Fluids. Fluid dynamics as a discipline is as much a part of physics as of engineering. Physics of fluids refers to research in areas closer to applied physics than to direct technical applications. Present active research includes studies in gasdynamics, diffraction of shock waves, detonation 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, the study of hypervelocity flows, 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 bluff-body aerodynamics, turbulent combustion, laminar diffusion flames and their instabilities, fires in buildings (turbulent mixing and flow fields driven by fire-produced buoyancy), explosions, hydrodynamics and two-phase flows, interaction of vorticity with free-surface, cardiac flows, and active and passive control of transition and turbulence.

Structural Mechanics. Structural mechanics research involves both the static and dynamic behavior of structures and solids. Included are buckling for both elastic and viscoelastic (composite) materials. Other subjects include the response and failure of composite materials, including high-temperature ceramics and composites that find application in future high-speed flight.

Computational Solid Mechanics. As a field of endeavor, Computational Solid Mechanics addresses phenomena ranging from the atomistic scale, e.g., nanoindentation, to the structural scale, e.g., fracture of aircraft components. It provides an indispensable tool for understanding the relation between structure and mechanical properties of materials; for predicting the efficiency of such industrial processes as machining and metal forming; and for assessing the safety of such structures as airplanes, automobiles, and bridges. The goals and objectives of the Computational Solid Mechanics facility at Caltech are to provide a state-of-the-art environment for the development of numerical methods in solid mechanics; to provide the computational resources required for medium-scale simulations in solid mechanics; and to serve as an instructional facility for advanced courses in Computational Solid Mechanics.

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 nonlinearly 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 aeroacoustics 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.

Jet Propulsion. The Daniel and Florence Guggenheim Jet Propulsion Center conducts a large portion of its instruction and research in close cooperation with the aeronautics group. 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.

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-foot 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 and a shock tunnel for studying hypervelocity gas flows up to 7 km/s. Shock tubes, plasma tunnels, and other special facilities are available for the study of extreme temperatures, shock waves, deflagrations, detonations, acoustics, and cryogenic flows.

The solid mechanics laboratories contain standard as well as special testing facilities for research related to aircraft, spacecraft structures, and failure/fracture behavior of 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 2 million frames per second, for the study of fast phenomena, e.g., wave propagation, dynamic buckling, and the mechanics of static and dynamic fracture. Dynamic testing facilities include specialized electromagnetic loading devices (stored energy ~120 KJ), a drop weight tower, split Hopkinson bars (axial/torsional), and plate impact apparatus. Diagnostic devices include full field interferometric and temperature measurements, both for static and dynamic applications.

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.

Computational facilities range from personal computers to powerful workstations to an on-campus large-scale parallel processing machine, and remote supercomputers such as those generally available at NSF and NASA centers. Graphics workstations are available to support research in computational fluid dynamics and computational solid dynamics. These workstations provide high resolution color graphics, with the capability of viewing three-dimensional information at high speed, a large storage capability, and a network interface so that programs and results can be sent to and from remote supercomputers.

APPLIED MATHEMATICS

An interdisciplinary program of study in applied mathematics that leads to the Ph.D. degree is offered by the Institute. In addition to various basic and advanced courses taught by the applied mathematics faculty, broad selections are available in mathematics, physics, engineering, and other areas. Students are expected to become proficient in some special physical or nonmathematical field. A subject minor in applied computation is offered jointly with the computer science option.

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 in parallel computation. The applied mathematics group has access to supercomputers and concurrent computers, and has a variety of its own computers, graphics terminals, and other equipment. Library facilities are excellent, comprising all the journals, a complete general library, and a special research library in applied mathematics.

The present graduate program is one leading mainly to the Ph.D. degree. The curriculum consists of two types of courses: those that survey the methods used in applied mathematics, and those that have a special applied mathematics flavor and represent active research interests of the members of the faculty. Among the latter have been wave motion, perturbation theory, fluid mechanics, stochastic processes, mathematical programming, numerical analysis, and computational fluid dynamics. Through study outside of applied mathematics, each student is expected to become competent in some special physical or nonmathematical 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 eight 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, theoretical and computational materials science, numerical analysis, ordinary and partial differential equations, integral equations, linear and nonlinear wave propagation, water waves, bifurcation theory, perturbation and asymptotic methods, stability theory, variational methods, mathematical programming, stochastic processes, mathematical biology, 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, and stability and control.

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 solids; mechanics of time-dependent fracture; 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 been developed 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.

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 will do research in 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 particle 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 by the construction of the 40,000-square-foot Thomas J. Watson, Sr., Laboratories of Applied Physics. This attractive building contains offices around a central courtyard and laboratories on the balance of the two floors. Conference rooms and a large classroom occupy the single-story entrance wing.

ASTRONOMY

The astronomical observatories at Palomar and Big Bear, plus the Owens Valley Radio Observatory and the Caltech Submillimeter Observatory, together constitute a unique and unprecedented concentration of scientific facilities in astronomy. The Division of Physics, Mathematics and Astronomy also conducts work in theoretical astrophysics, laboratory astrophysics, gravitational-wave physics, and infrared and submillimeter 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 cosmology, via observations of the microwave background radiation, and the physical properties of galactic and extragalactic radio sources, including quasars, pulsars, 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 Oschin 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. 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 Oschin Telescope 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. A second Sky Survey is now 80 percent complete. 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 Oschin Telescope 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 the Carnegie Institution of Washington was completed in 1969. It is used for photometry, spectroscopy, and photography. The Palomar telescopes have modern instrumentation and detectors designed for both optical and infrared wavelengths.

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 effort is the study of solar oscillations.

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 telescope, a six-element millimeter-wave synthesis interferometer array, a five-element interferometer for solar studies, and a 5.5-m telescope dedicated to observations of the microwave background radiation. The 40-m telescope is used for studies of radio sources and of the microwave background radiation. The high-precision 10-m telescopes of the millimeter array are used at wavelengths of 1.3 to 4 mm to map the distribution of interstellar gas and dust in star-forming regions of our own and other galaxies. The array also enables detailed studies of the sun, planetary atmospheres, and the envelopes around evolved stars. 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 special purpose instrument for imaging the microwave background is now under construction and expected to begin observations in 1999.

A major new facility is under construction on Mauna Kea, in Hawaii. The Caltech 10-m submillimeter telescope was completed in 1986. The Keck Foundation has funded the construction of two 10-m optical-infrared telescopes, ultimately to be operated jointly with the University of California as part of an interferometer. Keck I has four times the power of the Palomar 200-inch and is in operation. Keck II will be completed in 1996. These will be the two largest optical-infrared telescopes in the world. An adaptive optics system for Keck I is now being designed.

Biochemistry has been established as an interdisciplinary program at the interface of biology and chemistry that seeks to understand the chemistry of life. Thus, biochemists study the atomic structure and folding of biopolymers; their interactions with each other and with small molecules; and the roles of particular biopolymers and biopolymer assemblies in cellular physiology. The basic building block of life is the cell; the intellectual focus of modern biochemistry is to understand how individual parts interact to give cells their wide spectrum of functions. In particular, biochemistry addresses the principles through which the individual components of cells combine in an orderly self-association to produce their form, their function, and their dynamic behavior.

Areas of Research

General areas of research represented within the option include signal transduction, cell cycle, DNA and RNA structure and metabolism, control of gene transcription during development, electron transport proteins and bioenergetics, biological catalysis, macromolecular structure, membrane proteins, and biotechnology and biomolecular engineering. More specific examples of biological phenomena currently under study include the transduction of signals received by cell surface receptors into an appropriate response, as in chemotaxis or transmission of signals across synapses in the nervous system; the replication of DNA; the biochemical networks that control initiation and termination of cell division; the controlled transcription of DNA sequences in the genome into RNA and the processing of this RNA into mRNA and the subsequent translation into protein; the molecular mechanisms controlling the differentiation of precursor cells into specialized cells such as neurons, lymphocytes, and muscle cells; the mechanisms by which synaptic transmission in the brain is regulated during thinking and the formation of memories; the processes, driven by fundamental principles of chemical bonding and molecular energetics, by which a given linear sequence of amino acids folds into a specific three-dimensional structure in the appropriate cellular environment; how electrons move within a cell to accomplish the many redox reactions necessary for life; how light is harvested by photopigments and is perceived in vision; the function of integral membrane proteins in energy and signal transduction processes; and the mechanisms by which enzymes both efficiently and specifically catalyze biochemical interconversions. This fundamental understanding of the molecular basis of biological processes provides a powerful base for the development of applications in medicine, including biotechnology and rational drug design, and in the chemical industry, where nucleic acids, proteins, and their analogs are now being used in the development of chemical systems for novel applications, and where mutagenesis and selection systems are used to produce novel materials.

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 replicate 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 and computational 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, 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, structural biology, neurobiology, and virology. Biochemical methodology plays an important role in many of these fields, and there is extensive interaction with related programs in biochemistry 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 and instruction in neurobiology has been formulated to span from molecular and cellular neurobiology to the study of animal and human behavior including the computational modeling of neural processes.

Physical Facilities

The campus biological laboratories are housed in six 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, the Braun

Laboratories in Memory of Carl F and Winifred H Braun, and the Beckman Institute. 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, a confocal microscope facility, a magnetic resonance imaging center, a transgenic mouse facility, 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.

BIOTECHNOLOGY

Biotechnology is a growing area of interdisciplinary research with a long tradition at Caltech. It includes a wide range of research opportunities in the Divisions of Biology, Chemistry and Chemical Engineering, and Engineering and Applied Science. Areas of emphasis include the development and application of new methods and instruments for studying a spectrum of biological problems ranging from the structure, function, and chemistry of key macromolecules such as proteins and DNA to the imaging of cellular processes or the complex problems of neural systems. Other programs focus on the creation, study, and use of novel microorganisms and proteins, combining classical and molecular genetic approaches with modern chemistry and engineering science. New challenges in data analysis and molecular modeling bring together research in biology and chemistry with computer science and applied mathematics. Research in these areas leading to the Ph.D. may be pursued by entry into one of the relevant graduate options in the divisions listed above. The interdisciplinary nature of biotechnology often includes course work and research collaborations that embrace more than one division. Each graduate option specifies the emphasis of the educational program and its degree requirements.

Excellent facilities for biotechnology research are available in each of the participating divisions. For example, the Beckman Institute provides extraordinary resources for development and application of new instruments and methods.

CHEMICAL ENGINEERING

The chemical engineering faculty teach and conduct research on fundamental chemical and transport processes and their application in understanding, designing, and controlling a broad spectrum of complex chemical processes. The faculty and students utilize their analytical methods and resources to understand diverse processes and to synthesize new working materials and new operating strategies for improving process performance. The combination of engineering principles, chemistry, biology, and mathematics which characterizes chemical engineering at Caltech enables students and faculty to contribute to the solution of a broad spectrum of critical problems and to aid in creating emerging new high-technology industries.

Areas of Research

Many different research areas are offered to students seeking the degrees of Master of Science or Doctor of Philosophy in Chemical Engineering. Particular research fields emphasized in the department include:

- *Bioseparations:* Synthesis of new materials for recognition of biological molecules. Metal-affinity protein separations.
- *Protein engineering and processing:* Design of enzymes active in organic media. Nuclear magnetic resonance studies of protein structure. Protein and polymer design for highly selective protein separations.
- *Process control and design:* Robust control. Decentralized control. Control of nonlinear systems. Design for operability.
- *Fluid mechanics and transport processes:* Mechanics of polymeric liquids. Microstructured fluids. Transport in heterogeneous media.
- *Polymer physics and rheology:* Molecular understanding of polymer melt rheology. Optical properties of polymer blends. Dynamic modeling of polymer structure and rheology. Polymer diffusion in porous materials.
- *Catalysis:* Synthesis of molecular sieves and molecular sieve thin films. Development of supported aqueous phase catalysts. Synthesis of inorganic membranes for gas separations and catalysis.
- *Ceramics and electronic materials:* Aerosol formation of ceramic particles. Synthesis of inorganic materials and ceramics. Synthesis and characterization of quantum dots and nanostructural materials.
- *Plasma processing of electronic materials:* Etching and deposition. Dynamics of plasma-surface interactions. Nanofabrication on semiconductor matrices.

- *Environmental chemical engineering:* Physics and chemistry of atmospheric gases and aerosols.
- *Aerosols and colloids:* Nucleation and growth of particles. Particle formation and reactions. Structure and properties of colloidal dispersions.
- *Applied mathematics and computational physics:* Supercomputer applications in fluid mechanics, process control, and environmental modeling. Concurrent computing. Asymptotic analyses of transport processes.
- *Physics of complex fluids:* Structures, phase transitions, and dynamics of polymers, liquid crystals, and surfactant solutions.
- *Biomaterials:* Polymeric materials for medical applications, including implants and drug delivery. Biocompatibility. Degradable polymers.
- *Tissue engineering:* Control of wound healing. Immunoprotective barriers for cell transplantation.

Physical Facilities
The chemical engineering laboratories, housed in the Eudora Hull Spalding Laboratory of Engineering, are extremely well equipped. The equipment includes experimental reactors, computational facilities, and an NMR spectrometer, as well as numerous special research facilities for molecular graphics, DNA synthesis, and electronic, optical, and chemical measurements.

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 chemical synthesis, structural chemistry, chemical dynamics and reaction mechanisms, theoretical chemistry, biochemistry, bioinorganic, bioorganic, and biophysical chemistry, materials chemistry, and molecular engineering. Active interaction exists between chemistry and other disciplines at Caltech, especially applied physics, biology, chemical engineering, environmental engineering, geological and planetary sciences, and materials science. 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

macromolecules, covalent compounds and transition metal complexes, to investigations of the stereochemistry of organic molecules, conformations of oligopeptides, solution structures of proteins and nucleic acids, and dynamical structures of macromolecules and membrane systems by NMR spectroscopy. Active programs in other areas of spectroscopy include laser Raman of metalloproteins and inorganic complexes; laser spectroscopy of molecular ions and ionic clusters; ion-cyclotron resonance spectroscopy of biomolecules in the gas phase; multi-dimensional and multiple-pulse NMR of solids and interfaces; and scanning tunneling microscopy of semiconductors and biological systems.

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 molecular recognition and biomimetic catalysis in aqueous media; sequence specific recognition of DNA; and mechanistic enzymology. 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, water oxidation, methane oxidation, and nitrogen fixation. Reactions of molecules on surfaces are receiving increased attention, especially on semiconductors. 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. This research includes projects aimed at the synthesis of complex organic molecules of importance in biology and human medicine; new organic molecules and materials with novel optical and magnetic properties; and molecules required for the testing of structural theories. Efforts are also directed at the development of novel and synthetically useful chemical transformations. Recently, the division has initiated a new thrust in polymer science, with emphasis on the development of strategies and methodologies for the synthesis of designed polymers.

Research in biochemistry and molecular biology includes crystallographic studies of macromolecule structures, studies on the folding and stability of proteins, 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. 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, including studies of resonance-enhanced multiphoton ionization processes in molecules. Theoretical techniques are also being developed to facilitate detailed understanding of electron transfer processes, proton transfer reactions, 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 300 graduate students and postdoctoral research fellows. Crellin and Gates laboratories house several research groups, the divisional computing facility, the divisional 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. A number of resource centers serving researchers of the division are located in the Beckman Institute.

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, transportation, and space development. Dealing with the function and safety of such 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, the escalation of urban problems, and the exploration of space 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 structural dynamics; 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 faculty have pursued a variety of research programs, including the analysis of structures subjected to earthquakes and other dynamic loadings; system identification and control of structures; structural health monitoring; 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 library, 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

An 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 previously 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 analysis of circuitry used in insect olfaction and bird-sound localization; 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; 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; the study of the auditory system of birds; visual motion perception, movement planning, and spatial awareness using a combination of neurophysiological, psychophysical, and computer modeling techniques; light and magnetic resonance imaging of cell lineages, cell migrations, and axonal connections in the forming nervous system; design and implementation of novel algorithms and architectures that enable efficient fault-tolerant parallel and distributed computing; and learning theory and systems, pattern recognition, information theory, and computational complexity.

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 in 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.

Caltech students also have unusual opportunities for research in computer graphics through the recently established NSF Science and Technology Center for Computer Graphics and Scientific Visualization. Through this five-university collaboration, a new intellectual foundation is being developed for the field. In addition, the graphics group collaborates closely with Caltech's new Biological Imaging Center, for gathering and visualizing high-resolution three-dimensional data of (as yet unseen) biological structures.

Research in computer graphics and computer vision emphasizes the creation of realistic images and models. 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.

Research in the methods for designing computational structures addresses the complexity of computational structures by using composition to design them. In this view, a system is an elementary system or a composed system, and a composed system is a list of systems put together using a compositional operator. The study of design methods is the study of elementary systems and compositional operators. Research is conducted on the theory and application of compositional systems ranging from circuits to geographically distributed systems. Of particular interest is the use of compositional methods to develop programs that will execute efficiently on a variety of concurrent computers. Specific projects deal with notations for specification, compiler technology, methods of reasoning about correctness and efficiency, and human interfaces that aid systematic design. Caltech students have excellent opportunities for research and collaboration in concurrent computing through the NSF Science and Technology Center for Research on Parallel Computation.

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.

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.

Physical Facilities

The computer science department's computing facilities are interconnected by department networks that are part of the Internet. All department faculty, graduate students, research staff, secretaries, and librarians have terminals, personal computers, or workstations for access to these computing facilities.

The department computers include 25 Intel Pentiums, 15 HP 715 and 7 HP 735 workstations, 15 SGI Indy workstations, and 25 SPARCstations. Students also have access to other powerful workstations, such as IBM RS 6000s, and to a multimedia laboratory for developing electronic textbooks. Our graphics laboratory includes ten Hewlett-Packard RISC-based graphics workstations; an AT&T Pixel Machine ray-tracing engine; and a complete system for generating computer animation, using a VPR-3 one-inch videotape recorder or a digital magnetic video disk recorder. The Cosmic Cube multicomputers, two Symult Series 2010s, an IBM SP2, and various experimental Mosaic multicomputers are on the department network for system and application experiments. One of the most powerful computers in existence, the Intel Touchstone DELTA System, is available for research. In addition, through the Center for Research on Parallel Computing, students have access to a wide variety of parallel supercomputers. 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.

CONTROL AND DYNAMICAL SYSTEMS

Some of the most exciting interactions between mathematics and engineering are occurring in the area of analysis and control of uncertain, multivariable, and nonlinear dynamical systems. While changing technology has made control and dynamical systems theory increasingly relevant to a much broader class of problems, the interdisciplinary nature of this area means that they no longer have a natural home exclusively or even primarily within any one of the traditional engineering disciplines. The CDS option is designed to meet the challenge of educating students both in the mathematical methods of control and dynamical systems theory and their applications to engineering problems.

Automatic control is an enormously successful field that affects every aspect of our lives. A combination of technological developments, economic pressures, and research advances has promoted control into a central position in technology, and over the next several decades, the impact of automatic control systems will continue to grow. The applications we have seen so far—such as cheap and fast computer disk drives, active vehicle suspension control, fly-by-wire aircraft, highly integrated manufacturing facilities, and manned and unmanned space systems—are only the beginning of this trend.

The rapid development of dynamical systems theory as an intellectual discipline over the past ten years has been equally striking. Stimulated by the discovery of the phenomenon of "deterministic chaos," the "dynamical systems approach" has been adopted in a variety of diverse engineering disciplines (e.g., chemical, mechanical, electrical, civil, and aeronautics), as well as the physical, biological, and social sciences. At the same time, dynamical systems continues to enjoy strong links with pure and applied mathematics.

While research in both control and dynamical systems is inherently interdisciplinary and crosses many traditional engineering and scientific boundaries, their relationship is much deeper. As theoretical disciplines, they are moving together rapidly. The mathematical background required to do research in either control or dynamical systems is nearly identical and can be difficult to obtain within traditional curricula in engineering and mathematics. The CDS option provides a coherent and complete graduate curriculum with corresponding research opportunities, both theoretical and applied.

Areas of Research

Theoretical research is conducted in all aspects of control, with emphasis on robustness; multivariable and nonlinear systems; optimal control; decentralized control; modeling and system identification for robust control; exterior differential control systems; control of Hamiltonian and Lagrangian systems; and control of nonholonomic mechanical systems. Techniques from operator theory, differential geometry, dynamical systems, and computer science are combined to study control problems in a wide variety of areas. A central theme is the role of uncertainty and robustness, and the development of a unified theory for modeling, system identification, analysis, and synthesis of nonlinear control systems.

The CDS research program in nonlinear dynamics has two components; one mathematical and the other driven by specific areas of applications in science and engineering. The main thrust of the mathematical research is to develop mathematical methods for studying the dynamics of the types of nonlinear dynamical systems that arise in science and engineering. Active areas include developing methods for detecting and describing chaotic phenomena; local and global bifurcation theory; homoclinic and heteroclinic motions; Hamiltonian dynamics; geometric mechanics and mechanical systems with symmetry; phase space transport theory; geometrical dynamical systems theory for infinite dimensional systems; computational methods for visualizing higher dimensional phase space structures; and statistical methods for the description of chaotic dynamics.

Active application areas at Caltech include large flexible structures; chemical process control; vortex structures in complex fluid flows; mixing and transport processes in fluids; classical dynamics of triatomic molecules; phase space structure and mechanisms that enhance and inhibit transport and energy flow; turbomachines and complex combustion systems; nonlinear flight dynamics for highly maneuverable aircraft; robotic locomotion and manipulation; and the design of autonomous systems.

ELECTRICAL ENGINEERING

Electrical engineering at Caltech emphasizes both electronics and systems. Closely allied with both computation and neural systems and applied physics, it offers students the opportunity for study and research, both theoretical and experimental, in a wide variety of subjects, including wireless systems, quantum electronics, modern optics, solid-state materials and devices, power electronics, control theory, signal processing, data compression, and communications.

Areas of Research and Physical Facilities

Substantial experimental laboratory facilities, housed mainly in the Moore Laboratory of Engineering, are associated with each of the research fields described below.

1. *Solid-State Electronics* (Nicolet)—Projects emphasize experimental research in semiconductor device technology and currently include thin-film reactions, amorphous metallic alloys for thin-film diffusion barriers, characterization of epitaxial structures and their stability under ion irradiation and thermal processing.
2. *Quantum Electronics* (Yariv)—Research projects in progress

include the generation and control of ultrashort pulses, integrated optoelectric semiconductor circuits, semiconductor injection lasers, molecular beam epitaxy growth of sub-micron GaAs/GaAlAs structures for optoelectronics and electronics, phase conjugate optics, applications of nonlinear optics, ultra fast ($<10^{-12}$s) semiconductor lasers, crystal growth for image storage and processing, and theoretical and experimental quantum optics-light squeezing.

3. *Lasers and Guided Waves* (Bridges)—Experimental and theoretical studies in optical-, submillimeter-, and millimeter-wave technology and applications: EHF electro-optic modulation, dielectric waveguides and fiber optics, gas lasers; optical communication and measurement systems.
4. *Power Electronics* (Cuk)—Modern problems in the analysis, design, and synthesis of electronic circuits as applied to efficient conversion, control, and regulation of electrical energy. Fundamental research in the synthesis of new, more efficient, switched-mode power processing circuits, novel, more compact, integrated magnetics circuits, and advanced control techniques to improve the transient performance of regulated power supplies. Development of soft switching methods to reduce or eliminate switching losses in switching converters and produce high-efficiency, high-power-density converters operating at moderate switching frequencies ranging from 100 kHz to 1 MHz. Development of switched-mode converters with unity power factor input performance for off-line applications and fast load regulation. Synthesis of switching converters suitable for light ballast applications. Synthesis of dc-to-ac inverters for variable-speed motor drives, such as electric vehicles and switching amplifiers for servo applications. Ultra low (3V) and high voltage applications, such as TWT power supplies. Theoretical research is backed by experiments in a well-equipped power electronics laboratory.
5. *Communications* (Effros, Goldsmith, Goodman, McEliece, Vaidyanathan)—Theoretical and computer experimental work in a wide range of information, communication, and signaling problems. Current research emphases are in error control coding, modulation, and capacity calculations for channels that occur in communication networks, multiuser mobile and cellular radio, and deep-space communications; network communications, including general network reliability studies and ATM networks in particular; access, spectral sharing, dynamic channel allocation, and multiuser detection in wireless systems; information content and data compression; applications of neural networks to communication and signal processing problems; traffic modeling, routing, and network architectures for mobile services and ISDN; and design and simulation of single-rate and multi-rate digital filters and filter banks to mini-

mize the number of computational operations for a given accuracy. Digital filter banks, subband coding, wavelet transforms, multidimensional multirate signal processing. Possibilities exist for joint work with microsystems, wireless communication, digital signal processing, and data compression.

6. *Microsystems* (Goodman)—Theoretical and experimental research in the area of intelligent information processing systems. The group's goal is to design adaptive systems that learn and exhibit intelligent decision-making behavior, and to implement these on parallel VLSI architectures. Specific research topics are neural networks, autonomous systems, machine learning, expert systems, and analog and digital VLSI processing. The group collaborates with the communications, control, signal-processing, micromachining, and vision groups.

   The group's neural network research revolves around the NSF Center for Neuromorphic Systems Engineering, of which Professor Goodman is the director. The center's mission is to research the technologies for endowing the machines of the next century with the senses of vision, hearing, touch, and smell (chemical sensing). The multi-disciplinary research of the center spans the fields of biology and engineering, and has close ties with the CNS (Computation and Neural Systems) graduate option. Within this framework the experimental work of our group centers on the microsystems laboratory, which provides SUN workstations, VLSI design facilities, a wide variety of signal processing and hardware test equipment, and chip fabrication via MOSIS.

   Current research projects include real-time autonomous expert systems, vision recognition, analysis and synthesis of music, micromachine neural processors, neural and fuzzy control of autonomous vehicles, and electronic olfaction.

7. *Control* (Doyle)—Theoretical research is conducted in all aspects of control, with emphasis on robustness, multivariable and nonlinear systems, and optimal control. Theoretical developments are tested using the latest in computer and experimental facilities in a wide variety of application areas. Opportunities on campus, at Caltech's Jet Propulsion Laboratory, with industrial sponsors, and at NASA laboratories include control problems associated with large flexible space structures, refinery systems, flight control, robotics, control of unsteady flows, and various other aerospace and process control applications.

8. *Wireless Engineering* (Rutledge)—Devices for communications, radar, remote sensing, broadcasting, and industrial power from 1 MHz to 1 THz. Current projects include optically controlled antennas for phased-array radars, quasi-optical amplifiers and oscillators for millimeter-waves, multiplier grids for 1 THz and high-frequency switch-mode amplifiers.

9. *Learning Theory and Pattern Recognition* (Abu-Mostafa)—Systems and algorithms for machine learning and adaptive pattern recognition, and the underlying mathematical theory. Special emphasis on learning from hints. Practical implementations using neural networks and other models. Analysis tools from information theory and computational complexity.
10. *Optical Information Processing* (Psaltis)—Research to develop optical techniques and devices for information processing. Current areas of interest include optical memories, optical neural computers, neural network models of computation, pattern recognition and image processing, photorefractive crystals, liquid crystals, and Si and GaAs optoelectronic devices.

11. *Microsensors and Microactuators* (Tai)—Silicon micromachining technology is used to fabricate miniature solid-state microelectromechanical devices. Current research includes pressure sensors, flow sensors, IR sensors, accelerometers, microphones, micromotors, microvalves and micropumps, neuro-probes, and microsurgical tools. Device research requires broad exercise covering physics, design, fabrication, and testing. Hands-on training is especially emphasized in our Micromachining Laboratory.
12. *Digital Signal Processing* (Vaidyanathan)—Theoretical and computer oriented work on a wide variety of problems in digital signal processing. Multirate systems and filter banks, wavelets, filter design, quantization in signal processors, efficient signal coding and data compression, adaptive signal processing, multidimensional multirate systems, and wavelet transforms. Digital filter banks, subband coding, multidimensional multirate signal processing.
13. *Computational Vision* (Perona)—Theoretical and experimental research on the computational principles underlying vision processes. Psychophysics and modeling of the human visual system. Emphasis on multiresolution multiorientation image analysis, image segmentation, and visually guided navigation and recognition.
14. *Advanced Microfabrication* (Scherer)—High-resolution lithography and etching allow the miniaturization of structures to below 10 nm. These advanced fabrication tools are applied toward the development of microlasers, optoelectronic circuits, and detectors. Current research includes the application of these tools toward fabricating new metal and semiconductor devices.
15. 1. *Parallel and Distributed Computing* (Bruck)—Theoretical and experimental research on a number of fundamental issues related to the design of novel algorithms, protocols, and architectures that enable efficient parallel and distributed computing for scientific and commercial applications. Special emphasis on creating and experimenting with novel communication algo-

rithms and protocols for reliable and efficient inter-processor communication over a variety of communication media, including communication subsystems of parallel machines and local area networks. Also includes research on new models for computing inspired by neural networks with emphasis on the questions: What are the essential ingredients that make real neural networks computationally powerful? Can we improve computing systems based on these insights?

2. *Fault-Tolerant Computing*—Research on fault-tolerance aspects of high-performance computing systems. The focus is on the underlying theory as well as the practical challenges, including the creation of checkpointing schemes for scientific and commercial applications, the design of reliable communication algorithms and interconnection architectures, and the development of schemes based on error-correcting codes to enable reliable storage and high bandwidth communication.

16. *Data Compression* (Effros)—Theory and practice of lossy and lossless data compression. Current areas of interest include performance bounds for lossy and lossless systems; universal (or robust) codes; optimal rates of convergence in universal systems; joint source and channel codes; image and video compression using techniques such as vector quantization, transform coding, subband coding, bit allocation, and motion compensation; and distortion measures for visual data forms. The research combines ideas from information theory, stochastic processes, signal processing, and optimization. Possible areas of collaboration include communications, wireless communications, digital signal processing, and computational vision.
17. *Wireless Communications* (Goldsmith)—Theoretical research on link, system, and network aspects of wireless communications. Current areas of interest include time-varying channel modeling; capacity limits of wireless channels; adaptive coding, modulation, and joint source/channel coding; channel access and spectral sharing through TDMA, FDMA, CDMA, and hybrid techniques; multiuser detection and interference cancellation; dynamic channel allocation; models and performance analysis for multimedia wireless networks; and wireless network architectures and protocols. The research encompasses areas of channel modeling, information and communication theory, stochastic processes, multiuser communications, signal processing, and network theory and design.

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; 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 science and engineering of environmental systems. Research and instruction emphasize basic studies that underlie new solutions to challenging environmental problems such as urban, regional, and global air quality; water supply and water quality control; hazardous waste treatment; maintenance of stable ecosystems; and global environmental change.

Among the academic disciplines central to the program are: atmospheric and aquatic chemistry; environmental fluid mechanics; applied microbiology; hydraulics; hydrology; and aerosol physics and chemistry. 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 trace elements in the environment; coagulation and filtration of particles; enhanced chemical treatment of water supplies; aerosol chemistry and physics; cloud chemistry and global climate change; novel treatment processes for hazardous materials, e.g., ultrasound, pulsed-power plasmas, semiconductor photochemistry; environmental photochemistry; oxidation processes in aqueous systems; in situ bioremediation processes; pollutant and particle transport in alluvial streams and groundwaters; dilution in turbulent shear flows; buoyant discharges in coastal waters; the interaction of long waves with the shoreline; studies of the emissions sources and fate of organic chemicals in the atmosphere; regional air pollution modeling and control; and effects of air pollutants on works of art.

Environmental Quality Laboratory
The Environmental Quality Laboratory is a 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. 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 air pollutants; sources and distribution of carbon particles; visibility; development of advanced photochemical oxidant air quality models; reactive plume models; indoor air quality).
Water resources and water quality (pollution control for coastal waters; sewage sludge disposal; ground-water contamination and control).
Control of hazardous substances and residuals management (toxic substances in air and water; economics and regulation).

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 research projects and seminars.

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.

The Air Quality Laboratory includes a facility located on the roof of Keck that has been specially designed for studies of the photochemical reactions of gaseous and particulate pollutants. A large (60 m^3) outdoor chamber is used for direct simulations of atmospheric conditions using carefully prepared mixtures of hydrocarbons, nitrogen oxides, and other pollutants. Both gas phase chemistry and the formation of aerosol particles are probed with this system. A smaller (1 m^3) artificially illuminated chamber is used primarily for studies of chemical mechanisms and product identification. Analytical instrumentation includes monitors for major pollutants, gas chromatography, gas chromatography with mass spectrometry, and the resources of the Environmental Analysis Center for detailed chemical analysis of gas and aerosol samples. Measurements of aerosol particle formation and growth in the smog chamber experiments and in field studies are performed using the Scanning Electrical Mobility Spectrometer, a fast-response, high-resolution particle-sizing instrument developed at Caltech, along with more conventional particle measurement techniques (optical particle counters, cascade impactors, condensation nuclei counters, and filter samplers).

Flow reactors are used for controlled studies of nucleation processes, and to probe the dynamics of agglomerate aerosols. 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.

Through The Center for Interdisciplinary Remotely Piloted Aircraft Studies, a collaboration between Caltech and the Naval Postgraduate School in Monterey, California, a small aircraft that can be operated either piloted or remotely piloted is available for studies of the chemical, physical, and meteorological properties of the lower troposphere.

The environmental chemistry and aquatic chemistry laboratories and the Environmental Analysis Center are equipped for chemical analysis by atomic absorption, polarography, electrometry, plasma emission mass spectrophotometry, gas chromatography, high-performance liquid chromatography, fluorescence spectroscopy, infrared spectrometry, gas chromatography, mass spectrometry, liquid chromatography, mass spectrometry, high-resolution MS/MS/MS, ATR-FTIR, electrospray mass spectrometry, supercritical fluid extraction, SCF/MS, multi-component UV-visible spectrophotometry, electrophoresis chromatography, gradient-elution ion chromatography, gel permeation chromatography, total organic carbon analysis, and for physical characterization of aqueous particles by light scattering, electrophoresis and electrical particle size analysis.

The hydraulics laboratory has a variety of water channels and basins appropriate for studies of waves, sediment transport, turbulent diffusion, and density-stratified flows. A 40-meter-long glass-walled flume is equipped with dual circulating water systems for density-stratified shear flow studies. This tilting flume can also be used as a wave tank to generate breaking waves using a computer-operated hydraulic wave generator. Two smaller wave flumes also have computer-controlled wave generators that can produce waves of specified profiles. Four multi-beam laser-Doppler velocimetry systems are available for velocity measurements in turbulent flow studies or for wave-induced fluid velocity measurements. 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 department provides students with access to scientific computing and word processing through various departmental and personal computers and advanced supercomputers operated by the Institute.

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 on both 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 broadscale 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 well equipped for modern 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 the 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 a firm foundation for the instrument piers and tunnels. The Seismological Laboratory carries on a vigorous program of geophysical research and education and is headquarters for a 250-station seismological network and telemetered seismic array across Southern California. A smaller but state-of-the-art broadband and high dynamic range array called TERRAscope is also used for research.

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.

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 early fiction to the postmodern novel.

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 radicalism and demography. In certain courses, quantitative methods drawn from the social sciences are applied to historical studies.

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

A variety of courses in classical and modern European languages and in music and art history are available. Art history classes make use of the resources of the Huntington Library and Art Gallery, the Los Angeles County Museum of Art, and other museums in the area.

Areas of Research

The literature faculty, interested in new approaches to studying their subject, engage in research into the relationships between literature and psychology, literature and the pictorial arts, literature and history, and the material production of literature.

Research in history covers a wide range of historical fields and methodologies. Topics include an examination of the development of racial attitudes and behavior in the 19th-century U.S.; the history of the physical and biological sciences and of science in relationship to society; history and film; late British India; taxation and economic development in France; Chinese history and demography; and American working-class culture and labor relations. A cluster of faculty carry out research and teaching in the interrelated subjects of science, ethics, and public policy.

Research in philosophy includes work in philosophy of science, philosophy of mind and psychology, history of philosophy, ethics, and political philosophy.

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 183.)

MATERIALS SCIENCE

Materials scientists study relationships between the properties of materials and their internal structure, and how this structure can be controlled. The field of materials science at the California Institute of Technology is oriented toward fundamental issues in metals, semiconductors, ceramics, and composites. Additional faculty in electrical engineering, applied physics, and chemistry are also concerned with semiconductors and superconductors. Work in polymers is carried out in aeronautics, chemistry, and chemical engineering.

Areas of Research

The current areas of research by the materials science faculty are oriented toward a wide variety of nontraditional materials, many far removed from their equilibrium thermodynamic states. Examples of such materials include metallic glasses, metal-matrix composites, crystalline alloys containing chemical disorder, ball-milled powders, nanocrystalline materials, and shock-wave consolidated powders. The physical characteristics of interest span a wide range of mechanical, thermodynamic, and electrical properties. The internal structures of all these materials are being characterized and their origins explored. The studies often monitor how these structures relax toward equilibrium. In addition, there is significant interaction with the faculty in applied physics concerning ion-beam processing and epitaxial growth of semiconductor thin films. Materials science is a cross-disciplinary field, and materials research is performed by groups in many different options at Caltech. Graduate students in the materials science option can perform their thesis research with a supervisor or co-supervisor in a different option.

Physical Facilities

Research by the faculty, graduate students, and a few advanced undergraduates is conducted in the W. M. Keck Laboratory of Engineering Materials. Material-preparation facilities include equipment for physical vapor deposition under ultra-high vacuum conditions, shock-wave consolidation of powders, rapid solidification, high-energy ball milling, and ion-beam modifications of materials. Facilities for the characterization of materials include an extensive array of x-ray diffraction equipment including a double crystal diffractometer, two x-ray facilities with high-performance, position-sensitive detectors, a small-angle x-ray scattering system, a Rutherford backscattering spectrometer, Mössbauer spectrometers, two differential scanning calorimeters and two differential thermal analyzers, cryogenic facilities for the characterization of superconductors, and several test systems for the measurement of mechanical properties. A modern microscopy facility has been built around a Philips EM 430 300-keV transmission electron microscope with high resolution and analytical capabilities. Another 100-keV transmission electron microscope and an analytical scanning electron microscope are also dedicated to materials research. In addition to the equipment within materials science, a wide range of mechanical and microstructural characterization facilities 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, algebraic K-theory; *Algebraic geometry:* Hodge theory, arithmetical geometry; *Analysis:* classical real and complex analysis, complex dynamics, fractals, harmonic analysis, integration theory, and functional analysis; *Combinatorics:* block designs, coding theory, and combinatorial matrix theory; *Mathematical Logic:* recursion theory, set theory, and nonstandard analysis; *Mathematical Physics:* Schrödinger operators; *Mathematical Statistics:* sequential analysis; *Number Theory:* analytic and algebraic number theory, automorphic forms, and Galois representations; *Geometry and Topology:* low-dimensional and algebraic topology, Riemannian manifolds, and analysis on manifolds.

Physical Facilities

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

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

MECHANICAL ENGINEERING

Mechanical engineering embraces essentially all of those engineering aspects that have to do with fluid flow, heat and mass transport, combustion, power, propulsion, structural integrity, mechanical design, robotics, optimization, and systems analysis. Mechanical engineers are involved in the design and analysis of 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.

Mechanical Systems and Engineering Design. Activities in mechanical systems and engineering design encompass a broad range of traditional mechanical engineering fields, such as control systems, dynamics, kinematics, and mechanical design, as well as cross-disciplinary areas such as signal processing, computer control, engineering computation, electro-mechanical design, and micro-mechanical systems (MEMS) design. In the abstract, engineering design is the rigorous application of theory and analysis from traditional engineering disciplines to the synthesis of novel solutions to new problems. Analytical techniques from many fields must be used to analyze the performance, stability, and robustness of complicated systems. An imaginative, practical approach is emphasized for the solution of real problems involving many areas of technology. General areas of interest include design theory and methodology, imprecision in engineering design, engineering system design, MEMS design, kinematics, robotics, autonomous systems, and control of mechanical systems; computer-aided design and simulation.

Mechanics. Studies in the broad field of mechanics may be undertaken in either the applied mechanics, mechanical engineering, or civil engineering options. In general, work pursued within the mechanical engineering option will have a more physical orientation.

Thermal Systems and Applied Fluid Mechanics. This area encompasses a broad spectrum of research activities, including convective heat transfer (packed beds, moving granular media, rotating flows), fire research, chemical vapor deposition, materials processing and thin film growth, computational fluid dynamics, acoustics of turbulent flows, two-phase flow, cavitation, turbomachines for flow of liquids and rocket propellants, and air pollution.

Laboratory facilities are available in a large number of areas, especially computer-aided design, robotics, heat transfer, materials processing, pump dynamics, liquid phase turbomachines, hydrodynamic water tunnels for the study of cavitation, hydrofoils, and flow visualization. These facilities are shared with other groups in applied mechanics and civil engineering.

Jet Propulsion. The Daniel and Florence Guggenheim Jet Propulsion Center provides facilities for postgraduate education and research in jet propulsion and advanced spacecraft propulsion. 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, and 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. A collaborative program in advanced propulsion exists with the Jet Propulsion Laboratory.

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.

Particle Physics. Experiments in elementary particle physics are carried out with accelerators at the European Center for Nuclear Research (CERN), Cornell, and Beijing. Activities include studies of Z° decay at the LEP storage ring at CERN, studies of charmed quarks and τ leptons at IHEP, and studies of τ leptons at Cornell. In addition, a large project to search for magnetic monopoles and other phenomena in particle astrophysics is under way at the Gran Sasso underground laboratory in Italy. An active program is aimed at a future experiment to study CP-violation and rare B decays at a new accelerator at SLAC.

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 multi-GeV range, carried out at SLAC, CEBAF (Virginia), the Bates Linear Accelerator Center (MIT), and DESY (Hamburg, Germany). The lower-energy studies are designed to address important problems in nuclear astrophysics, while the high-energy studies emphasize the effects of the quark structure of nucleons on the structure and properties of nuclei. The group is active in research involving polarized and cryogenic targets that support the experimental program.

Nuclear and Neutrino Physics. This group focuses on fundamental properties of nuclei and elementary particles, particularly neutrinos. Experiments on neutrino oscillations being carried out at the San Onofre nuclear reactor and on double beta decay in an underground laboratory in the Gotthard tunnel in Switzerland help us understand neutrino mixing and neutrino mass. The experimental program, which also includes symmetry tests with polarized nuclei using a dilution refrigerator, is complemented by theoretical studies of nuclear structure and particle properties.

Experimental High-Energy Astrophysics. Research in this field encompasses X-ray and gamma-ray astronomy, compact object and gamma-ray burst astrophysics, cosmic-ray astrophysics, and magnetospheric and heliospheric physics. The Space Radiation Laboratory (SRL) is actively developing new instrumentation for hard X-ray and gamma-ray balloon and satellite experiments which will study compact objects, Active Gallactic Nuclei, gamma-ray bursts, and supernova remnants. An observational program concentrated on high-energy observations of neutron star and black hole systems using the Compton Gamma-Ray Observatory, the ROSAT and ASCA X-ray satellites, and the X-ray Timing Explorer is also a major effort in the group. SRL is also using instruments developed for launch on spacecraft and balloons to measure the composition of energetic nuclei arriving from the sun, the local interstellar medium, and nearby regions of the galaxy in order to study how these nuclei were synthesized and accelerated to high energies. There are a total of five SRL instruments currently active on Voyager, Galileo, and SAMPEX missions, with two or more to be launched on the Advanced Composition Explorer in 1997. The SAMPEX and Galileo missions are also supporting studies of trapped radiation in the magnetospheres of Earth and Jupiter, while the Voyager instruments are approaching the solar wind termination shock.

Experimental Ultraviolet and Optical Astrophysics. A sounding rocket program is developing novel telescopes and detectors for mapping the far cosmic ultraviolet background. New spectroscopic techniques are being exploited to study the dynamics and ionization of the violent interstellar medium. Ground- and space-based observations are being made to study the halos of galaxies, the history of star formation in the universe, the nature of UV bright objects, and the evolution of supernova shock waves in a heterogeneous interstellar medium. The first far UV all-sky imaging survey mission is currently under study. A new ground-based instrument for diffraction-limited imaging is being developed for the Palomar 5-meter telescope.

Infrared Astronomy. Astrophysical observations from 1-µm to 1-mm wavelengths are carried out with ground-based telescopes at the Palomar and Keck observatories. The infrared group constructs instruments for use on the 5-meter Hale and 10-meter Keck telescopes. 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 the Caltech 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 and bolometer detectors for use in future telescopes, both on the ground and in space.

Computational Astronomy. High-performance parallel computers are applied to computation-intensive problems in astronomy. Topics include radio pulsar searches, diffraction limited imaging with ground-based optical/IR telescopes, and large N-body simulations.

Condensed Matter Physics. Two-dimensional matter, phase transitions in two and three dimensions, phonon physics, and high-temperature superconductivity are areas of interest. Extensive new facilities for nanostructure fabrication and ultra-low-temperature physics have been established in Sloan Laboratory for exploration of mesoscopic systems. These facilities are complemented by the Microdevices Laboratory of the Jet Propulsion Laboratory (JPL), which plays a central role in a number of collaborative research efforts. Very recently, a new effort has been launched on the fractional quantum Hall effect and other strong correlation phenomena in semiconductor heterostructures.

Applied Physics. Techniques of theoretical and experimental physics are applied to problems in surfaces, materials, and planets. 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, the behavior of granular materials, and light-emission mechanisms in phosphors and scintillators.

Quantum Optics. Investigations of quantum dynamical processes in nonlinear dissipative systems are carried out in a number of fundamental optical experiments. Specific areas of research include the generation and application of squeezed and anti-bunched states of light, the realization of ideal quantum measurement and amplification schemes, and the investigation of nonperturbative radiative processes in cavity quantum electrodynamics.

Facilities in support of this work are located in the East Bridge Laboratory.

Experimental Gravitational Physics. Efforts are focused upon establishing a Laser Interferometer Gravitational-Wave Observatory (LIGO), which is presently under construction. The LIGO Project conducts research and development in precision measurement techniques and their application to gravitational-wave astronomy. On-campus research facilities include the 40-meter interferometer (currently the world's largest gravitational-wave detector prototype), special laboratory facilities for optics, vacuum studies, and electronics development, and an extensive network of computer workstations. The experimental program is complemented by work in the theoretical astrophysics group.

Neuroscience. Some properties of neural networks which underlie brain function are being investigated. The emphasis is on studies of neuronal networks grown in tissue culture, whose activity and response to stimuli are recorded as they change in response to imposed patterns of activity. Advanced biophysical and bioengineering technologies are used to obtain long-term electrical and optical records of neural signals.

Theoretical Physics. The particle theory group studies the unification of interactions based on superstring theory, the properties of hadrons described by QCD with an emphasis on heavy quarks, the quantum properties of black holes, and quantum cosmology.

Theoretical studies also include nuclear structure and reactions, condensed matter physics, including the quantum theory of solids and turbulent fluids, and various aspects of mathematical physics.

Theoretical Astrophysics. Many astrophysical interests are pursued in collaboration with the astronomy faculty, including problems in general relativity and cosmology, in relativistic astrophysics and accretion theory, in the interstellar medium, in the dynamics of stellar and planetary systems, in helioseismology, and in quasars, pulsars, and neutron stars.

Physical Facilities

The physics department is housed in six buildings grouped together on the south side of the campus: the Norman Bridge Laboratory, the Alfred P. Sloan Laboratory of Mathematics and Physics, the W. K. Kellogg Radiation Laboratory, the George W. Downs Laboratory of Physics, the 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, including the Intel Touchstone DELTA System, a high-performance supercomputer with a peak speed of 30 Gflop.

SCIENCE, ETHICS, AND SOCIETY

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The program in Science, Ethics, and Society is devoted to understanding the evolution of science and technology and their interactions, past and present, with the larger society. The program integrates historical, philosophical, and technical studies to explore the development and practice of the physical and biological sciences since the seventeenth century. Considerable attention is paid to the social, economic, political, and institutional context of technical development, particularly how the demands and organizations of industry, government, and philanthropy have shaped the scientific and technological enterprise. The program also examines the related moral and ethical issues—religious, social, and otherwise—that have pervaded disputes in areas such as weapons research and arms control, biotechnology and biomedicine, the environment, and scientific misconduct.

Areas of Research
Historical research in the program covers a broad range of subjects, including central developments in the fields of modern physics and physical chemistry, genetics and molecular biology, the sciences of mind, and special subjects such as the history of Big Science, federal policy for research and development, the political economy of patents, scientific instruments, biotechnology, and the environment. Philosophical research in the program deals with issues in causality and scientific inference, mind and the development of language, philosophy of psychology, foundations of probability and risk assessment, bioethics, and scientific fraud and misconduct. All research in the program is conducted in a multidisciplinary environment that ties together past and present as well as history, philosophy, politics, and economics. Work in Science, Ethics, and Society may be pursued as an undergraduate option and minor, a graduate minor, or on a course-by-course basis.

SOCIAL SCIENCE

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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 between economics, politics, and public policy in a rigorous scientific manner. Students can use their considerable quantitative talents to great advantage in these areas.

Areas of Research

The social science program is characterized by collaborative interdisciplinary research on the behavior of, and methods to improve the performance of, political and economic institutions.

Among the areas of research in political science are statistical analyses of campaign dynamics and the effect of economic conditions on voting, and theoretical models of legislative behavior and international relations.

Quantitative history incorporates economic and political models with statistical analysis to address such issues as the extent of racial discrimination in the U.S., the effect of the banking system on industrialization, and the role of capital markets in economic growth.

Economists study problems such as the role of computational complexity on politico-economic systems, and the design of institutions for the efficient provision of public goods, with applications to such diverse problems as railroad rights of way, the space shuttle resources, and the telecommunications industry. There is also interdisciplinary research on improving the theoretical and statistical models of individual choice behavior.

Caltech is a major center for the experimental investigation of game theory as a basis for economic and political decision making, and the application of these methods to public policy.

Information for Undergraduate Students

REQUIREMENTS FOR ADMISSION TO UNDERGRADUATE STANDING

The undergraduate program leads to a four-year Bachelor of Science degree. Admitted students matriculate in the fall term only. Caltech does not have a summer session or part-time program, and cannot consider you if you already have a bachelor's degree from another college, university, or the equivalent. If you have matriculated at any college, university, or the equivalent in a program leading to any degree, you will probably be required to apply as a transfer student, and should read the requirements in the section titled "Transfer Admissions."

ADMISSION TO THE FRESHMAN CLASS

Students are admitted to the freshman class on the basis of strong academic performance in a rigorous course of college preparatory study, especially in the areas of math and science; results of the SAT-I and three subject exams, SAT-II; teacher and counselor evaluations; personal characteristics; a demonstrated interest in math, science, or engineering; and information provided on the application.

Applying

An application for admission may be obtained by writing or calling the Office of Undergraduate Admissions, California Institute of Technology, Mail Code 55-63, Pasadena, California, 91125, (818) 395-6341. To be considered for admission, applications to the freshman class must be postmarked by January 1.

Early Action

Students who have a preference for Caltech may want to consider application under the Early Action plan. The Early Action application process requires that the completed application is postmarked by November 1. Under this application plan, students will be notified in late December of the admission decision. Students admitted under Early Action have until May 1 to make their commitment to attend.

High School Requirements

Students are expected to prepare for Caltech by successfully completing the following curriculum:

Four years of mathematics
(calculus or higher is strongly recommended)

One year of physics (calculus-based physics is recommended)
One year of chemistry
Three years of English (four years are recommended)
One year of U.S. history/government

College Board Tests

Applicants are required to take the following standardized tests by the November test series for Early Action consideration, and by the December test series for Regular Decision consideration:

SAT-I: Reasoning (Verbal and Mathematics)
SAT-II: Writing
SAT-II: Math II C
One of the following SAT-II subject exams: Biology, Chemistry, or Physics.

Information regarding the College Board examinations can be found in the Bulletin of Information, which may be obtained without charge at most high schools, or by writing to the appropriate address. Applicants who wish to take the examinations in the western United States or Canada, or in Mexico, Australia, or the Pacific Islands should write the College Board, P.O. Box 23060, Oakland, CA 94623-2306. For all other inquiries, write the College Board, P.O. Box 592, Princeton, NJ 08540.

Essays

The essays, which are required as a part of the application, are intended to provide students the opportunity to communicate their interests, experiences, and background. Since Caltech is interested in learning about each applicant, the essays are viewed as an important part of the admission decision process.

Evaluations

Three evaluations and a Secondary School Report are required. One must be from a math or science teacher, one from a humanities or social science teacher, one additional evaluation (see the instructions in the application), and a Secondary School Report filled out by your high-school counselor or other school official. You may submit more than required, but at least one must be submitted in each category.

Additional Information

Descriptions of research projects and hands-on science and engineering experience are helpful, as is material that demonstrates experiences outside of math and science. Additional material should be identified with name and social security number.

Acceptance

Caltech is a College Board member and therefore agrees to comply with the candidate's reply date of May 1. When accepting an offer of admission to Caltech, an admitted student is required to submit a matriculation form and registration deposit of $100, which will be applied to the first term's bill. Places in the entering class will not be held after May 1. Early Action applicants will be informed of their status in late December, and Regular Decision applicants will be informed by April 1.

Deferral of Entrance

For reasons of travel or work, Caltech will consider requests from admitted students for a one-year deferral of entrance. Students who request a deferment must submit a written request stating the purpose of postponement.

Advanced Placement, International Baccalaureate, and College Credit

Caltech encourages all prospective undergraduate applicants to prepare by challenging themselves with the most rigorous course of study available, including the Advanced Placement (AP) and International Baccalaureate programs. However, college credit for these classes is not automatic. (Please read the section on page 152 under "Humanities and Social Science Requirements" for a possible exception.) Course credit and/or placement in an accelerated program is *sometimes* granted as deemed appropriate by the department faculty. The awarding of Caltech course credit takes place at the time of registration each fall.

Biology
Prospective biology majors who pass both Bi 8 and Bi 9 in their freshman year would be considered to have met the core requirement of Bi 1.

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 15 units of Ch 1 ab 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 by performance on a placement examination to be administered in the summer prior to registration and on subsequent approval by the instructors of the courses to be taken and the courses to be substituted. Similarly, qualified students, with the instructor's consent, are allowed to substitute either Ch 3 b or Ch 4 a for the "core" chemistry laboratory requirement (Ch 3 a).

Mathematics

Normally, an entering freshman will take Ma 1 abc, Probability and Calculus of One and Several Variables. This course will cover the calculus of functions of one and several variables; basic probability; vector algebra; basic linear algebra; derivatives of vector functions, multiple integrals, line and path integrals, theorems of Green and Stokes; infinite series. The course will be divided into a lecture part, discussing primarily the mathematical notions, 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 ab. Students in need of additional background in elementary calculus may be advised to take Ma 9 (in addition to Ma 1 a) in the first quarter.

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 Ph 1; students who have performed 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.

The orientation, usually off campus, takes place during the 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

Transfer Admissions

Caltech admits transfer students for the fall term only. We require a completed application, letters of recommendation, SAT scores, an official transcript from the last secondary school attended and all colleges or universities attended, descriptions of all college-level math and science courses, and completion of the Caltech Transfer Entrance Examinations. Please review the section titled "Eligibility Criteria for Admission" to determine if you meet the eligibility requirements for transfer admissions consideration.

Academic Preparation
The following is a list of the Caltech core curriculum, taken by all Caltech students during their first two years. As a result of changes in the core curriculum instituted for this year's incoming freshman class, the list given below is a correct statement for new students, but not for continuing students. It is expected that transfer students will have had exposure to mathematics and science courses on a comparable level prior to entry to Caltech. Any of the following core courses that have not been covered by incoming transfer students must be taken upon matriculation to Caltech. However, transfer students who made plans on the basis of the previous core curriculum will be considered on that basis. There are no specific topics expected to have been covered in humanities and social science classes.

Freshman courses:
- Math 1 abc
- Physics 1 abc
- Chemistry 1 ab
- Chemistry 3 a
- Biology 1
- Humanities and Social Science electives

Sophomore courses:
- Math 2 ab
- Physics 2 ab
- *or*
- Physics 12 abc

Menu science class (currently either Ay 1 or Ge 1; can be taken freshman or sophomore year)
Additional laboratory science
Humanities and Social Science electives

Eligibility Criteria for Admission
The Institute admits to its sophomore and junior classes a small number of students who have excellent records at other institutions of collegiate rank and who perform satisfactorily on the Caltech Transfer Admissions Entrance Examinations.

- Students must have completed their secondary school education, and have subsequently enrolled at a college or university, in order to be considered for transfer admission.
- Transfer students are not admitted to the senior year at Caltech.
- Students who have already completed a bachelor's degree in any subject are not eligible for transfer.

Standardized Test Requirements
Transfer applicants must submit SAT-I: Reasoning (Verbal and Mathematics) scores. If the SAT-I has not been taken previously, it must be taken no later than the March sitting. International students are also expected to take the SAT-I administered by the College Board. Transfer applicants living in countries in which the SAT-I is not offered may be considered for admission, but should be aware that the lack of SAT-I scores will weaken their application.

The TOEFL (Test of English as a Foreign Language) is required of transfer applicants who are not citizens or permanent residents of the United States, and whose native language is not English. The TOEFL should be taken by the February sitting. International students who have studied in the United States for more than two years are exempt from taking the TOEFL.

Transfer Admissions Entrance Examinations
All applicants are required to take Caltech Transfer Admissions Entrance Examinations in math and physics. An additional exam in chemistry is required of those students planning to study chemistry or chemical engineering. Further instructions are included with the Caltech Transfer Application.

Transfer of Credit
The courses for which transfer applicants will receive credit, and the corresponding class standing, will be determined at the time of enrollment. Faculty members review each course submitted for credit on an individual basis. It is not possible, therefore, to answer general questions regarding the acceptability of coursework taken elsewhere. If the standard of work taken elsewhere is uncertain, additional examinations may be required before the question of

credit is finally determined.

Graduation Requirements
Admitted transfer students must meet the following requirements in order to receive a Caltech Bachelor of Science degree.

- Regardless of the amount of credit awarded upon matriculation, transfer students must spend at least two years (six terms) in residence at Caltech. Students must also earn at least 216 units at Caltech, not including courses taken to satisfy math and science core curriculum requirements.
- Students must take, or have taken the equivalent of, all core curriculum courses.
- Students must satisfy all of their chosen option's degree requirements. Transfer students may choose from among all Caltech undergraduate options.

Admissions Application
Applications are available September 1. Completed applications should be received by the Office of Undergraduate Admissions by March 1. Applicants will be notified of the decisions of the Admissions Committee in mid-June. Questions about transfer admission and application should be directed to Transfer Information, Office of Undergraduate Admissions, Caltech Mail Code 55-63, Pasadena, CA 91125, U.S.A., (818) 395-6341.

The 3/2 Dual Degree Plan

Caltech invites students from a select group of liberal arts colleges to transfer to Caltech upon completion of their junior year. After two years in residence at Caltech, and the successful completion of our requirements, 3/2 students will be granted a Bachelor of Science degree from Caltech and a second bachelor's degree from their liberal arts college. Students may transfer into any of the Caltech options, with the current exception of electrical engineering.

Students from the following institutions are eligible to apply to the 3/2 program:

Bowdoin College (ME)	Pomona College (CA)
Grinnell College (IA)	Reed College (OR)
Occidental College (CA)	Wesleyan University (CT)
Ohio Wesleyan University (OH)	Whitman College (WA)

Applications and a program description are available from the 3/2 liaison at each of the liberal arts college partners and from the Caltech Office of Undergraduate Admissions. Deadline for submission of 3/2 applications and support materials is April 1.

Admission to the 3/2 program is not guaranteed and will be determined by the Caltech Faculty Upperclass Admissions Committee. Students applying should have a record of superior academic achievement at their home institutions, and strong letters of recommendation from their 3/2 liaison and an additional faculty member. They must have completed a minimum of one year of calculus-based physics and mathematics (two years are recommended) including multivariable calculus and differential equations, and one year of chemistry.

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. 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 (USC), an Air Force Reserve Officers' Training Corps program 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 (UCLA). The Air Force (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. 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. Air Force ROTC offers two types of scholarships, Type I and Type II. The application process is the same for each scholarship type. Type I scholarship provides full tuition, required fees and books, uniforms, and $100 a month. The entitlement for a Type II scholarship is the same except the tuition is capped by Air Force ROTC. 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. For additional information on this program, contact the Department of Aerospace Studies (AFROTC) at the University of Southern California, Los Angeles, CA 90089, (213) 740-2670. 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, (310) 825-7381.

REGISTRATION REGULATIONS

Procedures

Students must register on the dates specified in the academic calendar. Students are not registered until they have both

- returned 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 undergraduate student sabbatical. If continuity is broken by withdrawal, reinstatement is required before academic work may be resumed.

Changes in 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 Registrar.

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.

Undergraduate Student Sabbatical

An undergraduate student sabbatical must be sought by written petition, which must be accompanied by a completed withdrawal card. The Dean or Associate Dean of Students may grant a sabbatical provided: (a) the student is in good standing, in other words does not have to meet special academic requirements as a result of reinstatement, (b) the sabbatical is for one year or less, and (c) the sabbatical extends over a period that includes at least one full term.

The Dean or Associate Dean may also grant a leave for medical reasons provided the petition is approved by the Director of Health Services or the Director of Counseling Services. Return from a leave for medical reasons also requires the recommendation of the Director of Health Services or the Director of Counseling Services, and the final approval of the Dean or the Associate Dean. A student returning from a leave for medical reasons will maintain the same academic standing that he or she had previously.

Involuntary Leave

The Dean of Students may place a student on an involuntary leave if persuaded by the evidence that such action is necessary for the protection of the Institute community or for the personal safety or welfare of the student involved. An involuntary leave may include a specific date after which the student may return or it may be indefinite as to term. In the latter case the Dean of Students may stipulate conditions that must be met before the student may return. These conditions might include a letter of approval from the Director of Health Services or the Director of Counseling Services. A decision by the dean to place a student on involuntary leave is subject to automatic review within seven days by the Vice President for Student Affairs (or his designee). Nothing in this statement precludes access to the normal student grievance procedure.

All other petitions pertaining to leaves should be addressed to the Undergraduate Academic Standards and Honors Committee.

Withdrawal from the Institute

Formal separation from the Institute is effected by filing a completed withdrawal card with the Registrar. The effective date of an immediate 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 undergraduate student sabbatical, 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 and the number of units will be noted on the record. The record will also indicate whether an undergraduate student sabbatical 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 or Summer Reading

Qualified undergraduate students who are regular students at the Institute are permitted to engage in research or reading 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. An undergraduate may not receive payment for research carried out for academic credit. Students who are registered for summer research or reading will not be required to pay tuition for the units. A student may apply up to 18 units of summer research per summer and 36 units in total toward Institute graduation requirements.

SCHOLASTIC REQUIREMENTS

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

Eligibility 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 24 or more units of E or F, or 3 or more course grades 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 first and second term 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 the first day of classes 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 by UASH 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 taking additional 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 GPA 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

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. To maintain satisfactory academic progress, students must also complete all freshman core courses by the end of their sixth term in residence and all sophomore core classes by the end of their ninth term in residence. Failure to do so will result in ineligibility.

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 12 terms must petition the Undergraduate Academic Standards and Honors Committee for approval to register for further work each term.

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.

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.

Allowance of Credit in the Humanities and Social Sciences
In general, Caltech students should fulfill Caltech course requirements by taking courses at Caltech. Students are expected to have a well-reasoned educational goal for taking classes elsewhere. The only exceptions are transfer students admitted to advanced standing. Credit for comparable work done at other institutions with similar academic standards is not granted automatically.

Students who wish to take courses elsewhere (whether on leave, in the summer, or during the academic year) should consult, *in* *advance*, with the Executive Officer for the Humanities or the Executive Officer for the Social Sciences, or their designees, to minimize any misunderstanding regarding the nature of credit they may receive. Upon completion of the course, the student must obtain an Allowance of Credit Form from the Registrar, obtain the signed approval of the Executive Officer, or his or her designee, for transfer credit, and return the completed form to the Registrar's Office. The Executive Officers are the final authority in the allowance of credit.

Guidelines and specific information about allowance of credit are available from the Division of the Humanities and Social Sciences.

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

By the middle 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 registration for the following year.

In exceptional circumstances an undergraduate may be allowed to major in two options for the Bachelor of Science degree. In order to do so the student must present a rationale for the double option and a plan of study leading to completion of the degree in four years. The plan, and any substantive modifications, must be approved by a committee composed of the option representatives of the two options. The plan must meet the minimum requirements for both options as set forth in this catalog, but the committee may impose additional requirements as well. The approved plan should be submitted to the Registrar during the sophomore year, but in any case no later than the start of the senior year. The student will then be assigned an adviser by each option. Consult the Registrar for appropriate procedures.

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. (See "Unpaid Bills" for complete details.)

ATHLETICS AND PHYSICAL EDUCATION

Before graduation each undergraduate is required to successfully complete 9 units of physical education. This requirement may be satisfied entirely or in part by participation in intercollegiate athletics, or successful completion of physical-education class coursework. All grades are issued pass/fail. Of this 9-unit PE requirement, only 3 units may be counted from the specialty classes under PE 1. A maximum of 6 units per term may be applied toward graduation requirements with the total not to exceed 36 units. Participation as a bona fide member of an intercollegiate team for the period covered by the sport in a given term satisfies the requirement for that term.

A broad program of instruction is provided each term. Enrollment in classes is conducted during registration. Late registration is permitted during the first week of each term, provided there is space available and with permission of the instructor. 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 class of the same activity.

UNDERGRADUATE EXPENSES

For freshmen and transfer students applying for admission, there is a $40 application fee. This fee is not refundable.

A registration fee, $100 for freshmen and 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 Director of Residence Life by the date specified in the instructions accompanying the contract.

Expense Summary 1996–97

General:		
General Deposit	$ 25.00	[1]
Tuition	18,000.00	
Student Body Dues, including *The California Tech*	60.00	[2]
Assessment for *Big T*	36.00	[2]
Assessment for Caltech Y	$ 15.00	
	$ 18,136.00	

Other:	
Student Housing: (Rates are subject to change)	
Room (on campus; other rates vary)	3,180.00
Board (provides 10 meals per week while Institute is in session)	2,298.00
Dues	105.00
Books and Supplies (approx.)	795.00
Personal Expenses (approx.)	1,493.00
Meals not on Board contract (approx.)	$ 1,483.00
	$ 9,354.00

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

The following is a list of undergraduate student fees at the California Institute of Technology for the academic year 1996–97 together with the dates on which these charges are due. Fees are subject to change at the discretion of the Institute.

First Term
September 24, 1996 (Freshmen)
September 30, 1996 (All Others)

	Fee
General Deposit	$ 25.00
Tuition	6,000.00
Associated Student Body Dues	20.00
Assessment for *Big T*	12.00
Assessment for Caltech Y	5.00
Room and Board (for on-campus residence)	1,826.00
Student House Dues and Assessment	35.00

Second Term
January 3, 1997

Tuition	$ 6,000.00
Associated Student Body Dues	20.00
Assessment for *Big T*	12.00
Assessment for Caltech Y	5.00
Room and Board (for on-campus residence)	1,826.00
Student House Dues and Assessment	35.00

Third Term
April 1, 1997

Tuition	$ 6,000.00
Associated Student Body Dues	20.00
Assessment for *Big T*	12.00
Assessment for Caltech Y	5.00
Room and Board (for on-campus residence)	1,826.00
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	$ 167.00
Minimum tuition per term	1,670.00

Audit Fee $167.00 per lecture hour, per term.

Other Items of Interest

Refunds
Students withdrawing from the Institute during the first half (first 38 days) 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.*

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

Calendar Days	*Percentage of tuition due the Institute*	*Percentage of tuition refund due the student*
Prior to first day of class	0%	100%
1–7	10%	90%
8–20	50%	50%
21–38	75%	25%
39 and after	100%	0%

- Registration for reduced units is approved by the Undergraduate Academic Standards and Honors Committee or the Registrar. For students enrolled in less than 36 units for the term, a tuition credit for the difference between the charge for 36 units and the appropriate charge for the reduced units will be applied to the student's account. This tuition credit will only be made for reduced units as of the published Add Day of each term. However, if tuition credit has been applied to students' accounts for reduced units, any subsequent increase in tuition units will result in the appropriate tuition charge for the increased number of units retroactive to the beginning of the academic term.

The Financial Aid Office is notified of refunds for aid recipients. The amount of refund is determined by the refund schedule stated above.

Tuition Refund for Call to Active Military Service
Students serving in reserve units of the U.S. Armed Services will receive a full refund of tuition charges for any term which they are unable to complete because they are called to active duty.

Refund and Repayment Policy

In accordance with federal regulations, Caltech has established a fair and equitable refund policy for students who find it necessary to withdraw from the Institute.

Withdrawal from the Institute: A student who officially withdraws from the Institute during an academic term will receive a tuition refund based on the schedule published on page 123. A student living in Caltech housing may also be eligible for a partial refund from the Housing Office.

When granting a refund to a financial aid recipient, it is Caltech's policy to reduce the aid award by the amount of the refund. Therefore, an aid recipient's refund is, in most cases, returned to the original aid account.

Should an overpayment or overaward occur (i.e., when a student receives more aid than he or she is eligible to receive), the Financial Aid Office will compare adjusted costs to aid disbursed in accordance with federal guidelines. If aid disbursed exceeds the costs, the student will be responsible for the overpayment. Overpayment(s) will be charged to the student on his or her student account. Additional information is available in the Financial Aid Office.

Appeals on Refunds: Any questions or problems related to refunds should be directed to Oliver Nandkishore, Assistant Director of Finance in the Student Accounts Office, Caltech, MC 116-6, Pasadena, CA 91125.

Dropping a Course: A student's financial aid package will be adjusted to reflect any tuition adjustment made by the Student Accounts Office as well as any other adjustments required by law or by the applicable fund donor(s). In addition, students who are not enrolled full time as of the last day to add courses may have their aid revised. Generally, students enrolling less than three-fourths time will have an increased work award. Additional information is available in the Financial Aid Office.

Refund upon Withdrawal: Should a student, for whatever reason, withdraw from Caltech during an academic term, a refund of tuition as well as room and board, if applicable, is calculated. The amount of refund is determined by how much of the term has elapsed. If the student is a recipient of student financial assistance, that assistance, if applicable, will be reduced as a result of his/her withdrawal. Recent federal legislation determines the amount of refund for recipients of federal Title IV student assistance. It is the purpose of this section to inform students of the financial implications of withdrawal.

If the student is not a recipient of federal student financial aid, the Institute's refund policy returns any refund of tuition or room and board first to the programs from which assistance has been received (i.e., scholarships, Caltech gift assistance). Any amount remaining will then be returned to the student. The non-Title IV portion will be distributed as appropriate, first to outside agencies, as required, then to Caltech grant, scholarship, or loan, depending on the composition of the aid package. These distributions will occur as credits to the appropriate aid funds and charge(s) to the student's Caltech account. This policy is consistent with the philosophy of financial aid being utilized after the resources of the student and parents. Refunds of tuition are given only through the first half of the academic term, while the room and board refunds are prorated for the entire academic term less forfeiture of any housing deposits.

A different refund policy is required if the student is the recipient of federal Title IV student assistance. For first-time students at Caltech, a pro rata refund is required through the 60 percent point of the term. Any refund must then be applied first to the federal aid program(s) in the following prescribed order:

1. Federal SLS
2. Federal Unsubsidized Stafford Loan
3. Federal Subsidized Stafford Loan
4. Federal PLUS Loan
5. William D. Ford Federal Direct Unsubsidized Stafford Loan
6. William D. Ford Federal Direct Subsidized Stafford Loan
7. William D. Ford Federal Direct PLUS Loan
8. Federal Perkins Loan
9. Federal Pell Grant

10. Federal Supplemental Educational Opportunity Grant
11. Other federal Title IV aid programs
12. Other federal sources of aid

Any remaining refund will then be returned to other state, institutional, or private student assistance that has been utilized.

If the student is the recipient of federal Title IV student assistance, but is not a first-time student, a comparison of institutional refund policy (previously mentioned) and a federal methodology (called Appendix A) must be made and the policy giving the greatest refund to be applied to the federal aid programs is to be used. Again, refunds are applied first to the federal aid programs in the prescribed order. The federal methodology of Appendix A is as follows:

	refund to the student's account
Start of term to 10% point of the term	90%
Between 10% and 25% point of the term	50%
Between 25% and 50% point of the term	25%
After 50% point of the term	0%

Specific examples of refund calculations are available upon request.

In the event that a student's disbursed financial aid exceeds the direct costs on the student's personal account, a credit balance will result. Withdrawal will result in the reversal or repayment of the resulting credit balance.

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 $36 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 returned the necessary forms for a program approved by his or her adviser and has paid tuition and other fees. A penalty fee of $50 is assessed for failure to register within five days of the scheduled dates. A $50 late penalty will be charged by Student Accounts for failure to clear a past-due account within five days of the beginning of instruction.

Honor System Matters
Monies owed to the Institute resulting from a Board of Control decision may be collected through Student Accounts, at the request of the Dean of Students.

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 Director of Residence Life, 115-51, California Institute of Technology, Pasadena, CA 91125.

Special Fees
Students taking the Summer Field Geology course (Ge 120) 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 the Institute should not be prevented from doing so for financial reasons. Although the Institute 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.

Demonstrated financial need is the difference between the annual 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, an allowance 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 United States, Mexico, or Canada.) Caltech's estimate of a family's ability to contribute is determined annually in accordance with guidelines established nationally by the U.S. Department of Education and the College Scholarship Service.

Eligibility for each type of assistance varies, depending upon the source of funds. Most students who attend Caltech qualify for some kind of financial aid from the Institute, federal and state agencies, outside organizations such as foundations and businesses, and/or lending institutions. Assistance offered by Caltech includes federal, state, 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 should not wait to be accepted for admission to Caltech before applying for financial aid. Applications for admission are evaluated separately from requests 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. In addition to direct financial assistance, information is available, upon request, about education payment plans and financial-planning resources. (For information on non-need-based scholarships and prizes, see pages 143 and 145–151.)

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 the determination of financial need, application procedures, as well as financial aid awards and programs, contact the Financial Aid Office, California Institute of Technology, 12-63, Pasadena, CA 91125, or call (818) 395-6280.

HOW TO APPLY FOR FINANCIAL AID

Slightly different procedures and deadlines exist for each category of student applying for financial aid. Descriptions of these procedures and deadline dates are listed below.

Application Process for Caltech Financial Aid PROFILE and Free Application for Federal Student Aid (FAFSA) Forms
The College Scholarship Service (CSS) PROFILE application and the Free Application for Federal Student Aid (FAFSA) forms are

both required of all applicants (with the exception of international applicants who should review the specific procedures listed on page 130) for Caltech need-based assistance. These forms provide essential information about the applicant's family's financial picture and enable the Financial Aid Office to determine eligibility for federal, state, and Caltech financial assistance.

Please note the following steps for filing the PROFILE and FAFSA forms:

Step 1
To receive a 1997–98 PROFILE application, students may register by telephone, 1-800-778-6888, beginning September 16. This number is available 7 days/16 hours per day, 8:00 a.m.–12 midnight (Eastern time). Students registering by telephone will have the option of paying PROFILE fees by credit card or being invoiced for check/money order payment at the time of application submission. The customized PROFILE application packet will be mailed within 24–48 hours of the student's phone call. Electronic options for registering are available as is the paper registration. Contact the College Scholarship Service at the above number for more information. Caltech's CSS code is 4034. Continuing CIT students file a Renewal PROFILE application and indicate Caltech in item #74.

Step 2
Complete the customized PROFILE application and return it to CSS for processing. CSS will then report the financial information to the colleges listed on the Registration form and mail each student a Data Confirmation Report (DCR) approximately 2–3 weeks after receipt of the PROFILE application.

Step 3
If the applicant has requested financial aid information, the Caltech Financial Aid Office will send a Free Application for Federal Student Aid (FAFSA) in late Fall. Complete the FAFSA with Caltech's code 001131 and mail it according to the schedule below. The completed FAFSA form is required to determine eligibility for federal financial aid programs.

CALTECH'S FINANCIAL AID PRIORITY MAILING DATES

Type of Applicant	*Submit PROFILE Registration by*	*Mail PROFILE Application by*	*Mail FAFSA by*	*Receive tentative aid award information by*
Early Action Applicant	October 15	November 15	January 15	February 1
Other Freshman Applicants	December 16	January 15	January 15	April 7
Transfer Applicants	January 15	March 3	March 2	June 16
Continuing 1997 CIT Students	Not applicable	March 3	March 2	Summer

International Applicants
International applicants who request financial aid information will be sent the Foreign Student Financial Aid Application and Certification of Finances in late December.

INTERNATIONAL STUDENT
FINANCIAL AID PRIORITY MAILING DATES

Applicants	*Mail Completed Foreign Student Financial Aid Application and Certification of Finances to Caltech by*
FRESHMAN INTERNATIONAL	March 3
TRANSFER INTERNATIONAL	April 15
CONTINUING CIT INTERNATIONAL	March 3

International applicants who do not apply for financial aid by published deadlines, or who are denied aid for their first year at Caltech, are not eligible for aid for any other academic period while they are undergraduates at the Institute. Citizens of Canada and Mexico are exempt from this rule. Those offered financial aid will be eligible to apply for aid in subsequent years.

All students must reapply for aid each year. *(See "Returning Students.")*

TYPES OF AID AVAILABLE

Once financial need has been determined, that need will be met either by a single type of aid or by a combination of grants or scholarships, student employment, and low-interest loans. Such a combination is called a financial aid "package."

Grants and scholarships, which include those provided both through Caltech and by the federal and state governments, do not have to be repaid. Employment wages are money earned during the academic year either on or off campus. Employment opportunities exist for students who work to help meet their educational costs. Loans are a sound means of meeting a portion of current educational expenses by borrowing against future earnings. Loans, of course, must be repaid.

Grants and scholarships are typically disbursed to the student's account, one-third at the beginning of each term. Federal Perkins Loans, Direct Loans, and Caltech Loans are also disbursed to the account in thirds, after a promissory note is signed (usually at registration). Wages for on-campus employment are paid as earned, by check, through the biweekly Caltech payroll system.

Grants and Scholarships

Caltech Grants and "Named" scholarships are awarded from an institutional fund or endowment specifically established for the purpose of helping undergraduates meet their demonstrated financial need. The amount of the award depends entirely on demonstrated financial need.

"Named" scholarships are awarded to undergraduates from gifts to the Institute given for scholarship purposes, and are named by or for the donor. All aid applicants who meet the specifications of the donor are considered for a "named" scholarship. No special application need be filed. Recipients may be asked to write a thank-you letter to one or more donors. Many donors are lifelong friends of the Institute, and they appreciate hearing about student life at Caltech today.

Federal and State Grants

The Federal Pell Grant Program is for undergraduate students who have not yet completed a baccalaureate degree. Eligible students may receive Federal Pell Grants for the period of time necessary to complete a first undergraduate baccalaureate degree.

The Federal Pell Grant program is intended to be the "floor" of the student's financial aid package. This is usually the first program for which a student's eligibility is determined. Many other federal aid programs require that a student's Federal Pell Grant eligibility be considered prior to determining eligibility for other aid.

Application for a Federal Pell Grant is made by using the *Free Application for Federal Student Aid (FAFSA)*. Applicants will receive a Student Aid Report (SAR) directly from the FAFSA processor. Upon receipt of the SAR, students should review the SAR for errors. If corrections need to be made, students can submit the SAR to the Financial Aid Office for corrections.

If eligible, the exact amount of the student's award will be determined by the Financial Aid Office based upon the cost of attendance, the Expected Family Contribution, and the student's enrollment status.

In 1996–97, Pell Grant awards will range up to $2,470 per year.

The Federal Supplemental Educational Opportunity Grants (FSEOG) Program provides grant funds for undergraduate students who have not completed their first baccalaureate degree and who are financially in need of this grant to enable them to pursue their education. Awards of FSEOG funds must be made first to students who show exceptional financial need (defined as those students with the lowest federal expected family contribution at the Institute). Priority for FSEOG funds must be given to Pell Grant recipients. No additional application is required. These grants are contingent upon federal appropriations. The minimum annual FSEOG award is $100, and the maximum annual award is $4,000.

Cal Grants are awarded to California residents by the California Student Aid Commission (CSAC). All students who are eligible to apply are required to do so each year at the time they apply for Caltech assistance. Students should complete a FAFSA and GPA Verification Form. Results from the FAFSA are sent by the processor to the CSAC, where eligibility is determined. Renewal materials are mailed to current recipients at their permanent addresses each year in December. Students must renew their Cal Grant eligibility on an annual basis by completing the FAFSA. The FAFSA deadline for new applicants is March 2.

Cal Grant A, which is awarded on the basis of financial need and academic achievement, is designed to assist with the cost of tuition and fees. In 1995–96, the maximum Cal Grant A awards were valued at $5,250.

Cal Grant B is awarded to students from disadvantaged/low-income families. During the first year, Cal Grant B recipients are awarded a monthly stipend for living costs. Renewal Cal Grant B recipients are awarded the monthly stipend and, in addition, assistance with tuition and fees. In 1995–96, Cal Grant B recipients received a maximum of $1,410 total in quarterly stipends and $5,250 in tuition and fee assistance.

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

Self-Help: Employment and Loans

A self-help award is a combination of loans and employment opportunities students may take advantage of during the year to help meet school expenses. Students often can choose how much of their self-help they wish to earn and how much they wish to borrow.

The amount of self-help expected of a student is established yearly by the Institute. For the 1996–97 academic year, a freshman typically was awarded $6,000 ($4,600 loan and $1,400 work) toward educational expenses. An eligible student is first awarded a combination of work and/or loan, with any remaining need being met with grant assistance.

At Caltech, in order to meet their expected self-help contribution, students are offered a suggested combination of loan and employment opportunities. Students often can choose how much they wish to earn and how much they wish to borrow, or they may decide to work or borrow less than the standard self-help amount. These choices will not affect the amount of their grant.

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 Center. Undergraduate students must receive approval from the Dean of Students to work more than 16 hours per week. Students typically work an average of 10 hours per week. Freshman students must receive permission from the Dean of Students to work before accepting their first work assignment.

The Federal Work Study Program provides jobs for eligible students who demonstrate need for such earnings to meet a portion of their educational expenses. Jobs may be located on campus or off campus. The employer may be Caltech; a federal, state, or local public agency (such as Caltech's Jet Propulsion Laboratory); or a private nonprofit organization, such as a community service agency. Beginning with the 1994–95 school year, Caltech placed an increased emphasis on placing Federal Work Study students in community service jobs. Federal Work Study employees are paid at least the federal minimum wage rate. Federal Work Study is part of a freshman's financial aid package for the second and third terms only.

The maximum amount of Federal Work Study wages that students may earn is determined by financial need. To locate a job, the student may contact the campus Career Development Center and the student newspaper. *Summer Federal Work Study* may also be available.

The Caltech Work Study Program is funded by the Institute to provide part-time employment for international students who have demonstrated financial need. This program is limited to the campus or to JPL. The program is designed to parallel the Federal Work Study Program, and the same guidelines apply to its administration. Summer Caltech Work Study Program funding may also be available.

Federal Perkins 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 have repaid or 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 nine months after leaving school or dropping below half-time status. Interest is then charged at a rate of 5 percent on the unpaid balance. Federal Perkins Loans are limited to a total of $3,000 annually during undergraduate study, a total of $15,000 for all years of undergraduate study, and a maximum of $30,000 for the entire undergraduate and graduate career. Students may be allowed up to ten years to repay, based upon the amount they have borrowed. Information concerning deferment, repayment, postponement, and cancellation will be provided on each borrower's loan promissory note and in a disclosure statement given to students prior to disbursements of the loan.

Caltech Loans are made from funds provided by many sources, and are used to supplement the Institute's Federal Perkins Loan 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 nine months after leaving school or dropping below half-time status. For Caltech Loans, interest is then charged at a rate of 5 percent on the unpaid balance until the loan has been repaid in full. As with Federal Perkins Loans, if the student transfers to another institution or attends graduate school, here or at another institution, no payments need be made on the principal or interest as long as half-time attendance is maintained. More specific information is provided to each borrower on the promissory note and in a disclosure statement given to students prior to disbursement of the loan. For example, *Cecil L. Killgore Student Loans* are available to members of all undergraduate and graduate classes, including freshmen, under the same general guidelines established for Caltech Loans as described above. It is the fund's policy to make loans available at the lowest possible cost to the student, with priority given to students in the field of power engineering.

Other Loans: Emergency Loans may be available to students regardless of their eligibility for financial aid. The Hoover Loan Fund enables students to borrow small sums of money to cover unforeseen emergencies. These loans are administered by the Dean of Students on a case-by-case basis. Additional information and applications may be obtained from the Dean of Students' Office.

The Caltech Y also has a no-interest, 30-day, emergency-loan program. Maximum loans are $25.

William D. Ford Federal Direct Student Loans

The *William D. Ford Federal Direct Student Loan Program* is an opportunity for students to borrow money from the federal government to pay for a Caltech education. Under this program, the U.S. Department of Education makes loans, through Caltech, directly to students. Caltech will use the William D. Ford Federal Direct Loan to pay tuition and fees, as well as room and board charges, and will refund any remaining money to the student for personal expenses. William D. Ford Federal Direct Loans simplify loan repayment—payments go directly to the federal government.

Direct Loans include:

1. The Federal Direct Stafford Loan Program
2. The Federal Direct Unsubsidized Stafford Loan Program
3. The Federal Direct PLUS Loan Program; and
4. The Federal Direct Consolidation Loan Program

Federal Direct Stafford Loan

The Federal Direct Stafford Loans (subsidized and unsubsidized) are available to both graduate and undergraduate students. The federal government "subsidizes" a loan by paying the interest while the student is in school, during the grace period, and during periods of deferment. For an unsubsidized loan, the government does not provide the subsidy; therefore, interest on the loan accrues during those periods. The calculated family contribution is taken into consideration when determining a student's need for a subsidized loan. To determine eligibility for an unsubsidized loan, the family contribution is not considered. Other than these two differences, the provisions of the Federal Direct Stafford Loan Program apply to both subsidized and unsubsidized loans (i.e., loan limits, deferment provisions, etc.).

Before Caltech can determine loan eligibility, a determination of the student's eligibility for a Pell Grant must be made. In order to make this determination, the applicant must complete a Free Application for Federal Student Aid (FAFSA). Subsidized Federal Direct Stafford Loans may not be used to substitute for the federally calculated expected family contribution; however, Federal Direct Unsubsidized Stafford Loans may be used in this capacity. Before a student can apply for a Federal Direct Unsubsidized Stafford Loan, eligibility for a subsidized loan will be determined. To reiterate, Federal Direct Unsubsidized Stafford Loan borrowers are not required to demonstrate need in order to be eligible. However, if the student is eligible for a Subsidized Federal Direct Stafford Loan, he or she will be awarded that loan first, and this award will be taken into consideration when determining eligibility for the Federal Direct Unsubsidized Stafford Loan. The amount borrowed under the subsidized and unsubsidized loans combined may not exceed the annual/aggregate loan limits, or the total cost of education.

The following chart summarizes loan limits for Federal Direct Stafford Loans and Federal Direct Unsubsidized Stafford Loans.

Maximum Loan Amount for a Full Academic Year

	Dependent Student *Maximum combined subsidized & unsubsidized Federal Direct Stafford Loan*	***Independent Student*** *Maximum combined subsidized & unsubsidized Federal Direct Stafford Loan*
1st year undergraduate	$2,625	$6,625
2nd year undergraduate	$3,500	$7,500
3rd & 4th year undergraduate	$5,500	$10,500
Graduate/Professional	N/A	$18,500

Note: The loan amounts listed above cannot exceed the cost of the student's education minus other financial aid received.

Aggregate loan amounts are $23,000 for dependent undergraduates, $46,000 for independent undergraduates, and $138,500 for graduate and professional students (including Stafford amounts borrowed as an undergraduate).

All loans must be disbursed in at least two installments. Further, loan disbursements for first-time, first-year undergraduate borrowers may not be released to the student until he or she has been enrolled in his or her program of study for at least 30 days.

Effective July 1, 1994, the maximum interest rate for new loans is 8.25 percent. The actual rate is variable, and is determined according to a formula linked to the 91-day Treasury-bill rate. For the 1996–97 academic year, the rate will be set in early summer 1996. To offset the federal government's cost of the program, the borrower must pay an up-front origination fee of 4 percent of the principal amount of the loan. This origination fee is used to offset some of the federal costs of the program.

Federal Direct PLUS (Parent) Loan Program

Under the Federal Direct PLUS Program, parents of dependent undergraduate students may borrow up to the difference between the cost of attendance and all other financial aid, per dependent student. Federal Direct PLUS loans are also limited to parent borrowers who have "no adverse credit history," as determined by the Secretary of Education. Federal Direct PLUS loans may be used to replace the expected family contribution. There is no cumulative maximum limit that can be borrowed under the Federal Direct PLUS program. Federal Direct PLUS loan amounts are credited to the student's account and must be disbursed in at least two installments.

Interest rates on Federal Direct PLUS loans are variable, linked to the 52-week Treasury-bill rate, but may not exceed 9 percent. For the 1996–97 academic year, the interest rate will be set in the summer of 1996. There is no federal interest subsidy on Federal Direct PLUS Loans. However, the government is authorized to charge the borrower an up-front origination fee of up to 4 percent to offset the federal government's cost of the program.

Unless the *parent* borrower qualifies for one of the deferments under the Federal Direct Stafford Loan Program, repayment of principal and interest must begin 60 days after disbursement. Parent borrowers who qualify for deferment may pay interest only, beginning 60 days after disbursement, unless interest is capitalized (i.e., deferred and added to the loan principal).

Applications for Federal Direct PLUS loans are available from the Caltech Financial Aid Office. Applications must be returned to the Financial Aid Office for eligibility certification and processing.

Repayment Plans

Under the Direct Loan program, student borrowers have four types of repayment plans available:

1. The Standard Repayment Plan;
2. The Extended Repayment Plan;
3. The Graduated Repayment Plan; or
4. The Income Contingent Repayment Plan.

The plans vary in a number of ways to meet the different needs of individual borrowers. The following information describes these plans and provides suggestions on how to choose among them.

Standard Repayment

Minimum monthly payment	$50
Maximum number of monthly payments	120 (10 years)

Under this plan no more than 120 monthly payments are required, and for small loan amounts, the number of monthly payments can be less than 120. Each monthly payment will be at least $50, and may be more if necessary to repay the loan within 10 years (excluding periods of deferment or forbearance). The number of monthly payments will be adjusted to reflect changes in the variable interest rate. This means that as the rate varies, the monthly amount will remain the same unless the borrower requests that the repayment amount be changed.

Extended Repayment

Minimum monthly payment	$50
Maximum number of monthly payments	see table below

Loan Amount and Maximum Number of Monthly Payments for the Extended and Graduated Repayment Plans

Loan Amount		*Maximum number of*
At least	*Less than*	*Monthly Payments*
$ 0	$10,000	144
10,000	20,000	180
20,000	40,000	240
40,000	60,000	300
60,000		360

Under this plan, the maximum number of months that payments are due (excluding periods of deferment and forbearance) depends on the loan amount. Each monthly payment will be at least $50 and may be more if necessary to pay off the loan in the maximum number of repayment months. The number of monthly payments will be adjusted to reflect changes in the variable interest rate. This means that as the rate varies, the monthly amount will remain the same unless the borrower requests that the repayment amount be changed.

Graduated Repayment

Minimum monthly payment	$25
Maximum number of monthly payments	see table above

Under the Graduated Repayment Plan, payments are lower at first and will increase over a period of time that varies depending on the amount borrowed. The minimum monthly payment is the larger of 50 percent of the amount that would be required under the Standard Repayment Plan or the amount of interest that accrues monthly on the loan. The maximum number of months the borrower will pay excludes periods of deferment and forbearance and depends on the loan amount (see table above). With this plan the monthly payment amount during the earlier portion of the repayment period is reduced. Later in the repayment period, the monthly payment amount will increase, but will never be more than 150 percent of the amount required by the Standard Plan. The monthly repayment amount is increased (graduated) every two years. The number of monthly payments will be adjusted to reflect changes in the variable interest rate. This means that as the rate varies, the monthly amount will remain the same unless the borrower requests that the repayment amount be changed.

Income Contingent Repayment

Minimum monthly payment:	Generally none (in certain circumstances, $15 – see below)
Maximum number of monthly payments	300 months (25 years)

The Income Contingent Repayment Plan allows the borrower to repay his or her loan as a percentage of income. In general, the amount the borrower repays depends on the amount borrowed and begins at 4 percent of income earned for loans of $1,000 or less. The percentage of income increases at the rate of 0.2 percent for each additional $1,000 borrowed, to a maximum of 15 percent for loans of $56,000 or more. However, the monthly payment will never be more than 20 percent of the borrower's discretionary income. Discretionary income is the federal adjusted gross income minus the poverty level for the borrower's family size. If the monthly repayment is calculated to be less than $15, no payment is required.

Under this plan, the option exists of limiting the monthly repayment to the amount one would be required to pay if loan payments were scheduled over 12 years in equal monthly installments. Thus, the maximum payment will never be more than one would pay under a level 12-year repayment plan. This ensures that as the borrower's income grows, the payments will be manageable. However, under this option, a monthly payment of at least $15 is required.

The repayment amount is adjusted annually. Under this plan, the monthly repayment amount will be more when the borrower's income is high and less when one's income is low. If the borrower's income is so low that he or she is not required to make payments, or if the payments are small, the interest may not be paid as it accrues on the loan. The unpaid interest will be added to the principal balance of the loan once a year until the principal balance is 10 percent higher than the original principal. After that, interest will accrue but will not be added to the principal balance.

Under either option, it is possible the borrower will not make payments large enough to pay off his or her loan in 25 years. If this happens, after 25 years (excluding periods of deferment, forbearance, or time spent in repayment plans other than the Standard and 12-year Extended Repayment Plans), the unpaid amount of the loan will be discharged, and the amount discharged will be considered taxable income.

Federal Direct PLUS Loans and Federal Direct PLUS Consolidation Loans are not eligible for Income Contingent Repayment.

Examples of Typical Beginning Payments for Direct Loan Repayment Plans:

Monthly and Total Payments Under Different Repayment Plans

Total Debt:	$2,500	$4,000	$7,500	$10,000	$15,000
STANDARD					
Per Month	$50	$50	$89	$118	$178
Total	3,148	5,539	10,650	14,200	21,300
GRADUATED					
Per Month	$25	$25	$47	$63	$95
Total	4,008	6,637	12,444	18,185	27,277
EXTENDED					
Per month	$50	$50	$79	$92	$138
Total	3,148	5,539	11,355	16,615	24,921
INCOME CONTINGENT[1] (INCOME = $25,000)					
Formula Amount					
Per month	$90	$96	$110	$121	$142
Total	2,867	4,613	9,522	13,451	22,197
Limited Amount					
Per month	$27	$42	$79	$105	$142
Total	3,937	6,056	11,356	15,141	23,126

Note: Payments are calculated using the 1994–95 rate of 7.43%.

[1] *Assumes a 5% annual income growth (Census Bureau).*
Under "Formula Amount" the borrower always pays the formula amount: i.e., payback rate times income.
Under "Limited Amount" the borrower pays the lower of the Formula Amount or what the borrower would pay using a 12-year standard amortization.

Choosing your Repayment Plan

In selecting a repayment plan, there are several factors to understand before making a decision.

The Standard Repayment Plan has a shorter repayment term than under the other plans. This means the loan is paid off more quickly, and the amount of interest paid will be less than if the other plans were selected. However, the Standard Repayment Plan requires higher monthly payment amounts. If one will be able to pay a higher monthly amount, the Standard Repayment Plan may be best. If the higher repayment amount would be difficult or uncertainty exists about income level, one of the other repayment plans may be best.

The Extended or Graduated Plan features a longer repayment term. As a result, the monthly payment is lower than under the Standard Plan (unless the minimum monthly payment applies), but more interest over the life of the loan will be repaid. Under the

Extended Plan, the payments are fixed amounts and less interest is paid than under the Graduated Plan.

The Income Contingent Repayment Plan features monthly repayment that will vary with the borrower's income. When income is low, one probably will have a longer repayment period than under one of the other repayment plans. As a result, a greater amount of interest is repaid over the repayment period but it may be easier to keep up with the monthly payments. If the borrower's income grows, the monthly repayment amount increases. This would reduce the repayment period and result in repaying a smaller total amount of interest over the repayment period. If the borrower's income is high and he or she chooses to limit the monthly repayment to the amount he or she would be required to pay if the loan was repaid over 12 years in equal monthly installments, the repayment period is extended, which results in more total interest paid. However, this also helps to ensure that one's payment will be manageable. In general, to be sure that a monthly payment amount will be manageable given one's income, select one of the Income Contingent Repayment Plan options.

If a consistent monthly payment amount is important throughout the repayment period, select either the Standard or the Extended Plan. On the other hand, if the borrower's income is expected to increase as time passes, it might be preferable to make smaller loan payments at first and larger payments later in one's career. If so, select the Graduated Repayment Plan.

Remember: One can prepay all or part of a student loan at any time without a prepayment penalty.

If a plan is not selected, the Standard Repayment Plan will be assigned. For help deciding which repayment plan to choose, call the Direct Loan Servicing Center at 1-800-848-0979. If none of these plans seems feasible, the Direct Loan Servicing Center will help to create a plan that meets a borrower's individual needs.

Changing Repayment Plans

One may experience significant changes in life during the repayment period. The borrower may change or lose jobs, receive salary increases or promotions, or choose to work in a career that provides less income than expected when a repayment plan was selected. The borrower can, at any time, change repayment plans to adjust to these changing circumstances (unless repaying a defaulted loan under the Income Contingent Repayment Plan). There is no limit to the number of times plans can be changed. If repaying under the Income Contingent Repayment Plan, one can choose the 12-year payment limit or remove the limit on the monthly amount once per year.

To change plans, the borrower can

- change to the Income Contingent Repayment Plan at any time. The repayment term will be 25 years, less any time previously spent in the Income Contingent, Standard, and Extended (12-year period only) Repayment Plans. Time spent in the Extended Plan under the 15- to 30-year periods and the Graduated Repayment Plan does not count toward the 25-year maximum term.
- change to another plan as long as that plan has a repayment term greater than the amount of time one already has been in repayment. For example, the borrower can change from the Extended Plan to the Standard Plan only if he or she has been in the Extended Plan less than 10 years. If this type of change is made, the remaining repayment term will be determined by subtracting the amount of time already in repayment from the term allowed for the new plan. For example, if the borrower has been on the Extended Plan for three years and then converts to the Standard Plan in order to pay off the loan more quickly and reduce the interest expense, he or she will have a maximum of seven years left to repay the loan.

If repaying a Federal Direct Consolidation Loan (Direct Consolidation Loan) that one agreed to repay under the Income Contingent Repayment Plan due to a previous defaulted loan, the borrower must make six consecutive monthly payments before changing to another plan.

Loan Consolidation

If the borrower has several student loans (including other federal education loans), it may be to his or her advantage to consolidate these loans into a single Direct Consolidation Loan. This allows extension of the repayment term, a reduction of monthly payments, and interaction with a single lender instead of several different lenders. For more information on a Direct Consolidation Loan, contact the Consolidations Department of the Direct Loan Servicing Center at 1-800-848-0982.

Loan Deferments

Once the borrower is no longer enrolled at least half-time in college and a six-month grace period has ended, loan repayment for Federal Direct Stafford Loans may be deferred

- during any period in which one is pursuing at least a half-time course of study as determined by the institution;
- during any period in which the borrower is pursuing a course of study under an approved graduate fellowship program or rehabilitation training program for disabled individuals;
- for up to three years during periods in which one is actively

seeking but unable to find full-time employment;

- for up to three years for any reason, which Caltech determines, that has caused or will cause the borrower to have an economic hardship.

These deferment provisions apply to new borrowers whose first Federal Direct Loan disbursement is made on or after July 1, 1994.

Unlike the Federal Perkins Loan program, which provides for a nine-month grace period following each period of statutory deferment, there are no post-deferment grace periods for Federal Direct Stafford Loans.

More specific information of repayment and deferments are included in the loan promissory note and the loan disclosure statement provided to student borrowers.

Financial Payment Plans

Several private organizations offer a variety of financing options (such as monthly payment plans and long-term loans) to assist students and families in meeting college expenses. Information describing these programs is available upon request from the Caltech Financial Aid Office.

No-Need Scholarships

Merit Awards are awarded annually to *returning* students solely on the basis of academic merit. These awards include Caltech Prizes, Carnation Scholarships, the Rosalind W. Alcott endowment, and several other private and corporate scholarships. The Faculty Committee on Scholarships and Financial Aid recommends a number of Caltech's most academically talented students to receive the Merit Award for their sophomore, junior, and/or senior year. These awards are made from the Caltech Prize, Carnation Scholarship, and Rosalind W. Alcott endowments. The John Stauffer Scholarship is also awarded to a student with a chemistry-related major. In 1994–95, 48 students were awarded the Caltech Merit Awards in amounts ranging from $6,000 to $16,695. The honor is recorded on transcripts and listed in the commencement bulletin when the scholar graduates.

Several corporations, including Northrop and Green Hills Computer Software, 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 to receive financial aid at Caltech, students must maintain satisfactory academic progress toward completion of the baccalaureate degree as defined on page 151. Whenever this is not maintained, approval for reinstatement by the Undergraduate Academic Standards and Honors Committee, the Registrar, or the Dean of Undergraduate Students (as described on page 115) shall reestablish satisfactory progress for purposes of financial aid eligibility.

In general, assistance is available to eligible students for the first 12 terms of enrollment (or the equivalent for transfer or less-than-full-time students). Exceptions may be approved after submission of a petition to the Financial Aid Office. Petition forms are available in the Financial Aid Office.

Class Level
For financial-aid purposes, undergraduate students are classified according to the number of units earned and the number of terms of residence at Caltech. Both these criteria must be satisfied for class-level eligibility. Students are regarded as freshman, until eligible for sophomore status, and as sophomore, junior, or senior, if they meet the corresponding criteria set below. Units earned are defined as units completed with a passing grade.

Classification	*Minimum Units Earned*	*Minimum Terms in Residence*
Sophomore	108	3
Junior	216	6
Senior	324	9

Refund and Repayment Policy

In accordance with federal regulations, Caltech has established a fair and equitable refund policy for students who find it necessary to withdraw from the Institute.

Withdrawal from the Institute: A student who officially withdraws from the Institute during an academic term will receive a tuition refund based on the schedule published on page 123. A student living in Caltech housing may also be eligible for a partial refund from the Housing Office.

When granting a refund to a financial aid recipient, it is Caltech's policy to reduce the aid award by the amount of the refund. Therefore, an aid recipient's refund is, in most cases, returned to the original aid account.

Should an overpayment or overaward occur (i.e., when a student receives more aid than he or she is eligible to receive), the Financial Aid Office will compare adjusted costs to aid disbursed in accordance with federal guidelines. If aid disbursed exceeds the costs, the student will be responsible for the overpayment. Overpayment(s) will be charged to the student on his or her student account. Additional information is available in the Financial

Aid Office.

Appeals on Refunds: Any questions or problems related to refunds should be directed to Oliver Nandkishore, Assistant Director of Finance in the Student Accounts Office, Caltech, Mail Code 116-6, Pasadena, CA 91125.

Dropping a Course: A student's financial aid package will be adjusted to reflect any tuition adjustment made by the Student Accounts Office as well as any other adjustments required by law or by the applicable fund donor(s). In addition, students who are not enrolled full time as of the last day to add courses may have their aid revised. Generally, students who enroll less than three-fourths time will have an increased work award. Additional information is available in the Financial Aid Office.

Withdrawal Tuition Refund Schedule

Tuition is refunded according to the following schedule:

Calendar Days	*Percentage of tuition due the Institute*	*Percentage of tuition refund due the student*
Prior to first day of class	0%	100%
1–7	10%	90%
8–20	50%	50%
21–38	75%	25%
39 and after	100%	0%

PRIZES

Mabel Beckman Prize

The Mabel Beckman Prize is given in memory 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.

Fritz B. Burns Prize in Geology
This prize is awarded to an undergraduate who has demonstrated both academic excellence and great promise of future contributions in the fields represented by the Division of Geological and Planetary Sciences.

Caltech Prize Scholarships and Carnation Scholarships
Each year Caltech awards these prizes for academic excellence to continuing students. 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 criterion.

Donald S. Clark Memorial Awards
From a fund contributed by the Caltech Alumni Association, annual awards of $1,000 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 Residence Life and Master's Award
Two awards, selected by the Deans, the Director of Residence Life, and the Master, 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 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 $350 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 chair 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, established a prize fund that provides an award of $1,000 to a junior in the upper 5 percent of his or her class who shows outstanding promise for a creative professional career. The student is selected by the division chairs 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 15 years served on the staff of the Caltech business office and was Vice President for Business Affairs from 1956 to 1962. The prize of $1,200 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 chairs 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 $750 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, consists of a cash award and a certificate.

Bibi Jentoft-Nilsen Memorial Award
Family and friends of Bibi Jentoft-Nilsen, class of 1989, have provided this award in her memory. The cash award of $500 is for an upperclass student who exhibits outstanding qualities of leadership and who actively contributes to the quality of student life at Caltech.

Dorothy B. and Harrison C. Lingle Scholarship
Each year, the Freshman Admissions Committee selects one incoming freshman for a $7,500 annual merit award. The Lingle Scholarship is awarded in recognition of interest in a career in science or engineering, outstanding academic record, demonstrated fair-mindedness, good work ethic, and unquestioned integrity. The award is renewable for three years, regardless of financial need, contingent upon continuing high academic performance. Such performance is defined as not failing any courses and maintaining honors standing. All admitted freshman applicants will be considered. No special application is required.

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 chair 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 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.

Millikan Scholarships
Millikan Scholarships are awarded to selected freshmen whose

record of personal and academic accomplishment is judged outstanding among the remarkable group of incoming freshmen.

Robert L. Noland Leadership Award
The Robert L. Noland Leadership Award is a cash award of $2,000 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 its 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.

Howard Reynolds Memorial Prize in Geology
The Howard Reynolds Memorial Prize in Geology is awarded to a sophomore or junior who demonstrates the potential to excel in the field of geology, and who actively contributes to the quality of student life at Caltech.

Herbert J. Ryser Scholarships
The Herbert 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.

SIF Award
The Student Investment Fund Award was established to promote outstanding research in finance. The award, $500, is funded by the Student Investment Fund. Competition is open to all students, but priority is given to undergraduates. Selection takes place on the basis of a research report, to be submitted to a committee appointed annually by the Humanities and Social Sciences faculty.

Sigma Xi Award
In accordance with the aim of Sigma Xi, The Scientific Research Society, to encourage original investigation in pure and applied science, the Institute chapter of the society annually awards a prize of $1,200, funded from membership dues, to a senior selected for an outstanding piece of original scientific research. The student is selected by the division chairs and the deans, together with the Undergraduate Academic Standards and Honors Committee.

Paul Studenski Memorial Fund Prize
This travel grant is awarded to a Caltech undergraduate who would benefit from a period away from the academic community in order to obtain a better understanding of self and his or her plans for the future. The recipient is selected by the Caltech Y Studenski Committee.

Alan R. Sweezy Economics Prize
The Alan R. Sweezy Economics Prize was established in 1995 by family, friends, and colleagues to honor Professor Sweezy for his 36 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 economics.

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.

Fredrick J. Zeigler Memorial Award
The Fredrick J. Zeigler Memorial Award was established in 1989 to honor Fredrick J. Zeigler, a member of the class of 1976 and an applied mathematics major. The award, which carries a cash prize of $2,500, is given to a pure or applied mathematics student in his or her sophomore or junior year. Selected by the faculty in pure and applied mathematics, the award recognizes excellence in scholarship as demonstrated in class activities or in the preparation of an original paper or essay in any subject area.

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.

It is the general policy of the Institute that to graduate, a student must meet the requirements of any one catalog that the student has registered under. In exceptional circumstances, the Curriculum Committee can recommend to the faculty exceptions to this policy. A list of any changes and exceptions to individual catalogs will be available from the Registrar.

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 Five.

Institute Requirements, All Options

The following requirements are applicable to incoming freshmen for 1996-97 and subsequent years. Some information for continuing students has been provided as footnotes, but guidance on special cases must be sought.

Course	Units
1. Freshman Mathematics (Ma 1 abc)	27
2. Sophomore Mathematics (Ma 2 ab[1])	18
3. Freshman Physics (Ph 1 abc)	27
4. Sophomore Physics (Ph 2 ab[2] or Ph 12 abc)	18
5. Freshman Chemistry (Ch 1 ab)[3]	15
6. Freshman Biology (Bi 1)	9
7. Menu Class (currently Ay 1 or Ge 1)	9
8. Freshman Chemistry Laboratory (Ch 3 a)[4]	6
9. Additional Introductory Laboratory	6
10. Science Communication Requirement[5]	3
11. Humanities Courses (as defined below)	36
12. Social Sciences Courses (as defined below)	36
13. Additional Humanities and Social Sciences Courses	36
14. Physical Education	9

[1] *Ma 2 c will still be offered in 1996-97 and will be expected of current sophomores. One term from the following courses may be substituted for Ma 2 c: Ma 112 abc, Ma 144 ab, AMa 153 abc.*

[2] *Ph 2 c no longer exists. Students who have taken part but not all of the old Ph 2 must take a set of courses that covers at least the material in the new Ph 2. One term from the following courses may be substituted for Ph 2 c: Ph 12 c, APh 17 c, Ch 21 c, Ch 24 a.*

[3] *Ch 1 c no longer exists. Continuing students who have not taken Ch 1 c should take Bi 1 or an acceptable replacement to Ch 1 c as follows: The Chemistry requirement can also be met by completing two terms of Ch 41 abc or Ch 21 abc. Ch 10 c can be taken in place of Ch 1 c.*

[4] *This requirement can also be met by completing Ch 3 b or Ch 4 a.*

[5] *The way in which this requirement is to be met has not yet been finalized. It is to be met in the sophomore or subsequent years by the current freshman or later classes and thus is not needed by any student during the current year.*

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), ChE 10 (6 units), CS/EE 11 (6 units), E 5 (6 units), Ge 3 (3 units), Ge 5 (3 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;

science, ethics, and society; 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 HSS Tutorial courses and (to the limit of 27 units) courses in business economics and management. They may *not* include reading courses unless granted credit by petition to the Humanities or Social Science faculty. No more than 18 units of Freshman Humanities may be counted toward the 108-unit requirement.

Entering freshmen are required to take two terms of "Freshman Humanities," humanities courses numbered 20 or below in the catalog, that require from 4,000 to 6,000 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.

Entering freshmen who have an Advanced Placement score in English of 3 or higher or who score 660 or above on the SAT II: Writing Test will be excused from taking the diagnostic English examination administered before the beginning of first term. Freshmen required to take the diagnostic test whose skills are judged inadequate in this examination may *not* enter Freshman Humanities courses until they complete successfully En 1 ab, English as a Second Language, or En 2, Basic English Composition, to be offered during the first term. These courses count as general Institute credit. They do 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 toward 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 11; Law: Law 33; Political Science: PS 12; Psychology: Psy 15; 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.

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 ab	General and Quantitative Chemistry (3-0-3 for Ch 1 a; 4-0-5 for Ch 1 b)	6		9		0
Bi 1	Fundamentals of Modern Biology	0		0		9
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
	Menu course[3] or Additional Electives[4]	x		x		x
PE	Physical Education[5]	3		3		3

x—Except for the minimum laboratory unit requirement, the number of units chosen here is optional. If a student chooses no electives except physical education and takes the minimum permissible laboratory courses, the total unit requirement will usually be in the range 39 to 45. A total load—including electives—of more than 48 units per term is considered a heavy load. Loads of more than 51 units for freshmen or 54 units for upperclass students require approval by the Dean of Students.

[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] *Students entering 1996-97 or later years must take a menu course (currently Ay 1 or Ge 1)in their freshman or sophomore year. These courses are offered third quarter only. It is also possible to take one of these courses as an elective.*
[4] *A partial list of electives particularly recommended for freshmen includes the following: Bi 8, ChE 10, CS/EE 4, CS 10, EE 1, Env 1, Ge 3, Ph 10, Ph 20, Ph 21, Ph 22.*
[5] *Three terms (9 units) of PE are required for the B.S. degree. Students need not elect to take the required PE in the freshman year. It may be taken in any three terms before graduation.*

Applied Mathematics Option

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

Option Requirements

1. Ma 5 abc, AMa 95 abc, and AMa 101 abc.
2. One of the following (or an approved combination): AMa 98 abc, AMa 151 abc, AMa 152 abc, AMa 153 abc, AMa 181 abc, or AMa 104 and AMa 105 abc.
3. One of the following (or an approved combination): Ma 108 abc, Ma 109 abc, Ma 110 abc, Ma 120 abc, Ma 121 abc, Ma 122 a, EE/Ma 126 ab, EE/Ma 127 ab, CS/EE/Ma 129 abc, Ma 151 abc.
4. One 27-unit 100 or higher level course in science or engineering not in AMa or Ma and approved by the student's adviser.
5. Passing grades must be obtained in a total of 483 units, including the courses listed above.

Typical Course Schedule

		Units per term		
		1st	*2nd*	*3rd*
Second Year				
Ma 2 ab[1]	Sophomore Mathematics (4-0-5)	9	9	0
Ph 2 ab	Statistical Physics, Waves, and Quantum Mechanics (4-0-5)	9	9	0
Ma 5 abc	Introduction to Abstract Algebra (3-0-6)	9	9	9
	Humanities Electives	9	9	9
	Electives	9	9	27
		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	18	18	18
		39	39	39
Fourth Year				
AMa 101 abc	Methods of Applied Mathematics (3-0-6)	9	9	9
	Humanities Electives	9	9	9
	Electives[2]	27	27	27
		45	45	45

[1] *Ma 2 c ceases to exist after 1996-97.*

[2] *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 result in 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 states. 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 9 b, APh 24, Ph 3, Ph 5, Ph 6, Ph 7.
2. APh 17 abc, APh 25, APh 125 ab, 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, Ph 77, EE 91, Ch 6, Ae/APh 104 bc, MS 123, APh 124.
5. 27 additional units of APh courses numbered over 100, which must include one of the following sequences: APh 101 abc, APh 105 abc, APh 114 abc, APh 156 abc, APh 181 ab, APh 190 abc, or the sequence APh / EE 130, 131, 132. 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. None of the courses taken to satisfy option requirements may be taken on a pass/fail basis.

Typical Course Schedule

		Units per term		
		1st	2nd	3rd
Second Year				
Ph 2 ab	Statistical Physics, Waves, and Quantum Mechanics (4-0-5)	9	9	0
Ma 2 ab[1]	Sophomore Mathematics (4-0-5)	9	9	0
	Humanities Electives	9	9	9
	Laboratory Electives[2]	6	6	6
APh 17 abc	Thermodynamics (3-0-6)	9	9	9
APh 25	Introductory Quantum Mechanics	-	-	9
	Other Electives	9	9	18
		51	51	51
Third Year				
APh 125 ab	Quantum Mechanics of Matter	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[3]	18	18	27
		50	50	50
Fourth Year				
APh 78 abc	Senior Thesis, Experimental[4]	6	6	6
or				
APh 77	Laboratory in Applied Physics[4]	9	9	-
APh 106 abc				
or				
Ph 106 abc	Topics in Classical Physics	9	9	9
APh	Electives[3]	9	9	9
	Humanities Electives	9	9	9
	Other Electives	18	18	18
		51-54	51-54	51

[1] *Ma 2 c ceases to exist after 1996-97.*
[2] *See item 1, option requirements.*
[3] *See item 5, option requirements.*
[4] *See item 4, 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, Bi 7, Ay 1, EE 14 abc, Ma 5 abc, MS 15 abc	APh 77, Ph 77 ab, EE 114 abc, Ch 6 ab, Ge 101, APh 100, ME 19 abc	APh 77, APh 100, Ae/APh 101 abc, APh 105 abc, APh AMa 101 abc, AMa 104, 114 abc, AMa 105 ab, Ch 125 abc, Ph 125 abc, Ph 129 abc, Ph 77 ab

More Specialized Courses
APh 156 abc, APh 181 ab, APh 190 abc, APh/EE 130, AM 135 abc, ChE 103 abc, EE 91 abc, Ge 102, Ge 103

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		
		1st	*2nd*	*3rd*
Second Year				
Ph 2 ab	Waves, Quantum Mechanics and			
or	Statistical Physics (4-0-5)	9	9	-
Ph 12 abc[1]	Quantum and Statistical Mechanics (3-0-6)			
Ma 2 ab[2]	Sophomore Mathematics (4-0-5)	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[3]	0-6	6	0-6
	Core Menu Course	-	-	9
	Humanities Electives	9	9	9
	Electives[4]	0-9	3-6	12-15
	Suggested total number of units	38-53	36-39	48-57

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[5], Ay 22, Ay 105, Ay 110, Ay 121[5], Ay 122, Ay 123, Ay 124, Ay 125, Ay 126, Ay 127, Ay 128, Ay 145, EE 14, EE 91, EE 157, Ge 1, Ge 4, Ge 103, Ge 131, Ge/Ay 132[5], Ge 153, Ge 167, Ma 5, Ma 112, Ph 77, Ph 125[5], Ph 129, Ph 136[5].

[1] *Prerequisite for Ph 98.*
[2] *Ma 2 c ceases to exist after 1996-97.*
[3] *Students are required to take (a) Ph 3 if not already taken, (b) Ph 5 or Ph 6, and (c) Ph 7.*
[4] *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.*
[5] *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. 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 in 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 undergraduate adviser, Dr. Jean-Paul Revel, and discuss their plans at the Career Development Center.

Option Requirements

1. Bi 8, Bi 9, Bi 11, Bi/Ch 110, Bi 122, Bi 150, and Ch 41 abc.
2. One advanced laboratory course chosen from Bi 123, Bi 161, Bi 162, or Bi 180.
3. Three courses chosen from Bi/Ch 111, Bi/Ch 113, Bi 114, Bi/Ch 132, Bi 156, Bi 170, Bi 189, Bi 190.
4. 3 units of Senior Seminar, Bi 81, or Senior Thesis Seminar, Bi 80.
5. 34–49 elective units in Biology courses numbered above 20, to reach a total of 143 units of Biology course work. Pass/fail grading may be elected, in the manner specified on page 40, for these Biology course electives, but not for courses taken to fulfill requirements (1) to (4).
6. Passing grades must be earned in a total of 486 units, including the courses listed above.

Recommended Course Schedule

		Units per term 1st	2nd	3rd
Second Year				
	HSS Electives	9	9	9
Ma 2 ab[1]	Linear Algebra, Statistics, and Differential Equations (4-0-5)	9	9	-
Ph 2 ab	Statistical Physics, Waves, and Quantum Mechanics (4-0-5)	9	9	-
Ch 41 abc	Chemistry of Covalent Compounds (3-0-6)	9	9	9
Bi 11	Organismic Biology (3-3-3)	9	-	-
Bi 8	Introduction to Molecular Biology (3-0-6)	-	9	-
Bi 9	Cell Biology (3-0-6)	-	-	9
Bi 10	Cell Biology Laboratory [2] (1-3-2)	-	-	6
	Electives[3]	0-6	0-6	9-18
		45-51	45-51	42-51
Third Year				
	HSS Electives	9	9	9
Bi/Ch 110	Biochemistry (4-0-8)	12	-	-
Bi 150	Neurobiology (4-0-6)	10	-	-
Bi 122	Genetics (3-0-6)	-	9	-
Ch 21 a	The Physical Description of Chemical Systems[4] (3-0-6)	9	-	-
Ch 24 ab	Introduction to Biophysical Chemistry[4] (3-0-6)	-	9	9
	Electives [5,6]	5-11	18-24	27-33
		45-51	45-51	45-51
Fourth Year				
	HSS Electives	9	9	9
Bi 80 or Bi 81	Senior Seminar	3	-	-
	Electives[5,6]	33-39	36-42	36-42
		45-51	45-51	45-51

Suggested Electives

Second Year: Bi 23, Ch 4 ab.

Third Year: Bi 22, Bi 23, Bi/Ch 111, Bi/Ch 113, Bi 114, Bi 115, Bi 123, Bi 137, Bi 145, Bi 152, Bi 156, Bi 157, Bi 158, Bi 161, Bi 162, Ch 7, Ge 5.

Fourth Year (in addition to those listed for the third year): Bi 90, Bi 125, Bi 127, Bi/Ch 132, Bi 170, Bi 180, Bi 189, Bi 190, Bi 217, Bi 218, Bi 219, Bi 220, Ch 145, Ch 146, CNS/Bi 186.

[1] *Ma 2 c ceases to exist after 1996-97.*
[2] *Bi 10 is not required for the biology option but is commonly taken by biology students to meet the Institute Introductory Laboratory requirement.*
[3] *Second-year electives should include an Institute Core Elective, if this requirement was not met during the first year.*
[4] *The combination of Ch 21 a and Ch 24 ab, or Ch 21 abc, is strongly recommended for students interested in postgraduate work in biology, as most graduate programs expect entering students to have taken a course in physical chemistry.*
[5] *Electives must include courses to satisfy option requirements (2) and (3), and sufficient additional units of work in biology to satisfy the total of 143 units as specified by requirement (5). Note that Bi 1, Bi 2, and Bi 10 are not counted toward this total.*
[6] *The sequence of courses Bi 150, Bi 152, Bi 156, and Bi 157 is intended to provide a comprehensive introduction to the field of neurobiology.*

Chemical Engineering Option

Chemical engineering involves applications of chemistry, physics, mathematics, and, increasingly, biology and biochemistry. In addition to basic physics, chemistry, and mathematics, the chemical engineering curriculum includes the study of applied mathematics, material and energy balances, properties and physics of gases, liquids and solids, fluid mechanics, heat and mass transfer, thermodynamics, chemical kinetics and chemical reactor design, and the integrating subjects of process design, process control, and optimization. Because of this broad-based foundation that emphasizes basic and engineering sciences, chemical engineering is perhaps the broadest of the engineering disciplines.

Because many industries utilize some chemical or physical transformation of matter, the chemical engineer is much in demand. He or she may work in the manufacture of inorganic products (ceramics, semiconductors, and other electronic materials); in the manufacture of organic products (polymer fibers, films, coatings, pharmaceuticals, hydrocarbon fuels, and petrochemicals); in the manufacture of graphite, abrasives, and fuel cells; in the metallurgical industries; or in the biotechnology industry. Chemical engineering underlies most of the energy field, including the efficient production and utilization of coal, petroleum, natural gas, oil shale, and geothermal deposits. Air and water pollution control and abatement are also within the domain of expertise of chemical engineers. The chemical engineer may also enter the field of biochemical engineering, where applications range from the utilization of microorganisms and cultured cells, to enzyme engineering and other areas of emerging biotechnology, to the manufacture of foods, to the design of artificial human organs.

Freshman and sophomore students normally take the core courses in mathematics, physics, chemistry, and biology (Ma 1 abc, Ma 2 ab, Ph 1 abc, Ph 2 ab, Ch 1 ab, and Bi 1). They also take the second-year chemistry course, Ch 141 abc, and the basic chemical engineering courses, ChE 63 ab and ChE 64. It is strongly recommended that they also take a course in computer programming (e.g., CS 1 or CS 2). 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.

Undergraduate research is emphasized, and students are encouraged, even in the freshman year, to participate in research with the faculty. An optional senior thesis is a unique aspect of the chemical engineering program.

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 3 b, Ch 41 abc, ChE 63 ab, ChE 64, AMa 95 abc, Ch 21 ac, ChE 103 abc, ChE 105, ChE 110 ab, ChE 126 a, ChE 126 b or ChE 90 ab, ChE 152, and either Ec 11, BEM 101, or BEM 103[1].
2. 18 units of chemistry electives[2].
3. 33 units of science and engineering electives[3].
4. Passing grades must be earned in all courses required by the Institute and the option.

Typical Course Schedule

		Units per term		
		1st	*2nd*	*3rd*
Second Year				
Ma 2 ab[4]	Sophomore Mathematics (4-0-5)	9	9	-
Ph 2 ab	Sophomore Physics (4-0-5)	9	9	-
Ch 3 b	Experimental Procedures of Synthetic Chemistry (1-6-1)	-	-	8
Ch 41 abc	Chemistry of Covalent Compounds (3-0-6)	9	9	9
ChE 63 ab	Chemical Engineering Thermodynamics (3-0-6)	9	9	-
ChE 64	Introductory Chemical Reaction Engineering (3-0-6)	-	-	9
	Introductory "menu" course from a specified list (3-0-6) or Elective	-	-	9
	Electives	9	9	9
		45	45	44

Third Year				
AMa 95 abc	Introductory Methods of Applied Mathematics (4-0-8)	12	12	12
Ch 21 ac	The Physical Description of Chemical Systems (3-0-6)	9	-	9
ChE 103 abc	Transport Phenomena (3-0-6)	9	9	9
	Electives	18	18	18
		48	39	48

Fourth Year				
ChE 90 ab	Senior Thesis (0-4-5)	-	9	9
ChE 105	Process Control (3-0-6)	9	-	-
ChE 110 ab	Optimal Design of Chemical Systems (3-0-6)	-	9	9
ChE 126 ab	Chemical Engineering Laboratory (1-6-2)	9	9	-
ChE 152	Heterogeneous Kinetics and Reaction Engineering (3-0-6)	9	-	-
	Electives	18	18	27
		45	36	45

[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/Ch 110 and Env 142 may be used to satisfy this requirement.*
[3] *These electives may include courses in chemistry and chemical engineering; up to 18 units may be satisfied by ChE 80.*
[4] *Ma 2 c ceases to exist after 1996-97.*

Chemistry Option

Study in the chemistry option leads, especially when followed by graduate work, to careers in teaching and research at colleges and universities, in research for government and industry, in the 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 chemistry course (at least two terms from 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. Qualified students, with the instructor's consent, are allowed to substitute either Ch 3 b or Ch 4 a for the core requirement of Ch 3 a.

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 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 ab, Ph 2 ab, and 108 units of humanities and/or social science as well as 9 units of PE.

Double Majors

For students simultaneously pursuing a degree in a second option, courses taken as *required* courses for that option can also be counted as chemistry electives (requirement 3 below) where appropriate. However, courses that count toward the electives requirement in the other option cannot simultaneously be counted toward satisfying the elective requirement in chemistry.

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 7, Ch 15, and Bi 10.
3. A minimum of five terms of advanced chemistry electives taken for a letter grade from chemistry course offerings at the 100 and 200 level, including cross-listed offerings such as Bi/Ch 110, Bi/Ch 111, Bi/Ch 113, 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		
		1st	*2nd*	*3rd*
Second Year				
Ch 41 abc	Chemistry of Covalent Compounds (3-0-6)	9	9	9
Ma 2 ab[1]	Sophomore Mathematics (4-0-5)	9	9	-
Ph 2 ab	Waves, Quantum Mechanics, and Statistical Physics (4-0-5)	9	9	-
Ch 5 a	Advanced Techniques of Synthesis and Analysis (1-6-2)	9	-	-
	Electives	6-9	15-18	33-36
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.

[1] *Ma 2 c ceases to exist after 1996-97.*

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 ab, Ph 2 ab, 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 ab, Ph 2 ab, HSS elective	Ch laboratory[8], Ch 41 abc[7], Ch elective(s)[9], Ch 80[6], Ch 90, HSS elective, AMa 95 abc	Ch 125 abc, Ch electives[8,9], Ch 80[6], HSS elective
Organic Chemistry	Ch 5 ab[3], Ch 41 abc, Ma 2 ab, Ph 2 ab, 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
Biochemistry	Ch 5 a[3], Ch 41 abc, Bi 1, Bi 9, Ma 2 ab, Ph 2 ab, 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, Bi/Ch 111, Bi/Ch 113, 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 121 ab, Ch 122 abc, Ch 135 ab, Ch/ChE 140, Ch 143, Ch 144 ab, Ch/ChE 147, Ch 154, ChE/Ch 155, Env/Ch/Ge 175 abc, Ch 212 ab, Ch 213 abc, Ch 221.*

5 *Ch 6 ab, Ch 7, Ch 15, Ch 118 ab, Bi 10.*

6 *See "Research Opportunities for Undergraduates in Chemistry," which may be obtained from the Chair of the Undergraduate Studies Committee. No more than 27 units of Ch 80 will count toward the 486 units graduation requirement without a senior thesis.*

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, Ch 15, Ch 118 ab, Bi 10.*

9 *Ch 120 ab, Ch 121 ab, Ch 126, Ge/Ch 128, Ch 130, Ch 135 ab, Ch/ChE 140, Ch 144 ab, Ch/ChE 147, ChE/Ch 148, ChE/Ch 164, ChE/Ch 165, Ch 221, Ch 224, Ch 227 ab, Ph 106 abc, AMa 105 ab.*

10 *Ch 112, Ch 120 ab, Ch 121 ab, Ch 122 abc, Ch 135 ab, Ch 143, Ch 144 ab, Ch 145, Ch 146, Ch/ChE 147, Ch 154, ChE/Ch 155, Env/Ch/Ge 175 abc, Ch 242 ab, Ch 247.*

11 *Ch 5 b, Ch 15, Ch 6 ab, Ch 7, Ch 118 ab.*

12 *Ch 122 ab, Bi/Ch 132 ab, Ch 143, Ch 144 ab, Ch 145, Ch 146, Ch 154, Bi/Ch 170, Ch/Bi 231, Ch 242 ab, Ch 244 , Ch 247.*

Suggested Elective Courses for the Chemistry Option

1. *Chemical Engineering:* Introduction to Chemical Engineering Systems (ChE 10), Chemical Engineering Thermodynamics (ChE 63), Undergraduate Research (ChE 80), Chemical Reaction Engineering (ChE 101), Transport Phenomena (ChE 103), Separation Processes (ChE 104), Physical and Chemical Rate Processes (ChE 151), Special Topics in Transport Phenomena (ChE 174), Protein Technology (ChE 177).
2. *Biology:* Introduction to Molecular Biology (Bi 7), Cell Biology (Bi 9), Genetics (Bi 122), Immunology: Signaling, Gene Regulation, and Development (Bi 114), Multicellular Assemblies (Bi 137), Molecular Neurobiology (Bi 156), Methods in Molecular Genetics (Bi 180).
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 9), Introduction to Digital Electronics (CS/EE 4), Digital Electronics Laboratory (CS/EE 11), Introduction to Sequential Programming (CS 1), Problem Solving and Computing Lab (CS 2).
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 11), Elementary French (L 102) or Elementary German (L 130) or Elementary Russian (L 141).
6. *Miscellaneous:* Introduction to Astronomy (Ay 1), Engineering Problems of the Environment (Env 1), Principles of Materials (MS 15), Introduction to Earth and Planetary Sciences (Ge 1), Introduction to Isotope Geochemistry (Ge 140), Classical Analysis (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 11; Theory of Value, Ec 121; and Econometrics, Ec 122. Students are strongly encouraged to supplement this core with additional electives in economics, political science, and mathematics.

Option Requirements

1. Ec 11, Ec 121 ab, and Ec 122.
2. Ma 112 a.
3. Ec 161 or Ec 162.
4. Ec 105 or Ec 145.
5. 54 additional units of advanced economics and social science courses. Students may take AMa 181 ab, BEM 103, or BEM 104 in partial fulfillment of this requirement.
6. 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.
7. 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		
		1st	*2nd*	*3rd*
Second Year				
Ma 2 ab[1]	Sophomore Mathematics (4-0-5)	9	9	-
Ph 2 ab	Waves, Quantum Mechanics, and Statistical Physics (4-0-5)	9	9	-
	Menu Course	-	-	9
Ec 11	Introduction to Economics (3-0-6)	9	-	-
PS 12	Introduction to Political Science (3-0-6)	-	-	9
	Electives[2]	18	27	27
		45	45	45
Third Year				
Ec 105	Industrial Organization (3-0-6)	9	-	-
Ec 121 ab	Theory of Value (3-0-6)	-	9	9
Ec 122	Econometrics (3-0-6)	-	9	-
Ec 162	Monetary Theory (3-0-6)	-	-	9
Ma 112 a	Statistics (3-0-6)	9	-	-
	Electives[2]	27	27	27
		45	45	45
Fourth Year				
	Electives[2]	45	45	45

[1] *Ma 2 c ceases to exist after 1996-97.*

[2] *See requirements 6 and 7 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 20 ab, EE/CS 51, EE/CS 52, and energy processing, EE 40. The junior-year program features basic courses in linear systems, EE 32 ab; communications, EE 160, or control, CDS 111; electromagnetic engineering, EE 151; analog circuits, EE 90; 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 80 abc, or the senior project laboratory, EE 91 ab. 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 20 ab, EE 32 ab, EE 40, EE 151, EE 160 or CDS 111, EE/APh 180.
4. EE/CS 51, EE/CS 52, EE 90.
5. EE 80 abc, or two courses selected from EE 91 ab and EE/CS 53.
6. In addition to the above courses, 27 units selected from any EE course numbered over 100, or any multilisted courses numbered over 100 that include EE in the listing. Also, CDS 111, CDS 112, and CDS 113 ab are acceptable.
7. Passing grades must be earned in a total of 486 units, including courses listed above.

Typical Course Schedule

		Units per term		
		1st	2nd	3rd
Second Year				
Ph 2 ab	Statistical Physics, Waves, and Quantum Mechanics (4-0-5)	9	9	0
Ma 2 ab[1]	Sophomore Mathematics (4-0-5)	9	9	0
	Humanities Electives[2]	9	9	9
EE 20 ab	Analog Electronics (3-2-7)	12	12	-
EE/CS 51	Principles of Microprocessor Systems (3-0-6)	9	-	-
EE/CS 52	Microprocessor Systems Laboratory (1-11-0)	-	12	-
	Electives	-	-	18
EE 40	Fundamentals of Energy Processing Systems (3-0-6)	-	-	9
		48	51	36
Third Year				
AMa 95 abc	Introductory Methods of Applied Mathematics (4-0-8)	12	12	12
	Humanities Electives[2]	9	9	9
EE 32 ab	Introduction to Linear Systems (3-0-6)	9	9	-
EE 151	Electromagnetic Engineering (3-2-7)	12	-	-
EE 90	Experimental Projects in Analog Circuits	-	-	9
EE 160[3]	Communication System Fundamentals (3-0-6)	-	-	9
EE/APh 180	Solid-State Devices (3-0-6)	-	9	-
	Electives	9	9	9
		51	48	48
Fourth Year				
	Humanities Electives[2]	9	9	9
E 10	Technical Seminar Presentations (1-0-1)	-	2	-
EE 91 ab[4]	Experimental Projects in Electronic Circuits	6	6	-
	Electives	27	27	36
		42	44	45

1 *Ma 2 c ceases to exist after 1996-97.*
2 *See Institute requirements for specific rules regarding humanities.*
3 *See option requirement 3.*
4 *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 1, Ph 3.

Suggested elective courses 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.

Communications

Second Year: Selected from APh 17 abc, APh 23, APh 24, CS/EE 53, CS/EE 54

Third and Fourth Year: EE 112 ab, EE/Ma 126, EE/Ma 127 ab, EE 128, EE 161, EE 162, EE 163 ab, EE 164, EE 165, EE 166, EE 167, APh/EE 130, CNS/EE 124, APh/EE 131, APh/EE 132, Ma 112 a

Computer Engineering

Second Year: CS/EE 53, CS/EE 54

Third and Fourth Year: CS 137, CS 139 ab, CS/EE 181 abc, and selections from EE 50, CNS/EE 124, CS 171 ab, CS/EE/Ma 129 abc

Control

Second Year: APh 17 abc

Third and Fourth Year: CDS 110 ab, CDS 111, and selections from CDS 113 ab, CDS 112, EE 112 ab, EE 128, EE 162, EE 164

Electronic Circuits

Second Year: APh 17 abc

Third and Fourth Year: CDS 111, EE 112 ab, EE 114 abc, and selections from EE 50, CDS 113 ab, EE/Mu 107 abc, EE 117 ab, EE 152, EE 153, CS/EE 181 abc, CNS/CS/EE 182 abc, APh 181 ab

Microwave and Radio Engineering

Second Year: APh 23, APh 24, APh 17 abc

Third and Fourth Year: EE 152, EE 153, EE 157 abc, EE 158, APh 50 abc, APh/EE 130, APh/EE 131, APh 132, APh 181 ab

Optoelectronics

Second Year: APh 23, APh 24, APh 17 abc

Third and Fourth Year: APh/EE 130, APh/EE 131, APh/EE 132, APh 105 abc, APh 114 abc, APh/CNS/EE 133, APh 190 abc, EE 152

Solid-State Electronics
Second Year: APh 17 abc
Third and Fourth Year: APh 50 abc, APh 181 ab, and selections from APh 105 abc, APh 114 abc, EE 153

Engineering and Applied Science Option

The engineering and applied science option offers the opportunity for study in challenging areas of science and technology. In addition to such engineering disciplines as mechanical or civil engineering, computer science, etc., the student may undertake work in such diverse fields as environmental engineering science, energy engineering and thermal science, the physics of fluids, earthquake engineering, aerodynamics, solid mechanics, materials science, soil mechanics, engineering science, elasticity and plasticity, the theory of waves and vibrations, mechanical systems, and engineering design. 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 as well as pursue one of the more traditional engineering curricula.

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 as close to their expressed field of interest as possible, 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. 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.

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, APh, CDS, CE, ChE, CNS, CS, E, EE, ES, Env, 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 or Ma 109 abc. Neither sequence of courses may be taken pass/fail.
3. 126 additional units in courses in the following: Ae, AM, APh, CDS, CE, ChE, CNS, CS, E, EE, ES, Env, 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 124, APh/MS 141, Ae/APh 104 bc, CE 95, CE 97, CE 180, CS/EE 53 and 54, CS 140 abc, CS 174 abc, CS/EE 181 abc, CNS/CS/EE 184 abc, EE 91 abc, Env 116, Env 143, MS 90, MS 123, ME 72, ME 90 bc, ME 96.
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.*

All students selecting the E&AS option should have a minimum competency in computer science by the end of the first year. This competency may be established in one of two ways. Students with little or no programming skills should take CS 1, 2 in their freshman year. Students possessing basic programming skills may omit CS 1. Students especially interested in computer science should take the full sequence of CS 1, 2, 3 in consecutive terms of their freshman year.

Concentrations within the E&AS option
Students who wish to focus their studies in a particular field of Engineering and Applied Science may declare a concentration within the E&AS option. Currently, two concentrations are available—Aeronautics and Mechanical Engineering. Students who satisfy their E&AS option requirements using courses from the lists below will have both the option (E&AS) and the concentration (Aeronautics or Mechanical Engineering) noted on their transcript.

Aeronautics Requirements
A student can earn a concentration in Aeronautics by completing the following courses as part of the option requirements for E&AS: AM 35 abc, ME 18 ab, ME 71, ME 19 abc, MS 15 ab, AM/ME 65, CDS 110 a, and Ae 103 abc.

Mechanical Engineering Requirements
A student can earn a concentration in Mechanical Engineering by completing the following courses as part of the option requirements for E&AS:

1. AM 35 abc, ME 18 ab, ME 19 ab, ME 70, ME 71, AM/ME 65 (or MS 15 a), and CDS 110 ab.
2. CE/ME 96 and 9 units of additional laboratory (e.g., ME 72 or CE/ME 97), or a senior thesis (ME 90 abc).
3. 18 units—in addition to those listed in items (1) and (2)—chosen from ME 19 c, ME 20, or any course numbered above

100 in ME, JP, AM, Ae, CDS, CE, Env, or ChE.

A typical course schedule and typical course sequences are given in the following pages for several engineering disciplines. Except for the Aeronautics concentration and the Mechanical Engineering concentration, these should be considered not as requirements but as guides, with the details to be worked out by the student and his or her adviser.

Typical Course Schedule

	Units per term		
	1st	*2nd*	*3rd*
Second Year			
Ma 2 ab[1]	9	9	-
Ph 2 ab	9	9	-
Humanities Electives	9	9	9
Electives	18	18	36
	45	45	45
Third Year			
AMa 95 abc or Ma 108 abc or Ma 109 abc	12	12	12
Humanities Electives	9	9	9
Electives	24	24	24
	45	45	45
Fourth Year			
E 10	-	3	-
Humanities Electives	9	9	9
Electives	33	33	33
	42	45	42

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Aeronautics (suggested schedule of requirements)

	First Term	*Second Term*	*Third Term*
First Year[2]	Elective	E 5	Elective
Second Year[3]	AM 35 a	AM 35 b	AM 35 c
	ME 18 a[4]	ME 18 b[4]	ME 71
Third Year[5]	ME 19 a	ME 19 b	ME 19 c
	MS 15 a	MS 15 b	
Fourth Year[6]	Ae 103 a	Ae 103 b	Ae 103 c
	CDS 110 a	AM/ME 65	

[1] *Ma 2 c ceases to exist after 1996-97.*

[2] *Recommend one course per term selected from CS 1, CS 2, CS/EE 4, CS/EE 11.*

[3] *Suggested electives include APh 23, APh 24.*

[4] *APh 17 abc is a suggested alternative for ME 18 ab.*

[5] *Suggested electives include APh 50 abc, CE 97, CS 3, EE 14 abc, MS 90.*

[6] *Suggested electives include Ae/APh 101 abc, Ae/AM 102 abc, Ae/APh 104 abc, Ae 107, AMa 101 abc, CE/ME 101 abc, CS 20 abc, EE 32 ab, JP 121 abc, ME 20 ab, ME 96, ME 115, ME 171 ab.*

Applied Mechanics

	First Term	Second Term	Third Term
First Year[1]	Elective	E 5	Elective
Second Year[2]	AM 35a	AM 35 b	AM 35 c
	ME 18 a	ME 18 b	Electives
Third Year[3]	Elective	AM/ME 65	AM/ME 66
	ME 19 a	ME 19 b	ME 19 c
Fourth Year[4]	AM 151 a[5]	AM 151 b[5]	AM 151 c[5]
	Ae/AM 102 a[5]	Ae/AM 102 b[5]	Ae/AM 102 c[5]

1 *Recommend one course per term selected from CS 1, CS 2, E 5, Env 1, Ge 1.*
2 *Recommended electives include Bi 1, ME 71, MS 15 ab, MS 90.*
3 *Recommended electives include APh 25, MS 15 ab, MS 90, Ph 106 abc.*
4 *Recommended electives include AM 135 abc, MS 120, CE/ME 101 abc, CE 97, ME 96, CDS 110 ab, CDS 111, and AM 125 abc or AMa 101 abc..*
5 *Both Ae/AM 102 abc and AM 151 abc are strongly recommended..*

Civil Engineering (a)
Structural and Soil Mechanics

	First Term	Second Term	Third Term
First Year[1]	Elective	E 5	Elective
Second Year[2]	AM 35 a	AM 35 b	AM 35 c
	ME 18 a	ME 18 b	Electives
Third Year[3]	CE 90 a	CE 90 b	CE 90 c
	ME 19 a	ME 19 b	AM/ME 66
	Elective	AM/ME 65	Elective
Fourth Year[4]	AM 151 a	AM 151 b	AM 151 c
	Ae/AM 102 a	Ae/AM 102 b	Ae/AM 102 c
	CE 115 a	CE 115 b	CE 150

1 *Recommend one course per term selected from CS 1, CS 2, E 5, Env 1, Ge 1.*
2 *Recommended electives include ME 71, MS 15 abc.*
3 *Recommended electives include CE 97, ME 96, MS 15 abc.*
4 *Recommended electives include CE/ME 101 abc, CE 97, CE 113 ab, CE 160 abc, CE 180, CE 181, Env 112 abc, ME 96.*

Civil Engineering (b)
Hydraulics and Water Resources

	First Term	Second Term	Third Term
First Year[1]	Elective	E 5	Elective
Second Year[2]	AM 35 a	AM 35 b	AM 35 c
	ME 18 a	ME 18 b	Electives
Third Year[3]	CE 90 a	CE 90 b	CE 90 c
	ME 19 a	ME 19 b	ME 19 c

Fourth Year[4]	CE/ME 101 a	CE/ME 101 b	CE/ME 101 c
	Env 112 a	Env 112 b	Env 112 c
	CE 115 a	CE 115 b	CE 150

[1] *Recommend one course per term selected from CS 1, CS 2, E 5, Env 1, Ge 1.*
[2] *Recommended electives include ME 71, MS 15 ab.*
[3] *Recommended electives include CE 97, ME 96, MS 15 ab, MS 90.*
[4] *Recommended electives include Ae/AM 102 abc, AM 151 abc, CE 97, CE 113 ab, Env 146, Env 175 abc, ME 96.*

Computer Science

	First Term	*Second Term*	*Third Term*
First Year[1]	CS 1	CS 2	CS 3
Second Year	CS 20 a	CS 20 b	CS 20 c
	CS/Ma 6 a[2]	CS/Ma 6 b[2]	CS/Ma 6 c[2]
Third Year[3]	Electives	Electives	Electives
Fourth Year[3]	Electives	Electives	Electives

[1] *Also recommended: CS/EE 4, CS/EE 11.*
[2] *EE/CS 51, EE/CS 52, EE/CS 53 recommended as an alternative to CS/Ma 6 abc for those students with a stronger electronics interest.*
[3] *Electives recommended for most computer science students include CS/EE/Ma 129 abc, CS 138 abc, CS 139 abc, CS/CNS 174 abc, and CS/EE 181 abc. At least two full abc sequences should be taken.*

Environmental Engineering Science

	First Term	*Second Term*	*Third Term*
First Year[1]	Elective	Elective	Env 1
Second Year	Me 18 a[2]	Me 18 b[2]	Electives[3]
	Elective[3]	Elective[3]	
Third Year	Me 19 a[4]	Me 19 b[4]	CE 97
	Electives[5]	Electives[5]	Electives[5]
Fourth Year	Electives[5]	Electives[5]	Electives[5]

[1] *Recommend additional electives selected from Bi 9, ChE 10, CS 1, CS 2, E 5, Ge 1.*
[2] *APh 17 abc and ChE 63 ab are alternatives.*
[3] *Recommend one course per term selected from Ch 14, Ch 15, Ch 41 abc, CS/EE 4, CS/EE 11, Env 144, Env 145 ab, Ge 5, MS 15 a.*
[4] *ChE 103 abc is an alternative.*
[5] *Junior and senior electives should be individually planned with the adviser to provide coherent sequences depending on the student's special interests (e.g., air quality, water quality, fluid mechanics and hydrology, and applied biology). Strongly recommended electives by area are: air quality, ChE/Env 157, 158, 159; water quality, Env 142 ab, 143; fluid mechanics and hydrology, Env 112 abc; and applied biology, Env/Bi 166, 168. Other recommended electives include: AMa 101 abc, AMa 104, AMa 105, Bi/Ch 110 abc, Ch 21 abc, Ch 24 ab, CE 113 ab, CE/ME 101 abc, Env 146, Ge 152 abc.*

Materials Science

	First Term	Second Term	Third Term
First Year[1]	APh 9 a	E 5[2]	ChE 10
Second Year	APh 17 a MS 15 a	APh 17 b MS 15 b	APh 17 c MS 90
Third Year[3]	MS 120 AM 35 a	MS 121 AM 35 b	MS 122 AM 35 c APh 25
Fourth Year[3]	APh 125 a APh/MS 140 Electives	APh 125 b APh/MS 141 Electives	APh 125 c Electives MS 123

[1] *Recommend at least one term from CS 2.*
[2] *Or APh 9 b.*
[3] *Recommended additional electives to be agreed upon by student and adviser. Electives of general interest may be chosen from the Institute catalog.*

Mechanical Engineering (suggested schedule of requirements)

	First Term	Second Term	Third Term
Second Year	AM 35 a ME 18 a	AM 35 b ME 18 b	AM 35 c ME 96[1]
Third Year[2]	ME 19 a	ME 19 b ME 70	Add. Lab.[1] ME 71
Fourth Year[2]	CDS 110 a	CDS 110 b AM/ME 65[3]	

[1] *Or ME 90 abc, senior thesis.*
[2] *See Mechanical Engineering requirement 3.*
[3] *Or MS 15 a.*

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 student's 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 pursue further training at the graduate level. For students beginning their junior year, it is possible to complete the requirements for each of the options within two years.

Passing grades must be earned in a total of 486 units, including courses listed below. 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

INSTITUTE REQUIREMENTS

	Freshman			*Sophomore*			*Junior*				*Senior*		
Term:	*F*	*W*	*S*	*F*	*W*	*S*	*F*	*W*	*S*	*Smr*	*F*	*W*	*S*
Ma 1 abc Freshman Mathematics	9	9	9										
Ph 1 abc Freshman Physics	9	9	9										
Ch 1 ab General Chemistry	6	9	0										
Bi 1 Freshman Biology	0	0	9										
Ch 3 a F. T. Experimental Chemistry		6											
Freshman Lab and Electives or Menu Course[a]			9										
HSS Humanities & S.S. Electives	9	9	9	9	9	9	9	9	9		9	9	9
PE 1 abc Physical Education	3	3	3										
Ma 2 ab[b] Sophomore Mathematics				9	9	0							
Ph 2 ab Sophomore Physics				9	9	0							
Sophomore Science Electives				9	9	27							

DIVISION REQUIREMENTS
(All Options)

	Freshman			*Sophomore*			*Junior*				*Senior*		
Term:	*F*	*W*	*S*	*F*	*W*	*S*	*F*	*W*	*S*	*Smr*	*F*	*W*	*S*
Ge 11 ab[c] General Geology				c	c								
Ge 44 Introduction to Planetary Science								9					
Ge 66 Planet Earth									9				
Ge 107 Field Geology									9				
Ge 109 Oral Presentation													2
TOTAL UNITS	36	42	45	36	36	36	9	18	27	0	9	9	11

(Institute and Division Requirements)

[a] *Ge 1 or 3, and Ge 10 recommended.*
[b] *Ma 2 c ceases to exist after 1996-97.*
[c] *This course should represent 18 of the 27 units of sophomore science electives.*

GEOLOGY OPTION REQUIREMENTS

Term:	Freshman F	Freshman W	Freshman S	Sophomore F	Sophomore W	Sophomore S	Junior F	Junior W	Junior S	Junior Smr	Senior F	Senior W	Senior S
Ge 106 Structural Geology								9					
Ge 110 Sedimentary Geology								9					
Ge 114 Mineralogy							12						
Ge 115 ab Petrology and Petrography								12	12				
Ge 120 Summer Field Geology										15			
Ge 121 ab Advanced Field Geology[d]											12	12	
Math, Science & Engineering Electives[e]											18	18	18
TOTAL UNITS	36	42	45	45	45	36	21	48	39	15	39	39	29

GEOCHEMISTRY OPTION REQUIREMENTS

Term:	Freshman F	Freshman W	Freshman S	Sophomore F	Sophomore W	Sophomore S	Junior F	Junior W	Junior S	Junior Smr	Senior F	Senior W	Senior S
Ge 114 Mineralogy							12						
Ge 115 ab Petrology & Petrography								12	12				
Ch 21 abc The Physical Description of Chemical Systems[f]							9	9	9				
Ch 14 Chemical Equilibrium and Analysis											6		
Ch 15 Chemical Equilibrium and Analysis Laboratory											10		
Math, Science & Engineering Electives[e]											18	18	18
TOTAL UNITS							30	39	48	0	43	27	29

GEOPHYSICS AND PLANETARY SCIENCE OPTION REQUIREMENTS

Term:	Freshman F	Freshman W	Freshman S	Sophomore F	Sophomore W	Sophomore S	Junior F	Junior W	Junior S	Junior Smr	Senior F	Senior W	Senior S
Ph 106 abc Topics in Classical Physics							9	9	9				
AMa 95 abc Introductory Methods of Applied Mathematics							12	12	12				
Option Electives											18	18	18
Math, Science & Engineering Electives											9	9	9
TOTAL UNITS							30	39	48	0	36	36	38

[d] *The student must select two of the three Ge 121 course offerings.*
[e] *At least 18 of these units must be from courses outside the division.*
[f] *Ch 41 abc or other chemistry courses may be substituted with prior consent of adviser and option representative.*

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 concentrate on three areas: 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 as required by the history option.

A student considering the history option when he or she comes to Caltech will be well advised to take one sequence of Hum 2, 6, 7, 8, or 9. In the sophomore year the student should take 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 the student's chosen area. The first term will be devoted to preparation, the second to research, and the third to the writing of 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

Ay 1, Bi 7, CS/EE 4, EE 14, Env 1.

4. Passing grades must be earned in a total of 486 units, including the courses listed above.

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 individuals, 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 chair 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 between 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 amend-

ments 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 Chair 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 can take a broad range of literature courses or, if they wish, concentrate on American, English, or comparative (cross-national) literature. All majors are assigned an adviser who will help them select the courses best suited to their needs, including courses in fields closely related to literature. Majors will be expected to consult their adviser before registering for each quarter's work. Those who are preparing for graduate work should take more than the minimum requirements listed below, and should be prepared to take courses in several periods of English literature and in the literature of one or more foreign languages. All literature courses must be taken for grades.

Option Requirements

1. 108 units in the Lit 98–180 group of courses (or, with authorization, certain Hum courses), to be taken under the guidance of the major adviser, and including at least one quarter of Lit 114 (Shakespeare) and Lit 99. An additional quarter concentrating on a second major author (e.g., Chaucer, Milton, Wordsworth, Melville, Joyce) is also recommended.
2. 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 Ay 1, Bi 7, CS/EE 4, EE 14, Env 1.

3. 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 courses Ma 108 abc and 109 abc. 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, Ma 109 abc.
2. Two quarters (18 units) of a single course, chosen from the following: Ma 110, Ma 116, Ma/CS 117, Ma 120, Ma 121, Ma 122, Ma/EE 126-127, Ma/CS/EE 129, Ma 142, Ma 144, Ma 147, Ma 151, Ma 160.
3. 27 additional units in Ma or AMa.

4. Passing grades must be earned in a total of 483 units, including the courses listed above.

Typical Course Schedule

		Units per term		
		1st	*2nd*	*3rd*
Second Year				
Ma 2 ab[1]	Linear Algebra, Statistics, and Differential Equations (4-0-5)	9	9	-
Ph 2 ab	Statistical Physics, Waves, and Quantum Mechanics (4-0-5)	9	9	-
Ma 5 abc	Introduction to Abstract Algebra (3-0-6)	9	9	9
	Electives in Science, Engineering, or Humanities*	9	9	27
	Humanities Electives	9	9	9
		45	45	45
Third Year				
Ma 108 abc	Classical Analysis (3-0-6)	9	9	9
	Selected course in Mathematics, minimum	9	9	9
	Humanities Electives	18	18	18
	Electives in Science, Engineering, or Humanities*	9	9	9
		45	45	45
Fourth Year				
Ma 109 abc	Geometric Analysis (3-0-6)	9	9	9
	Selected course in Mathematics	9	9	9
	Humanities Electives	18	18	18
	Electives in Mathematics, Science, Engineering, or Humanities*	18	18	18
		54	54	54

[1] Ma 2 c ceases to exist after 1996-97.
**Includes menu course (2nd year, if not taken in freshman year) and science communication requirements.*

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 five terms 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:

The first 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.

1. Ph 3.
2. One of the following: Ph 5[1], Ph 6, or APh 24.
3. Ph 7.
4. 18 units of Ph 78, or 18 units from Ph 77 and Ph 76, or 9 units from Ph 77 or Ph 76 and 9 units from APh 77 or Ay 105.

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. Nine units toward the 54 elective units will be given for taking all three of Ph 5, Ph 6, Ph 7. Other courses in other departments with substantial physics content may be approved by the Physics Undergraduate Committee in individual cases; seniors must submit their petition for this purpose before the first day of the third term. 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. Core Science Electives can be counted. If the student has taken Bi 1, then only 18 units are required.
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[1]

	Units per term		
	1st	2nd	3rd
Second Year			
Ph 12	9	9	9
Ma 2 ab[2]	9	9	0
Humanities	9	9	9
Physics Laboratory	0	9	9
Electives	12	9	9
Core Science Elective if not taken earlier	0	0	9
	39	45	45

[1] In addition to the required courses listed here, facility with computer programming at the level of CS 1 is strongly recommended, and further computer-related course work such as CS 2, CS/EE 4, or Ph 20–22 is highly desirable.
[2] Ma 2 c ceases to exist after 1996-97.

Third Year			
Ph 106	9	9	9
Ph 98	9	9	9
AMa 95 or Ma 108 or Ma 109	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

Science, Ethics, and Society Option and Minor

The option in science, ethics, and society (SES) provides students with a broad historical and philosophical education in the social, economic, ethical, and political issues that have arisen in the modern world in connection with the advance of science and technology. The program is concerned with study of the long-term development of science and technology and with the evolution of disputes over ethics and policy in areas such as research and development, technological innovation, energy supply and conservation, the environment, and biomedicine. The curricular core of the program resides in historical and/or philosophical study of subjects such as the Scientific Revolution, the politics of research and development, the social uses of biological knowledge, the nature of scientific explanation, and the evolution of theories of cognition; but the program also takes up contemporary issues concerning science and technology, treating them in philosophical, ethical, and historical perspective. The option thus focuses on the acquisition of broad basic knowledge about persistent issues in the affairs of science, technology, and society so as to enable students to deal with such issues in the future, whatever particular form they may take. The option offers students the advantage of developing special literacy in and understanding of issues of science and society, because the program combines courses that directly address such issues with the strong technical background gained at Caltech. It provides excellent preparation for students going into law, business, medicine, and public affairs, as well as solid preparation for graduate work in history and/or philosophy of science.

SES may be pursued as a minor concentration by undergraduates who are taking degrees in science, mathematics, or engineering. The SES minor is a valuable supplement to a technical degree, since it helps equip students to meet the nontechnical social challenges that people in technical careers increasingly encounter. It also enables students to pursue a guided coherent and cumulative program of study that culminates in the writing of a research paper and that provides advantageous preparation for students who may choose to pursue careers in law, business, public policy, and history or philosophy of science. Students who successfully complete the SES minor will be recognized with official credit for the achievement on their transcripts.

Option Requirements

1. SES 101 ab, SES 102 abc, and SES 103. SES 101 ab is a two-quarter introductory course normally to be taken in the sophomore year, one quarter of which emphasizes historical issues, the other quarter of which focuses on philosophical ones. SES 103 is a lecture series featuring outside speakers roughly four times per quarter that introduces students to a broad variety of SES-related topics past and present. Students are expected to participate in the lecture series through their sophomore, junior, and senior years. SES 102 abc is a three-quarter course devoted to the writing of a senior research paper. The first two quarters will be taught primarily as a directed tutorial under the guidance of a faculty supervisor; students will pursue intensive reading to develop deep knowledge in a field of concentration and begin work on a senior research project. The third quarter will be taught as a seminar in which the students discuss and criticize each other's developing research papers. The senior research paper stresses independent work and can cover any one of a number of topics from a historical and/or philosophical/ethical perspective, including biotechnology, biomedicine, the environment, science and national defense, the historical politics of research and development, Big Science, the nature and growth of scientific knowledge, cosmology, or science, and theories of cognition, language, and perception. Among the resources available for writing the senior paper is the Caltech

Archives, which contains a substantial collection of rare books in the history of science going back to the 16th century and houses the correspondence and other papers of a number of distinguished scientists, including George Ellery Hale, Robert Millikan, Richard P. Feynman, Lee A. DuBridge, and Max Delbrück. The materials in the Caltech Archives throw considerable light on the development of key fields in modern science—for example, astrophysics, quantum mechanics and relativity, molecular biology, geology and planetary science—and are rich in information on topics such as the relationship of science to government and industry.

2. Four advanced history courses, two of which must be in the history of science (SES/H/Lit 128, SES/H 156, SES/H 157, SES/H 158, SES/H 159, SES/H 160 ab, SES/H 162, SES/H 163, SES/H 164, SES/H 165, SES/H 166, SES/H 168, SES/H 169). Four advanced philosophy courses, two of which must be in philosophy of science or ethics (SES/Pl 122, SES/Pl 125, SES/Pl 126, SES/Pl 127, SES/Pl 131, SES/Pl 169, SES/Pl 185). Students are expected to choose their mix of required courses and electives with an eye to developing an area of concentration—such as the history and politics of science and technology, or science, ethics, and philosophy, or science and culture—in which they will choose the topic for the senior research paper. Students are also encouraged to take course work in literature (for example, Lit 127 and/or Lit 138).
3. 45 units of science, mathematics, and engineering courses. This requirement cannot be satisfied by courses listed as satisfying the introductory laboratory requirement or by any course with a number less than 10.
4. Passing grades must be earned in a total of 486 units, including all courses used to satisfy the above requirements.
5. It is desirable that students enter the option in the sophomore year. However, students may also enter the option in the junior year if they can complete the option's requirements in time for graduation.

Typical Course Schedule

First Year

It is recommended that students take the following courses: history of early modern Europe or the American revolution; introduction to or history of philosophy; and Ec 11 or PS 12.

		Units per term		
		1st	*2nd*	*3rd*
Second Year				
SES 101 ab	Introduction to Science, Ethics, and Society	9	9	-
	Advanced Philosophy or History	-	-	9
SES 103	Lecture Series (1-0-0)	1	1	1
Ma 2 ab[1]	Sophomore Mathematics (4-0-5)	9	9	-
Ph 2 ab	Waves, Quantum Mechanics, and Statistical Physics (4-0-5)	9	9	-
	Menu Course	-	-	9
	Electives	18	18	27
		46	46	46

[1] *Ma 2 c ceases to exist after 1996-97.*

It is recommended that one of the electives be either Ec 11 or PS 12, whichever one has not been taken in the freshman year.

Third Year				
SES 103	Lecture Series (1-0-0)	1	1	1
	Advanced SES/History	9	9	9
	Advanced SES/Philosophy	9	9	9
	Science, Math, Engineering	9	9	9
	Electives	18	18	18
		46	46	46
Fourth Year				
SES 103	Lecture Series (1-0-0)	1	1	1
SES 102 ab	Senior Research Tutorial (1-0-8)	9	9	-
SES 102 c	Senior Research Seminar (2-0-7)	-	-	9
	Advanced SES/History or Philosophy	9	-	-
	Science, Math, Engineering	9	9	-
	Electives	18	27	36
		46	46	46

It is recommended that students choose their advanced social science electives from among courses that will enlarge their perspective on topics related to SES (for example, Ec 118, Ec/SS 128, Ec/SS 129, Ec/SS 130, PS 120, PS 121, PS 122, An 22, An 123).

SES Minor Requirements

Undergraduates taking the SES minor will pursue a two-part program of study using the 108-unit humanities and social sciences

(HSS) requirement in a way that is tailored, with the help of a program adviser, to their particular interests. The first part is introductory, comprising SES 101 ab as well as general but related courses in humanities and social sciences selected so as to develop a coherent and solid foundation for work in an area of SES concentration. The second part consists of advanced courses clustered in an area of concentration such as those described in the option requirements. To this end, SES minor students are required to complete at least one advanced course in the history of science and one in the philosophy of science or ethics. Qualifying history courses are: SES/H/Lit 128, SES/H 156, SES/H 157, SES/H 158, SES/H 159, SES/H 160 ab, SES/H 162, SES/H 163, SES/H 164, SES/H 165, SES/H 166, SES/H 168, SES/H 169. Qualifying philosophy courses are: SES/Pl 122, SES/Pl 125, SES/Pl 126, SES/Pl 127, SES/Pl 131, SES/Pl 169, SES/Pl 185.

In addition to completing the 108-unit HSS requirement, SES undergraduates must participate in their junior and senior years in SES 103 and complete SES 102 bc. The research paper expected of SES minor students will be shorter than that expected of students in the option; hence, only the second two quarters of SES 102 are required. The remaining choice of courses in both humanities and social sciences will be determined by a student's expected SES concentration. It is recommended that SES minor students use their social science requirement to develop a strong grounding in economics and politics and that they take at least one course in literature (Lit 138 and/or Lit 127 are recommended).

All SES courses required for the SES minor must be taken for grades, with the exception of SES 103.

Course of Minor Study

During four years, the normal SES minor course of study will resemble the following:

1st Year

1. freshman history and/or philosophy (2 quarters; 18 units)
2. introductory economics or political science (1 quarter; 9 units)

2nd Year

1. SES 101 ab, Introduction to Science, Ethics, and Society (2 quarters; 18 units)
2. social science (1 quarter; 9 units)
3. SES 103 lecture series (3 quarters; 3 units) (recommended but optional)

3rd Year

1. history or philosophy of science (1 quarter; 9 units)
2. advanced humanities (1 quarter; 9 units)
3. advanced social science (1 quarter; 9 units)

4. SES 103 lecture series (3 quarters; 3units)

4th Year
1. history or philosophy of science (1 quarter; 9 units)
2. advanced humanities (1 quarter; 9 units)
3. advanced social science (1 quarter; 9 units)
4. SES 102 bc research tutorial and seminar (2 quarters; 18 units)
5. SES 103 lecture series (3 quarters; 3 units)

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, or in law or business.

Option Requirements

1. Ec 11, PS 12, Ec 121 a, Ma 112 a, Ec 122, PS/Ec 172.
2. One of the following: An 22, An 101, or Psy 15.
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, law, 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		
		1st	*2nd*	*3rd*
Second Year				
Ec 11	Introduction to Economics (3-0-6)	9	-	-
PS 12	Introduction to Political Science (3-0-6)	-	-	9
Ma 2 ab[1]	Sophomore Mathematics (4-0-5)	9	9	-
Ph 2 ab	Waves, Quantum Mechanics, and Statistical Physics (4-0-5)	9	9	-
	Menu Course	-	-	9
	Electives	18	27	27
		45	45	45

[1] *Ma 2 c ceases to exist after 1996-97.*

Third Year

Ma 112 a	Statistics (3-0-6)	9	-	-
Ec 121 a	Theory of Value (3-0-6)	-	9	-
Ec 122	Econometrics (3-0-6)	-	9	-
PS/Ec 172	Noncooperative Games in Social Science (3-0-6)	-	9	-
An 101 or	Selected Topics in Anthropology (3-0-6)	-	-	-
An 22 or	Introduction to the Anthropology of Development (3-0-6)	9	-	-
Psy 15	Cognitive Psychology (3-0-6)	-	9	-
	Electives	27	9	45
		45	45	45

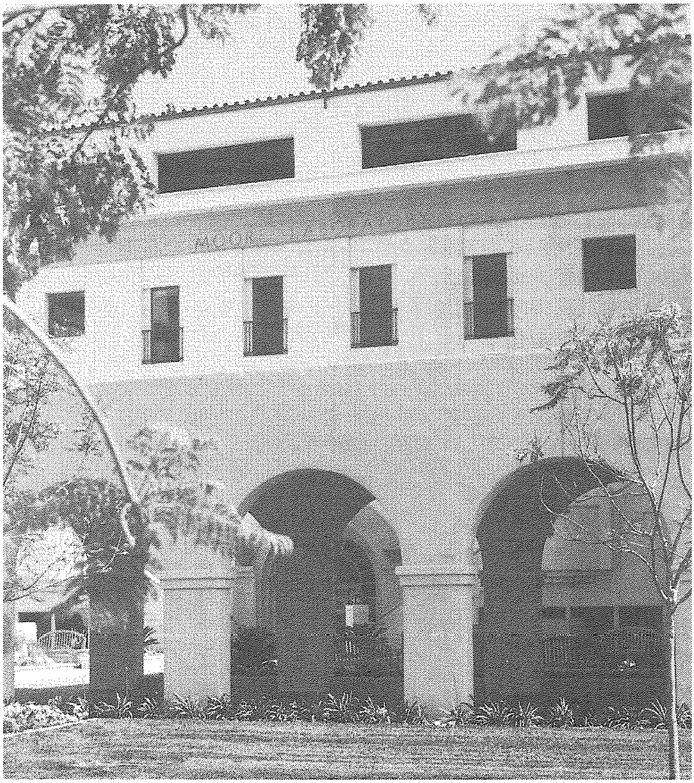
Fourth Year

	Electives[1]	45	45	45

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

Section Four

Information for Graduate Students



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 option representatives for 1996–97 are as follows:

Aeronautics	Prof. W. G. Knauss
Applied Mathematics	Prof. D. Meiron
Applied Mechanics	Profs. E. K. Antonsson and J. F. Hall
Applied Physics	Prof. K. Vahala
Astronomy	Prof. S. Phinney
Biochemistry	Prof. D. Rees
Biology	Prof. P. Sternberg
Chemical Engineering	Prof. G. Gavalas
Chemistry	Prof. J. E. Bercaw
Civil Engineering	Profs. E. K. Antonsson and J. F. Hall
Computation and Neural Systems	Prof. C. Koch
Computer Science	Prof. A. J. Martin
Control and Dynamical Systems	Prof. R. Murray
Electrical Engineering	Prof. P. P. Vaidyanathan
Engineering Science	Prof. T. Y. Wu
Environmental Engineering Science	Prof. G. Cass
Geological and Planetary Sciences	Prof. P. Wyllie
Materials Science	Prof. B. Fultz

Mathematics	Prof. D. Ramakrishnan
Mechanical Engineering	Profs. E. K. Antonsson and J. F. Hall
Physics	Prof. F. Porter
Social Science	Prof. K. Border

GENERAL REGULATIONS

Admission to Graduate Standing

Application

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. 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. Admission sometimes may have to be refused solely on the basis of limited facilities in the option concerned.

Students from non-English-speaking countries are expected to read, write, and speak English and comprehend the spoken language in order to be admitted for graduate study. In addition, to be a candidate for an advanced degree, the student must have acquired the power of clear and forceful self-expression in both oral and written English. Although not *required* for admission, it is important to demonstrate a strong capability in English prior to admission to Caltech, as it is part of the criteria for admission and financial aid.

Required Tests
The Graduate Record Examination is very strongly recommended by all options, and scores are required by most options as part of the application for graduate admission.

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. Nearly all successful applicants have TOEFL scores better than 600. In addition, applicants are highly encouraged to take the Test of Written English (TWE) and the Test of Spoken English (TSE) and submit these scores as part of their application. These tests are 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 or electronically at www.gre.org. Results of these tests should be sent to the Graduate Office.

It is strongly recommended that students who do not achieve a high score on these tests or who have little opportunity to communicate in English make arrangements for intensive work during the summer preceding their registration. Students are tested upon their arrival at Caltech and if found to be seriously deficient in their ability to communicate in English must take special non-credit courses. A student may not serve as a graduate teaching assistant with responsibility for a section until this requirement has been satisfied.

Special Students
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. 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

Graduate students are required to register and file a program card in the Registrar's Office for 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. Mail registration is provided for graduate students during a two-week period near the end of the previous quarter. A late registration fee of $50 is assessed for failure to register on time.

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. This registration 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. 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.

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 if he or she feels that the progress of the research does not justify the full number originally registered for.

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.

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 is registered for 36 or more units is classified as a full-time student. A graduate student who registers for less than 36 units, or who undertakes activities related to the Institute aggregating more than 62 hours per week (in class, research, and teaching assistantship units) 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 Dean of Graduate Studies.

Academic Year and Summer Registration

Most courses are taught during the three 12-week quarters that make up the academic year. However, predoctoral students are strongly encouraged to continue their research throughout the summer quarter. They are entitled to at least two weeks' annual vacation (in addition to Institute holidays), but they should arrange their vacation schedules with their research advisers early in each academic year.

All students in residence must be registered. A registration card for summer research must be filed with the Registrar's Office in May. There is no tuition charge for summer research units. To maintain full-time student status, 36 units must be taken in the summer quarter.

Leave of Absence

Graduate students are 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. A leave of absence for medical or other reasons may be approved for up to one year at a time. Leave will be approved to meet military obligations, and tuition adjustments will be made if the leave must be initiated within a term. (See page 124.) An approved leave of absence indicates that the student can return to the option at the end of the leave. Financial aid awarded by the Institute will not be deferred from the term for which it was originally offered and must be requested again for the term of reenrollment.

Detached duty status continues registration for a student doing research at another location, such as a national facility, for an extended period. Reduced duty status continues registration for a student who cannot carry a full load due to medical disability, including pregnancy.

Petition forms for an approved leave of absence, or detached or reduced duty status, may be obtained from the Graduate Office and must, before submission to the Dean of Graduate Studies, carry the recommendations of the student's option representative and, where appropriate, the thesis adviser. In case of a lapse in admission status, 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 each quarter.

The Dean of Graduate Studies may place a graduate student on involuntary leave of absence if persuaded by the evidence that such an action is necessary for the protection of the Institute community or for the personal safety or welfare of the student involved.

Such a decision by the dean is subject to automatic review within seven days by the Vice President for Student Affairs.

Part-Time Programs

Part-time graduate study programs at the Institute are for graduate students who cannot devote full time to their studies and are allowed to register only under special arrangements with a sponsoring organization, and 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.
- During the second year, students may register for less than 27 units each term. All degree requirements must be met by the end of the second academic year.
- 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.
- Any option at the Institute retains the right to not participate in the program or to accept it under more stringent conditions.

Nondegree 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 an 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 course instructor and the option representative, 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 nondegree students are subject to the Honor System (see page 29) 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 nondegree students admitted to any one course.

Working at Special Laboratories

- Any student who desires to take advantage of the unique opportunities available at one of the special laboratories, e.g., JPL or EQL, for Ph.D. thesis work, may be allowed to do so, provided that he or she maintains good contact with academic life on campus, and the laboratory involved commits support for the duration of the thesis research, and provided that all Caltech graduate thesis research carried out at a special laboratory is 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 should recognize its commitment of special equipment or any other resources required for the thesis work. Approval by 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.
- A special laboratory's support of a Caltech student doing thesis research at the laboratory should be provided, if possible, through a campus graduate research assistantship (GRA) under a suitable work order. In this way, the student would be eligible for a tuition award on the same basis as a campus thesis student.
- Employment by a special laboratory 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. Several options do not offer an M.S. degree except in special circumstances.

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.

Joint B.S./M.S. Degree. In exceptional cases, undergraduate students may pursue a joint B.S./M.S. program of study in some options. Students should contact the graduate option representative to find out if the joint B.S./M.S. degree is possible in a particular option. Such students must follow the normal procedures for admission to the M.S. program in the option of their choice. Students attending courses or carrying out research toward an M.S. degree before completion of their B.S. degree requirements will be considered as undergraduate students and will not be eligible for graduate financial aid, graduate housing, or other graduate student privileges.

Admission to Candidacy. Before the midpoint 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.

Admission to Candidacy. Before the midpoint 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 chair of the appropriate division, will appoint a committee of three members of the faculty to supervise the student's work and to certify 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 his or her work. The schedule of 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 can be finished at the expected date; (c) that the candidate demonstrates competence in oral and written English.

Competency in English can be demonstrated in several ways. The student from a non-English-speaking country can meet the oral portion of the requirement by acquiring TSE or SPEAK scores better than 50 prior to admission; by testing or screening at the time of admission, within the ESL class; or by arranging to take a test with the Office of International Students. A record of the test scores will be maintained in the Graduate Office and provided to the option representative as required for attesting to preparation for candidacy. The writing portion of the requirement may be demonstrated by a score better than 5 on the TWE test or by acceptance of the final thesis by the faculty.

Such admission to candidacy must be obtained by the midpoint 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. These regulations may be obtained from the Graduate Office. The candidate must obtain written approval of the thesis by the chair 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 the 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 English.

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 most options as specified in this catalog under the section "Special Regulations of Graduate Options." Completion of a minor program of study is recognized on the Ph.D. diploma by the statement, "...and by additional studies constituting a minor 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 the recommendation of the chair 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; demonstrates the ability for clear and forceful self-expression in both oral and written English; and has shown ability in carrying on research in a subject approved by the chair 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.

Competency in English can be demonstrated in several ways. The student from a non-English-speaking country can meet the oral portion of the requirement by acquiring TSE or SPEAK scores better than 50 prior to admission; by testing or screening at the time of admission, within the ESL class; or by arranging to take a test with the Office of International Students. A record of the test scores will be maintained in the Graduate Office and provided to the option representative as required for attesting to preparation for candidacy. The writing portion of the requirement may be demonstrated by a score better than 5 on the TWE test or by acceptance of the final thesis by the faculty.

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 Chair 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 three 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 adhering 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 the fifth week of the succeeding term if the candidate defended his or her thesis during the previous summer or the first or second terms; or two weeks before the degree is to be conferred if the candidate defended his or her thesis during the month of May. 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 chair 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 coauthors. 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.

The tuition charge for all students registering for graduate work is currently $18,000 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 the form available from the Graduate Office. If reduced registration is permitted, the tuition for each term is at the rate of $167 a unit for fewer than 36 units, with a minimum of $1,670 a term. This tuition credit will only be made for reduced units as of the published Add Day of each term. However, if tuition credit has been applied to students' accounts for reduced units, any subsequent increase in tuition units will result in the appropriate tuition charge for the increased number of units retroactive to the beginning of the academic 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 in the following pages. Students of high scholastic attainment may be offered special tuition awards covering all or part of the tuition fee. Loans also may be arranged by applying at the Graduate Office.

Expense Summary 1996-97

General:

General Deposit	$ 25.00[1]
Tuition	18,000.00
Graduate Student Council Dues	24.00[2]
	$ 18,049.00

Other:

Books and Supplies *(approx.)*	$ 965.00
Room[3]:	
On-campus graduate houses	
For single students	$ 339.30 per 30-day month
For single students (suite)	$ 356.70 per 30-day month
Catalina apartments	
For single or married students	
4 bedroom quad apt.	$ 384.60 per person per 30-day month
4 bedroom triple apt.	$ 396.00 per person per 30-day month
2 bedroom apt.	$ 396.00 per person per 30-day month
1 bedroom apt.	$ 727.20 per apt. per 30-day month
Avery House private room	$ 396.30 plus full board plan (M–F)
	$ 719.82/term

Meals: Available at Chandler Dining Hall
or the Athenaeum (members only)

On the following page is a list of graduate fees at the California Institute of Technology for the Academic Year 1996-97, together with the dates on which these charges are due. Fees are subject to change at the discretion of the Institute.

[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 $8.00 in Graduate Student Council dues.*

[3] *Room rent is billed at the end of each month and is payable upon receipt of the monthly statement.*

First Term	*Fee*
September 30, 1996	
General Deposit	$ 25.00
Tuition	6,000.00
Graduate Student Council Dues	8.00
Second Term	
January 6, 1997	
Tuition	$ 6,000.00
Graduate Student Council Dues	8.00
Third Term	
April 1, 1997	
Tuition	$ 6,000.00
Graduate Student Council Dues	8.00

Tuition fees for fewer than the normal number of units:	
36 units	Full Tuition
Per unit per term	$ 167.00
Minimum per term	1,670.00
Audit Fee, $167.00 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 $50 is assessed for failure to register within five days of the scheduled dates.

A $50 late penalty will be charged by Student Accounts for failure to clear a past-due account within five days of the beginning of instruction.

Graduate Student Council Dues. Dues of $24 are currently charged to each graduate student for the academic year. In addition, $8 is charged to 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.

Honor System Matters. Monies owed to the Institute resulting from a Graduate Review Board decision may be collected through Student Accounts, at the request of the Dean of Graduate Studies.

Housing Facilities. The Institute has three dormitories on campus providing single rooms for 119 graduate students. In September 1984, the Institute completed construction of an apartment complex, Catalina Central, that provides approximately 148 single rooms in four-bedroom furnished units. Catalina North, completed in September 1986, has 156 single rooms in two-bedroom furnished units. Catalina South, completed in September 1988, has 54 single rooms in two-bedroom furnished units, and 29 one-bedroom furnished units. These apartments are also available to married students with families. In addition, there are about 35 spaces for graduate students in Avery House, an innovative residential community of faculty, undergraduates, and graduate students completed in 1996 (see catalog section on Student Life).

Rates for housing vary, depending upon the accommodations and services provided. A contract is required to live in these houses for the academic year. A $100 deposit must accompany each housing application, and is refunded within one month of check-in. Complete information and reservations can be obtained by writing to the Graduate Housing Office, Mail Code 105-104, 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 limited availability, 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 Graduate Housing Office, Mail Code 105-104, California Institute of Technology, Pasadena, CA 91125.

The Housing Office maintains a current file of available rooms, apartments, and houses in the Pasadena area. The listings are available on the WWW at http://housing.caltech.edu. Students preferring to live in non-Institute housing typically pay approximately $425–$460 per month in rent for a shared apartment, and somewhat 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 Caltech, 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 One.

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 such applicants 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 to the Dean of Graduate Studies any financial aid from other sources. 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 up to 15 hours per week during the academic year and are devoted to preparation, grading, or consulting with students. Students may not be a teaching assistant for a course in which they receive credit without advance permission from the Dean of Graduate Studies. Research assistantships are up to 20 hours per week during the academic year and may be greater during the summer. Combined teaching and research assistantships are common. **Stipends are based on four 12-week quarters and are normally paid monthly.** Assistantships normally permit carrying a full graduate residence schedule also. Only teaching assistants with good oral English are allowed to teach sections.

Teaching assistants must familiarize themselves with Caltech's policy on harassment (see page 46). Classes should foster academic achievement in a "hassle-free" environment. Teaching assistants should not attempt to date a student in their class, and should disqualify themselves from teaching a section in which a spouse or current partner is enrolled. Any questions should be referred to the Dean of Graduate Studies.

Teaching and research obligations of graduate assistants shall not exceed 50 weeks per year, but may be less depending on departmental policy and the arrangements made by the adviser and the student. Graduate assistantship appointments include regular Institute holidays occurring during specified appointment periods. In addition, when necessary, graduate assistants may arrange for short-term medical disability leave (including maternity leave). Assistants should schedule their vacation and planned disability leaves with their adviser or option representative. Any questions should be referred to the Dean of Graduate Studies.

Graduate Scholarships, Fellowships, and Research Funds

The Institute offers a number of endowed fellowships and scholarships for tuition and/or stipends 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), the Northrop Corporation Fellowship Program (P.O. Box 1138, Pico Rivera, CA 90660-9977), and the Jet Propulsion Laboratory of the California Institute of Technology. Potential students considering participation in the Hughes or Northrop programs may make inquiry to the addresses 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

Several types of loans are available to graduate students. To qualify for any of these loans, a student must demonstrate financial need and must maintain satisfactory academic progress in the course of study for which he or she is enrolled. Application forms and further information are available in the Graduate Office.

Loan applicants will be asked to submit signed copies of their federal income tax returns (form 1040, 1040A, or 1040EZ), complete with all supporting schedules and attachments.

Satisfactory Academic Progress

In order to continue receiving financial aid at Caltech, graduate students must maintain satisfactory academic progress toward completion of their degree. Continuity of registration must be maintained until all requirements for the degree being sought have been completed, with the exception of summer terms and authorized leaves of absence.

The Master of Science degree requires at least one academic year of residence at the Institute and 135 units of graduate work with a grade-point average of at least 1.9. Under normal circumstances a master's degree requires a minimum of three academic terms (one year) and cannot take more than two years, without a petition approved by the Dean of Graduate Studies.

The engineer's degree must consist of advanced studies and research in the field appropriate to the degree desired. At least six terms (two years) of graduate residence are required with a minimum 1.9 overall grade-point average. The engineer's degree cannot take more than three years to complete, without a petition approved by the Dean of Graduate Studies.

For the doctor's degree at least nine terms (three years) of residence are required, but the necessary study and research typically requires more than five years. The work for the degree consists 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 English.

The requirements for each degree include special regulations established by each option and detailed in the Institute catalog for the year of initial registration. Many options require a C grade or better in particular courses or groups of courses. Hence, a limited number of courses may be repeated while still maintaining a status of satisfactory academic progress and would count toward the 36-unit-per-term requirement. A full-time graduate student must register for (and complete) 36 units per term. Approval of the Dean of Graduate Studies is required before dropping any course that brings a student below 36 units. All graduate students are expected to complete 108 units each academic year. The treatment of incomplete grades and withdrawals is specified on page 37. Satisfactory academic progress is checked each academic year by the Graduate Office.

The special regulations for the options typically include the completion of specific courses, oral and/or written examinations, petitions, research requirements, etc., by specific times. Satisfactory academic progress is judged by the options against these regulations, and revocation of permission to register may be recommended by the option to the Dean of Graduate Studies prior to or in response to the student's petition for admission to candidacy. Further, even after admission to candidacy, the candidacy (and permission to register) may be withdrawn by formal action of an option for a student whose research is not satisfactory, or for other compelling reasons. However, the option must petition through its Division Chair to the Dean of Graduate Studies before taking such action.

A doctoral student who has not been admitted to candidacy by the beginning of the fourth year must petition to the Dean of Graduate Studies for permission to register for further work. In addition, no doctoral student will be allowed to register for a sixth year 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.

Petitions approved by the option and the Dean of Graduate Studies reinstate student eligibility for all financial aid.

Refund and Repayment Policy

Caltech has established an equitable refund policy for students who find it necessary to withdraw or take a leave of absence from the Institute.

Students who officially withdraw or take a leave of absence from the Institute during an academic term will receive a tuition refund based on the schedule published on page 123. 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 account.

An overpayment or overaward occurs when a student receives more aid than he or she is eligible to receive. Therefore, the Graduate 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 Graduate Office.

Students receiving financial aid from any source are expected to register for 36 units each term unless special arrangements have been made with the Dean of Graduate Studies.

PRIZES

Charles D. Babcock Award

The Charles D. Babcock Award recognizes a student whose achievements in teaching (or other ways of assisting students) have made a significant contribution to the aeronautics department. The criteria for the award selection are as follows: The award can be made as unscheduled support for a graduate student associated with aeronautics, e.g., for travel to a technical meeting for professional advancement. All aeronautics-associated students are eligible, with preference given to those in the structures and solid mechanics group. The award may be made yearly, as merited. The timing of the award will be as special recognition warrants.

The Charles D. Babcock Award was established in 1992 in memory of Charles D. Babcock, who was Professor of Aeronautics and Applied Mechanics until 1987; he served aeronautics as Option Representative and the Institute as Vice Provost.

William F. Ballhaus Prize
A prize of $750 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 in the U.S. 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.

Rolf D. Buhler Memorial Award in Aeronautics
An award of $500 is made annually to a student in the Aeronautics Master's Program whose academic performance was exemplary and who shows high potential for future achievements at Caltech.

The Rolf D. Buhler Memorial Award in Aeronautics was established in 1990 in memory of Rolf Buhler, a 1952 graduate of GALCIT and Professor of Space Flight at the Technical University of Stuttgart in Germany.

W. P. Carey & Co., Inc., Prizes in Mathematics
Prizes of up to $500 will be awarded by a faculty committee in applied mathematics for outstanding doctoral dissertations. If there is no appropriate candidate, then the awardee can be chosen from pure math. 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 $500 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 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 chair of the Division of Engineering and Applied Science names the student to receive the award.

Graduate Dean's Award for Outstanding Community Service
This award is made annually to a Ph.D. candidate who, throughout his or her graduate years at the Institute, has made great contributions to graduate life and whose qualities of leadership and responsibility have been outstanding. The award consists of a cash award and a certificate.

The Herbert Newby McCoy Award
A cash award is made annually to a graduate student in chemistry to acknowledge an "outstanding contribution to the science of chemistry." 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 $1,000 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 $500 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.

Charles Wilts Prize
Awarded for outstanding independent research in electrical engineering leading to a Ph.D.

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 education 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 pursue major study in, for example, one of the following areas: physics of fluids, technical fluid mechanics, structural mechanics, mechanics of materials, 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. A program of study consists of courses totaling at least 138 units; of these 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

Also, an elective course or course sequence of 27 units must be included, in addition to three units of Ae 150. 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. All students working for the engineer's degree or the Ph.D. degree are expected to register for and attend one of the advanced seminars (Ae 208 abc or Ae 209 abc).

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 138 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 or Ae/AM 209; 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 first 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 as the second topic, or both as the second and third topics. Alternate topics must be discussed with the option representative and adviser.
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).

In the event of an unsatisfactory performance, the examining faculty members may permit a repeat examination in the appropriate topic(s). This reexamination must be scheduled prior to finals week of the third term and must be completed before the end of June of the same year.

Candidacy. To be recommended for candidacy for the Ph.D. in aeronautics, the applicant must have satisfactorily completed at least 138 units of graduate work equivalent to the above Master of Science program and 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
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
- a subject minor offered outside of aeronautics, or at least 54 units of courses outside of the applicant's chosen discipline and approved by the aeronautics faculty. If, in the latter context a language is chosen, letter grades are required.

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 in the second or third year of residence at the Institute. 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. Each candidate is required before graduation to give a public seminar presenting the results of his or her thesis research. For final examination and thesis completion, see general degree requirements.

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 include AMa 101, AMa 104, AMa 105, AMa 204, Ma 109 abc, Ma 121, 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 210, 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 or second quarter 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. Students who have taken some of these courses as undergraduates may use them to satisfy this distribution requirement, even though the units may not be used to satisfy the total unit requirement for the Ph.D. degree.

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
A subject minor is not required for the Ph.D. degree in applied mathematics. However, graduate students in other options may pursue a subject minor in applied mathematics. The group of courses must differ markedly from the major subject of study and include 54 units of advanced courses in applied mathematics, excluding AMa 101, 104, 105. The student must pass an oral examination that is separate from the examination in the student's major.

Subject Minor in Applied Computation
The subject minor in applied computation is administered jointly by the applied mathematics and computer science options, and is open to graduate students in all options. This minor emphasizes the mathematical, numerical, algorithmic, and programming methods underlying the application of computation—particularly parallel and concurrent computation—to research in science and engineering.

To pursue the applied computation minor, applied mathematics students should seek a minor adviser in computer science; computer science students should seek a minor adviser in applied mathematics; and students in other options should seek a minor adviser in either applied mathematics or computer science. The minor adviser and the student formulate a program of courses individually tailored to the student's background and needs, with the objective that the student achieve a level of competence in specific subjects relevant to applied computation that is comparable to that of candidacy-level graduate students in applied mathematics *and* computer science in these same subjects. These subjects include *at minimum* mathematical and numerical methods, algorithms, and advanced programming, and may also include other areas of particular relevance to a student's research area, such as specialized mathematical methods, computer graphics, simulation, or computer-aided design.

Each proposed program must be approved by a faculty committee composed of the option representatives of applied mathematics and computer science, and one faculty member appointed by the chair of each division from which students are enrolled in the program. The number of course units is variable, with a minimum of 45 units of graduate-level courses. The satisfaction of the intended level of competence is assured by the student's passing an oral examination.

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 courses numbered 100 or above totaling at least 138 units. The program must include E 150 abc and one course from among the following: AM 114 abc, AM 125 abc, AMa 101 abc, or either of the combinations Ma 107, Ma 108 ab, or Ma 107, Ma 109 ab. Note that neither AM 114 nor either of the combinations involving Ma 107 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 must be selected from courses in AM, AMa, Ae, JP, CE, and ME. The program must be approved by the student's adviser and the option representative for applied mechanics.

Students admitted for study toward a master's degree but interested in pursuing subsequent study toward a Ph.D. degree should also read the section below concerning this degree.

Degree of Doctor of Philosophy in Applied Mechanics
Study and research programs for the Ph.D. degree are individually planned to fit the interests and background of the student. A comprehensive research project leading to a thesis is required.

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 chair and interim adviser until this responsibility is assumed by the dissertation supervisor. This committee must meet during the first term of each year of Ph.D. study.

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, is confined to elementary but basic topics.

Admission to Candidacy. 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 27 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 so taken 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 additional 27 units of course work in advanced mathematics, such as AM 125 abc, Ph 129 abc, or AMa 101 abc or a substitute, 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; if the student has a minor, an examination on the subject of that program may be included at the request of the discipline offering the minor. The student must take the oral candidacy examination before the end of the second academic year of graduate residence at the Institute.

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 courses approved by the faculty in applied mechanics. The student must 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
The graduate program in applied physics is regarded by its faculty to be a doctoral program. Students whose goal is the master's degree are admitted rarely, and only in special situations.

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, APh 125, APh 105, Ae/APh 101, and APh 156. Topics in Applied Physics, APh 110 ab, 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 124, APh/EE 130, APh/EE 131, APh/EE 132, APh 156, APh 181, APh 190, APh 200, APh 125, Ph 129, AMa 101, AMa 104, AMa 105, AM 135, AM 176, ChE 103, ChE 165, Ch 120, Ch 125, Ge 101, Ge 102, Ge 103, Ge 104, and Ge 260. 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: APh 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, a student supplying evidence of having done equivalent work elsewhere may 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 research adviser for the student's proposed thesis; normally the topic will be the projected research. 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/EE 131, APh/EE 132, APh 190

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 273) 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 121, Ay 122, Ay 123, Ay 124, Ay 125, Ay 126, Ay 127, and Ay 128. 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. The two first-term courses are required of all students: Ay 121 and Ay 122; in addition, 36 units chosen from Ay 123, Ay 124, Ay 125, Ay 126, Ay 127, and Ay 128 are required for candidacy. The student should take the six courses necessary for this 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 nine 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 121 and Ay 122, plus four of the following: Ay 123, Ay 124, Ay 125, Ay 126, Ay 127, and Ay 128;
- 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 Observatories of the Carnegie Institution of Washington.

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 by the Executive Officer in consultation with the student's adviser. It will stand until the final examination and be charged with ensuring that satisfactory progress toward the Ph.D. is being made. 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.

Biochemistry

Aims and Scope of Graduate Study in Biochemistry

An integrated approach to graduate study in biochemistry has been organized primarily by the Division of Biology and the Division of Chemistry and Chemical Engineering. The curriculum is designed to provide a broad background in protein biochemistry, structural biology, and molecular genetics, in addition to an appropriate depth of knowledge in the field selected for the Ph.D. thesis research.

Admission

The option in biochemistry is open to students with undergraduate degrees in biochemistry, biology, chemistry, biophysics, and related areas. All applicants for admission, including those from foreign countries, are required to submit the verbal, quantitative, and analytical scores for the Graduate Record Examination and are also strongly urged to submit the results of an advanced test in a scientific field. Applicants whose native language is not English are also required to submit results of the TOEFL exam, and, after admission, are required to satisfy the English language requirements of the Institute.

Master's Degree in Biochemistry

Students are not normally admitted to 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.

Degree of Doctor of Philosophy in Biochemistry

The Option Graduate Study Committee will counsel and oversee the student's progress upon admission to the graduate program. In the first year of graduate study, the course requirement consists of a sequence of three core courses covering topics in structural biochemistry (Bch/Bi/Ch 170), the molecular basis of protein function (Bch 176), and molecular genetics (Bch 178). These courses will expose the student to contemporary issues in modern biochemistry, and to the tools and methods that are essential for biochemical research. Students are generally expected to conduct a 10–12 week research rotation in three different laboratories during the first year. Research advisers are normally selected at the end of the first year. In consultation with their adviser and the Option Graduate Study Committee, students are expected to take three advanced courses in the second year that are appropriate for their particular research interests.

Laboratory Rotations. In consultation with the Option Graduate Study Committee and individual professors, students will choose three laboratories in which to do short research projects during their first year of residence. These laboratory rotations are designed to provide the student with an introduction to different areas of biochemistry. It is possible to waive some or all of the rotations by petitioning the Option Graduate Study Committee.

Admission to Candidacy. By the end of the sixth term of residency, the student will take an oral examination to assess mastery of the field of biochemistry and to evaluate research progress. As part of this examination, each student will submit a written research report summarizing the progress in their research, and an original research proposition in a field outside the student's chosen field of research. A candidacy examination committee will be assembled by the Option Graduate Study Committee to administer the examination. When the student advances to candidacy upon successful completion of the exam, this committee will become the thesis advisory committee and will meet with the student once a year to evaluate research progress. This committee will also serve as the Ph.D. thesis examination committee.

Thesis and Final Examination. Thesis research will be carried out under the direction of one or more faculty members in the biochemistry option. The thesis defense will consist of a thesis seminar, followed by an examination by the Ph.D. thesis committee.

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; and (b) 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 and the Institute Academic Council (IACC) if there are circumstances 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, with 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 chair 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; 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:

- Biotechnology
- Cellular Biology and Biophysics
- Cellular and Molecular Neurobiology
- Developmental Biology
- Genetics
- Immunology
- Integrative Neurobiology
- Molecular Biology and Biochemistry

At graduation, a student may choose whether the degree is to be awarded in biology or in the selected major subject. As part of their Ph.D. program, students may complete a minor in another graduate option, in accordance with the regulations of that option. Students should consult with their advisory committee in planning such a program.

Dual Major in Biotechnology. Students who wish their Ph.D. education to emphasize the development of new techniques and instruments for studying fundamental problems of biology may elect a dual major, combining biotechnology with one of the major subjects of specialization listed in the preceding paragraph. A significant component of the thesis research will be the development of an innovative technique, method of analysis, or instrument. It will also include application of the new technology to a significant biological problem. In preparation for this research, studies in biotechnology may involve significant work outside of biology, in fields such as computer science, chemistry, engineering, and applied mathematics.

Additional Opportunities in Biotechnology. Biotechnology is a highly interdisciplinary area of research, and students interested in this area will find additional graduate opportunities within graduate options including chemistry and chemical engineering, environmental engineering, computer science, and computation and neural systems.

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 the ability to carry out original research and have passed, with a grade of B or better, the candidacy examination in the major subject and one or two minor subjects from the list of major subjects of specialization. Students with a dual major in biotechnology must pass the candidacy examination in the major subject (omitting the normal minor subject or subjects), and a second examination covering knowledge fundamental to the particular work in biotechnology that is proposed by the student. In addition, all students will be expected to make an oral defense to their thesis advisory committee of a written research proposal, on the topic of their anticipated thesis project. This defense will occur 6–9 months following passage of the candidacy examination.

Thesis Committee. Before admission to candidacy, a thesis advisory committee is appointed for each student by the chair of the division upon consultation with the student and the major professor. This committee will consist of the student's major professor as chair and four other appropriate members of the faculty. The thesis committee will meet with the student before admission to candidacy to certify that the student has demonstrated the ability to carry out independent research, and at regular 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 chair, 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 regulations 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, with 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 mathematics; the physical, chemical, and biological sciences; and engineering to the 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 option may prescribe additional work in these subjects before recommending him or her as a candidate.

Master's Degree in Chemical Engineering
Course Requirements. At least 135 units of course work must be completed in order to satisfy the Institute requirements. These units must include ChE 151 ab, ChE 152, ChE 165, 18 additional units of advanced courses in chemical engineering, 27 units of science or engineering electives, and 18 units of general electives. Finally, the M.S. requirements include at least 27 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. At least three weeks before the end of the final term of residence, a research report on the work performed under ChE 280 must be submitted to a designated member of the faculty, who will ask that it be read and approved by two members of the faculty. A copy of each approved M.S. report will be kept in the chemical engineering library. Doctoral students who have been admitted to candidacy can use their approved candidacy report to satisfy the research report requirement of the M.S. degree.

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.

Admission. Upon arrival at Caltech, each prospective Ph.D. student will meet in consultation with members of the faculty so that they may evaluate the level of the student's preparation with respect to that expected at the Ph.D. level in the areas of kinetics, thermodynamics, and transport phenomena. These consultations are made to help the student set up a course program for the first year of study. A written copy of the recommendations will be entered into each student's permanent file.

Oral Qualifying Exam. Each student is required to take a subject oral qualifying examination at the beginning of the second quarter in residence, the purpose of which is to examine expertise in kinetics, thermodynamics, and transport phenomena. The intended level of the exam is approximately that of the corresponding undergraduate courses at Caltech. Students who fail one or more of the three subjects may be permitted, by approval of the chemical engineering faculty, to repeat the examination on the failed subject immediately after the spring term. The format and topics of the examination are distributed to the first-year students at the beginning of the fall quarter.

Course Requirements. Students are required to take ChE 151 ab, ChE 152, ChE 164, ChE 165, and an additional ChE course from a designated list. Each student is required to complete either a subject minor, or a general program of courses outside chemical engineering consisting of at least 54 units. The general program of courses must be approved *in advance* by the option representative. It is intended that the courses chosen should constitute some integrated program of study rather than a randomly chosen collection of courses outside chemical engineering. Within these guidelines, the only courses specifically excluded are AM 113, AM 114, and research in another option. A grade of C or better is required in any course. The requirements for a subject minor in any option are listed in this catalog.

Candidacy Report/Examination. Before the end of the fall quarter of the second year of residence, each student must submit a written progress report on his or her research for approval to a specially constituted candidacy committee consisting of faculty members familiar with his or her general area of research. An oral examination is subsequently held by this committee to evaluate the student's ability to carry out research at the Ph.D. level. A student who fails to satisfy the candidacy requirements by the end of the second year in graduate residence will not be allowed to register in a subsequent term except by special permission of the option and the Dean of Graduate Studies.

Admission to Candidacy. To be admitted to candidacy, the student must have passed the qualifying and candidacy examinations, must have had the candidacy report approved, and must have submitted an approved list of courses already taken or to be taken.

Thesis and Final Examination. See page 208 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 his or her Ph.D. thesis.

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 151 ab, ChE 152, ChE 164, ChE 165, and a list of chemical engineering courses provided by the option representative. 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 attends 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, geology, chemical engineering, and environmental engineering science 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 chemistry and electrochemistry, organometallic chemistry, and biochemistry and biophysics. 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, the examinations 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

A student is required to complete at least 36 units of course work in science or engineering. These courses may be either inside or outside the chemistry option, must be numbered 100 or greater, and must be taken on a letter-grade basis unless the course is offered with only the pass/fail option. A grade of B or better is required for credit. The student should discuss with his or her adviser which courses best serve his or her individual needs. Course work outside the scientific area in which the dissertation research is performed is encouraged. The program of courses must be approved by the research adviser and the Chemistry Graduate Study Committee. Alternatively, a student may complete a subject minor in another option, the course requirements being set by that option.

Master's Degree in Chemistry

Students are not ordinarily admitted to graduate work leading to an M.S. degree. Under special circumstances, and with prior approval of the Graduate Study Committee, a master's degree can be obtained. 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 the 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 chair of the Chemistry Graduate Study Committee.

Degree of Doctor of Philosophy in Chemistry

Candidacy. 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 original research 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. The research report and propositions must be in the hands of the examining committee one week before the examination.

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 Study 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.

Thesis Research Progress. Before the thirteenth term of graduate residence (excluding summer terms), the student will be expected to demonstrate satisfactory progress in the course of thesis research. To this end an informal meeting with the Ph.D. Thesis Committee will be held, at which time the student will present an oral summary of research completed to date as well as an outline of future research plans. Following the presentation, an appropriate timetable for completion of the degree requirements will be discussed and agreed upon. If the student has not progressed sufficiently, completion of the Ph.D. may be considered inappropriate.

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 petition must be approved by the chair of the Chemistry Graduate Study Committee, and, in cases where financial support is an issue, also by the Executive Officer or Division Chair, 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 the oral presentation and defense of a brief résumé of the student's research and in part of the defense of a set of propositions he or she prepares. Three original research 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 is normally taken after the Thesis Research Progress meeting, but must be held before the end of the fifth year of residence, and not less than ten weeks in advance of the final doctoral 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 doctoral 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 doctoral examination. A copy of the thesis should also be submitted to the Institute Graduate Office for proofreading three weeks prior to the final doctoral 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.

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 Study 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 Study 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 undergraduate deficiencies in engineering science courses. However, in every case the student will be urged to take some courses that will broaden his or her 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 engineering 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 for courses numbered 100 or above is required. The program must include three units of CE 130 abc and 108 units (minimum) of graduate-level courses from at least three of the five general subject areas of structures and solid mechanics, soil mechanics, hydraulics and water resources, environmental engineering science, and mathematics. Students who have not had AMa 95 abc or its equivalent will be required to include AM 114 abc in their program. The program must be approved by the student's adviser and the option representative for civil engineering.

Students admitted for study toward a master's degree but interested in pursuing subsequent study toward a Ph.D. degree should also read the section below concerning this degree.

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
Study and research programs for the Ph.D. degree are individually planned to fit the interests and background of the student. A comprehensive research project leading to a thesis is required. Suggested areas of research are described in Section Two.

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 civil 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 chair and interim adviser until this responsibility is assumed by the dissertation supervisor. This committee must meet during the first term of each year of Ph.D. study.

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, is confined to elementary but basic topics.

Admission to Candidacy. To be recommended for candidacy for the Ph.D. degree in civil engineering, the student must, in addition to meeting the general Institute requirements:

- complete 27 units of research;
- 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 technical subjects, other than the required mathematics, not closely related to their thesis research. If a student chooses to take a subject minor, the units so taken may be included in the total of 108, subject to the approval of the faculty in civil engineering;
- pass an additional 27 units of course work in advanced mathematics, such as AM 125, AMa 101, Ph 129, or a substitute acceptable to the faculty in civil engineering. 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 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 student must take the oral candidacy examination before the

end of the second academic year of graduate residence at the Institute.

Thesis and Final Examination. A final oral examination will be given after the thesis has been formally completed. Copies of the completed thesis must be provided to the examining committee two weeks prior to the examination. 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 Civil Engineering
A student majoring in another branch of engineering, or in another division of the Institute, may elect civil engineering as a subject minor, with the approval of the faculty in civil engineering and the faculty in the student's 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 courses approved by the faculty in civil engineering. The student must pass an oral examination that is separate from the examination in the student's major.

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 strong interest that will permit enrolling in courses in all the relevant disciplines. 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
An advisory committee of three CNS faculty members is constituted for each student by the CNS admissions committee upon admission to the program. The faculty in whose lab the student is staying first chairs this committee. The advisory committee meets with the student when he/she arrives, guides and approves first-

year course choices, and answers questions and offers advice about the program and the way of life in CNS. Further meetings with this committee should be arranged as needed by the student or by an adviser. The CNS faculty are available to students during the year for formal and/or informal discussions.

Laboratory Rotations

Mandatory rotations through research groups (labs) provide a unique opportunity for the student to experience the CNS culture. To broaden the student's knowledge and to provide familiarity with different techniques and ways of thinking or doing research, each student spends three 12-week laboratory rotations (one per term) during the first year, and is encouraged to engage in research. During each rotation, the student is expected to take part in the life and routine of the lab by attending lab meetings; participating in research projects and discussions with members of the lab; and meeting monthly with the faculty of that lab to discuss science.

First-Year Course Requirements

Six nine-unit courses are required during the first year: CNS 185, Bi 150, a neurobiology or modeling course, a math course, and two other CNS, Bi, EE, AMa, or Ph courses (for example, a schedule of CNS 185, CNS 221, CNS 182, Bi 150, Bi 161, and CNS 124 satisfies this requirement). Students are free to take additional classes, and a research adviser may require that a student take a specific, complementary course as a requirement for joining his or her lab.

Candidacy

The three faculty in whose labs rotations have been done are on the student's candidacy exam committee. At the end of the first year, the student is expected to decide on a research group and begin work there. The first summer is thus expected to be spent entirely on research in that lab. Advancing to candidacy requires passing two tests: the general knowledge exam, and the research and candidacy exam. These exams are supervised by the CNS option representative.

The general knowledge exam satisfies the breadth requirement. A list of about 100 questions, grouped by category, and a list of classical research papers are provided to the students at the beginning of the year, thus providing a clear idea of the scope of knowledge that each student is expected to know well. Students are encouraged to organize working and discussion groups to prepare for this exam; the format and implementation of such a system, however, is left to the students.

This is an oral exam, with five faculty (including the heads of the student's three rotation labs and two others chosen for "breadth," of whom one can be from outside CIT). It should be scheduled by the student (who contacts the committee members) to take place during the last six weeks of the third term of year 1. For the exam, the student must answer questions (from more than one category) taken from the list, which is modified each year. (The exam can be retaken after six months.)

The research and candidacy exam satisfies the depth requirement. During year 2, the student is expected to produce a piece of work of a quality sufficient to be presented at a professional meeting during the first term of year 3. (The objective of this description is to offer a way to calibrate the level of expected research achievement and involvement. Acceptance of the abstract or paper is not a requirement for passing candidacy.) This work is presented in an oral exam that takes place in spring term of year 2 to the same exam committee (if possible) that conducted part 1 of the exam. The exam focuses exclusively on research (accomplished and/or planned). During year 2, the student may take other courses, as needed, but is expected to present a high standard (quality, originality) of research at the time of this second part of the candidacy exam.

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. 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, or (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.

Subject Minor in Applied Computation

The subject minor in applied computation is administered jointly by the applied mathematics and computer science options, and is open to graduate students in all options. This minor emphasizes the mathematical, numerical, algorithmic, and programming methods underlying the application of computation — particularly parallel and concurrent computation — to research in science and engineering.

The requirements are listed under applied mathematics.

Control and Dynamical Systems

Aims and Scope of Graduate Study in Control and Dynamical Systems
The option in control and dynamical systems (CDS) is open to students with an undergraduate degree in engineering, mathematics, or science. 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 undergraduate deficiencies in engineering science courses.

The CDS option emphasizes the interdisciplinary nature of modern theory of dynamical systems and control. The curriculum is designed to promote a broad knowledge of mathematical and experimental techniques in dynamical systems theory and control. In addition to taking courses in the CDS option, students must select a focus area (see below).

Master's Degree in Control and Dynamical 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, satisfying the focus requirements, and receiving a recommendation for awarding of the degree from the candidacy oral examination committee.

Degree of Doctor of Philosophy in Control and Dynamical Systems
Institute requirements for the Ph.D. degree are described in the section on degree requirements. Approximately two years of course work are required and two or more years are usually needed for preparation of the dissertation.

Counseling. 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 focus 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. An exam given during the first year of study will be used to evaluate the student's preparation for continued study.

Admission to Candidacy. To be recommended for candidacy for the Ph.D. degree in control and dynamical systems, the student must, in addition to meeting the general Institute requirements:

- Complete the following required courses: CDS 101, CDS 102, CDS 112, CDS 140;

- Complete the focus requirement, consisting of at least 27 units in a particular area outside of CDS. Courses taken to satisfy the focus must represent a coherent program of advanced study in the chosen area. Possible areas include fluids, vehicles, vibrations, transport phenomena, process design, analog VLSI, propulsion, robotics, turbomachines, power electronics, micromachines, economics, and neurobiology. The program of study must be approved by the student's counseling committee and the option representative.
- Complete an additional 45 units in CDS or other advanced courses in dynamical systems and/or mathematics;
- Prepare a Research Progress Report;
- Pass an oral examination on the major subject. The oral examination must be taken before the end of the second year of graduate academic residence at the Institute.

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 the specialized field of research.

Subject Minor in Control and Dynamical Systems
A student majoring in another option at the Institute may elect a subject minor in control and dynamical systems. He or she must obtain approval from the CDS faculty of a course of study containing at least 54 units of advanced courses with a CDS listing.

Electrical Engineering

Aims and Scope of Graduate Study in Electrical Engineering
Award of the Bachelor of Science degree may be followed by graduate study leading to the Master of Science degree in electrical engineering, and the more advanced degrees of Electrical Engineer or Doctor of Philosophy. Because admission to graduate studies in electrical engineering at Caltech is extremely competitive, the Admissions Committee attempts to select those applicants it judges both best qualified and best suited for the graduate program. Applicants should submit Graduate Record Examination scores.

Master's Degree in Electrical Engineering
Normally, the master's degree in electrical engineering is completed in one academic year. The principal criteria for evaluating applicants for the MSEE are the excellence of their preparation for the math- and physics-oriented nature of Caltech's graduate courses, and the judgment of the Admissions Committee on their ability to successfully pursue and benefit from the course program. The Institute does not normally admit an applicant to the master's degree in a field in which the applicant already has a master's degree from another U.S. institution. Financial aid is seldom

offered to those who intend to complete their graduate work with a master's degree. A joint B.S./M.S. degree is not available in electrical engineering.

135 units are required as approved by the electrical engineering graduate student adviser. Engineering Seminar, E 150 abc, is required. Students are urged to consider including a humanities course in the remaining free electives.

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

As a rule, applicants who wish to undertake research work leading to a degree of Doctor of Philosophy in electrical engineering are admitted initially only for the MSEE. They are, however, evaluated according to additional criteria, the most important of which is the applicant's interest in and potential for research in one of the areas described below. The statement of purpose required as part of the application should clearly address this match. Considerable weight is also given to the opinions expressed in the applicant's letters of recommendation.

During the Ph.D. applicant's master's degree year, evaluation continues. It is based in part on performance in courses and in part on a one-hour oral presentation scheduled early in the second quarter. As the year progresses, the electrical engineering faculty get to know the student, and the student makes contact with the professor in his or her area of research interest. Upon acceptance into a research group, the student begins research work and defers receiving the master's degree until formal admission into the Ph.D. program. Before the end of his or her second academic year of graduate study, the student is expected to take the Ph.D. qualifying oral examination.

Ph.D. applicants who already hold a master's degree in electrical engineering from another U.S. institution may be admitted directly to the Ph.D. program, but must provide sufficient information to obtain advance acceptance into a research group.

Financial aid available to a Ph.D. applicant includes teaching assistantships and fellowships. TA duties consist of grading papers or lab instruction but not classroom lecturing. A fellowship may be supplemented by a teaching assistantship, and either or both include a full tuition scholarship. Tuition scholarships alone are not available. If financial aid is not requested, or if the box on the application form labeled "willing to come without aid" is checked, information on the source of funds for each year of intended graduate study must be included.

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 27 units of mathematics courses, as approved by the student's research adviser, with letter grade no lower than C.
- Pass a qualifying oral examination covering broadly the major field. Students are strongly encouraged to do this before the end of the second year of residency.

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).

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 candidate's knowledge in his or her specialized field 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 knowledge from several fields of science and engineering 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. 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 three 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 units under Env 100 and 300). Students who have not had AMa 95 abc or its equivalent are required to include 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, ChE/Env 157, ChE/Env 158, ChE/Env 159, Env/Ch/Ge 175 a, Ge 152 b.
- *Water quality:* Env 142 ab, Env 143, Env 146, Env/Ch/Ge 175 bc, Env 216, Bi/Ch 110 abc, Bi/Ch 132, ChE 101, ChE 151 c, ChE/Ch 164, ChE 165, Ch 117, Ch 118 ab, Ge 104, Ge 140 a, Ge 152 c.

- *Applied and environmental biology:* Env 144, Env/Bi 166, Env/Bi 168, Env 208, Env 210, Bi/Ch 110 abc, Bi 122, Bi 180, ChE 163.
- *Fluid mechanics and transport:* Env 112 abc, Env 214 abc, Env 216, CE/ME 101 abc, CE 113 ab, CE 210 ab, CE 212, CE 213, ChE 103 abc, ChE 151 ab, Ge 152 ac.
- *Applied mathematics:* AMa 101 abc, AMa 104, AMa 105 ab, AMa 181 ab, AM 114 abc, AM 125 abc, Ma 112 a.
- *Social science:* Ec 118, Ec 122, 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 a 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 chair 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, environmental fluid mechanics, water resources, environmental health engineering, hydraulic engineering, and 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 as approved by the faculty of environmen-

tal engineering science.
- pass the oral candidacy examinations.

Major Course Requirements. The major program should be tailored to meet the student's needs in preparation for research and yet provide some breadth as well as depth. For breadth the student must take course work in at least two of the following 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.

Mathematics Requirement. Each student must pass at least 27 units of graduate courses in mathematics selected from: AM 114 abc, AMa 101 abc, AMa 104, AMa 105 ab, AMa 181 abc, AM 125 abc, Ph 129 abc, Ma 112 a, or a satisfactory substitute.

Additional advanced mathematics courses will be required as appropriate for each student's area of research on a case-by-case basis as approved by the EES faculty.

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 if that program 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 202. 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 must pass a minimum of 27 units of advanced mathematics in addition to 135 units of graduate course work in EES and related disciplines. The decision as to the actual total number of math courses needed beyond the minimum requirement for a particular student rests with the student's adviser, advisory committee, and the EES faculty. 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 *spring* 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 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 option representative for approval. The proposed program must consist of 45 or more units in Env courses. 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 are 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 required 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 and physics. 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 nine 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 105 abc and 109.

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 consists of oral and written defense of two research propositions, supplemented by a written description of one of them. 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 chair's office.

The basic divisional course requirement includes 47 units within the division but outside the area of the student's option. The required 47 units of courses outside the major field may be used to satisfy a subject minor in another option of the division. Every graduate student in the division is required to take the course series Ge 105 abc. Oral presentation, Ge 109, is required of all degree candidates and counts for two of the units listed above. Throughout their graduate careers, students are expected to attend departmental seminars and seminar courses led by visiting scientists. 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 chair 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:

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

By the 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.

By the 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 47 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- to 200-level courses, including the advanced 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 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.

Geochemistry. In addition to general Institute and basic division requirements, the candidate for a Ph.D. degree in geochemistry is required to complete 90 additional units of course work at the 100 level or greater. These courses must include 45 units outside the division and include the advanced courses most relevant to the student's thesis research. This option requires all students to have a basic knowledge of chemistry at the level of Ch 21. The 45 units of courses submitted for fulfillment of the basic division requirement must include one quarter of field geology. 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- to 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, which shall include at least one quarter in Planetary Atmospheres (Ge 152 a, or b, or c) and one quarter in Planetary Surfaces (Ge 151). 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. 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 from 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 Executive Officer for the Humanities 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
The graduate program is designed to give students an understanding of general phenomena in synthesis–structure–property relationships in all materials, plus a detailed understanding of phenomena for at least one particular class of materials. Students may enter the graduate program in materials science with undergraduate preparation in physics, chemistry, engineering, or materials science. Students interested in terminating their graduate study at the master's level are not normally admitted. 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 complete the core course program, 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 option representative for materials science will approve his or her course of study.

Study for the degree of Master of Science in Materials Science will ordinarily require three terms of courses. The courses shall be chosen from the list of core courses below, although 27 units of research (MS 200 or equivalent) may be substituted for 27 units of lecture or laboratory courses. Completion of 138 units of these courses within two years with no grade less than a C constitutes the academic requirements for the M.S. degree.

Core Courses

1. Ch 120 a or MS 131, MS 132, MS 133: Structure and Bonding in Materials, Diffraction and Structure of Materials, Kinetic Processes in Materials.
2. APh 105 a or ChE 165, APh 105 b or ChE/Ch 164, MS 105: Thermodynamics, Statistical Mechanics, Phase Transformations.
3. Two quarters of courses focused on specific materials, such as APh 114 ab: Solid State Physics; Ch/ChE 147, ChE/Ch 148: Polymer Synthesis and Physics; Ge 114, Ge 214, Ge 260: Mineralogy, Spectroscopy of Minerals, Physics of Earth Materials.
4. Two quarters of courses focused on internal interactions in materials, such as APh 125 ab, Ph 125 ab, Ch 125 ab: Quantum Mechanics; AM 135 ab: Mathematical Elasticity Theory; Ch 120 b: Nature of the Chemical Bond; Ch 121 ab: Materials and Molecular Simulations.
5. 18 units of courses comprising either the third terms of the sequences taken in 3 and 4 above, or other courses appropriate for the student's research interests.
6. Mathematics at the level expected of research in the student's field. This may be satisfied by the courses AM 114 abc, or AM 125 abc, or AMa 101 abc, or Ph 129 abc, or may be waived at the discretion of the student's adviser and option representative.
7. MS 110 abc (3 units) or APh 110 ab (2 units) or E 150 abc (3 units), seminar.

Degree of Doctor of Philosophy in Materials Science

Residency. Work toward 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.

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.* To continue in the graduate program, the student must maintain a B- average for each term. Advancement to candidacy requires the successful completion of the core course program listed above. Alternatively, if the student has taken equivalent courses elsewhere, he or she must prove competency 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 core of the examination is based on the student's course work and how it is related to the topic of the presentation. This examination should be taken 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 200.

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 45 units of advanced courses. 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 96. 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 in mapping 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 Five, 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 in the U.S. 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 for 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, or 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 ensure 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

Aims and Scope of Graduate Study in Mechanical Engineering

Students who have not specialized in mechanical 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 undergraduate deficiencies in engineering science courses. However, in every case the student will be urged to take some courses that will broaden an understanding of the overall field, as well as courses in the specialty. Most graduate students are also required to take further work in applied mathematics.

Master's Degree in Mechanical Engineering

The program must be approved by the option representative in mechanical engineering. A total of 138 units of courses numbered 100 or above is the minimum number required for completion of the master's degree in mechanical engineering. The master's degree is based upon course work drawn from the following distribution of courses:

Program Required for Mechanical Engineering

- Graduate Mechanical Engineering core—54 units
  These units should provide a solid base for the student's engineering interest. The courses may be selected from the following list: CE/ME 101 abc, ME 119 abc, AM 102 abc, AM 151 abc, CDS 110 ab, and CDS 111.
- Mathematics, Engineering, and Research electives—54 units
  Students who have not taken the equivalent of AMa 95 abc are required to take AM 114 abc for 36 units. Mechanical engineering students are urged to consider taking 27 units of courses in aerosols and air pollution Env 116, ChE/Env 158, ChE/Env 159; automation and robotics ME 115 ab, ME 131, ME 132; combustion ChE 157, JP 213 abc; engineering design ME 171 ab; multiphase flows ME 202 abc; propulsion JP 121 abc; experimental methods Ae 104 abc; or any additional courses listed in the Graduate Mechanical Engineering courses. Other courses may also be taken in Ae, AM, AMa, ME, JP, MS, EE, Env, APh, CDS, CS, ChE, CNS. Students who are considering study beyond the master's degree are encouraged to take research units, ME 300, up to a maximum of 27.
- Free Electives—27 units
  These units may be selected from any course with a number of

100 or greater, except that research units may not be included.

- Engineering Seminar, E 150—3 units

Students admitted for study toward a master's degree but interested in pursuing subsequent study toward a Ph.D. degree should also read the section below relating to this degree.

Degree of Mechanical Engineer

Greater specialization is provided by work for the engineer's degree than for the master's. The degree of Mechanical Engineer is considered to be a terminal degree for the student who desires more highly specialized advanced training 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.

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. 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 finally determined by the supervising committee. The courses must include an advanced course in mathematics or applied mathematics, such as AM 125 abc or AMa 101 abc, that is acceptable to the faculty in mechanical engineering. A suitable course program may usually be organized from the more advanced courses listed under AM, AMa, JP, ME, MS, and Ae.

Degree of Doctor of Philosophy in Mechanical Engineering

Institute requirements for the Ph.D. degree are described in the section on degree requirements. Approximately two years of course work are required, and two or more years are usually needed for preparation of the dissertation.

Counseling. An initial counseling committee of three faculty members is appointed for each student upon admission to work toward a Ph.D. degree in mechanical engineering. The committee member closest to the student's current interests acts as committee chair and interim adviser.

Ph.D. Dissertation Supervision Committee. It is the responsibility of the student to find a research adviser. In consultation with the adviser, the student must form a Ph.D. dissertation supervision committee which will meet during the first and third terms of each year of Ph.D. study. This committee shall consist of at least three members of the Caltech professorial faculty, with at least two members from the faculty in mechanical engineering. The student's adviser shall serve as chair of this committee. It is the student's responsibility to obtain the signature of his or her adviser at least twice a year (once for the academic year and once for the summer); this signature indicates the adviser's willingness to supervise the research program of the student.

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 the preliminary oral examination early in the third term of their first year of graduate study at the Institute.

Admission to Candidacy for the Ph.D. in Mechanical Engineering. To be recommended for candidacy for the Ph.D. degree in mechanical engineering, the student must, in addition to meeting the general Institute requirements:

- obtain the agreement of a professorial faculty member to serve as his or her academic and research adviser;
- complete at least 54 units of research and demonstrate satisfactory research progress;
- complete a minimum of 27 units of course work in each of three of the core areas of mechanical engineering listed below. Examples of suitable courses are given in parentheses.
  - Fluid Mechanics (CE/ME 101 abc or Ae/APh 101)
  - Thermo/Heat Transfer (ME 119 abc)
  - Solid Mechanics (AM 102 abc)
  - Dynamics and Vibrations (AM 151 abc)
  - Mechanical Systems and Design (ME 115 ab, ME 171, ME 175)
  - Controls (CDS 110 ab, CDS 111, CDS 112, or CDS 113 ab)

  The student may petition the mechanical engineering faculty to replace one of the areas with an area not listed above. These 81 units may also be used in the student's program for the master's degree.
- complete an additional 27 units in engineering or science (with a course number above 100) which pertain to the student's specialty.
- pass with a grade of at least C an advanced course in mathematics or applied mathematics (for example, AM 125 abc, AMa 101 abc, or 27 units from CDS 101, 102, 103) that is acceptable to the student's committee and the faculty in mechanical engineering. The requirement in mathematics is in addition to the requirements above and cannot be counted toward a minor.
- pass the oral candidacy examination. 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 the subject minor. The oral candidacy examination must be taken before the end of the second year of graduate academic residence at the Institute.

If the student elects to take a subject minor, these units cannot be used to satisfy any of the Ph.D. degree requirements in mechanical engineering.

The faculty will evaluate the student's research progress, class performance, adviser's input, and oral candidacy exam results to determine whether a student will be admitted to candidacy for the Ph.D. degree.

Thesis and Final Examination. The thesis examination will be given after the thesis has been formally completed. This examination will be a defense of the doctoral thesis and a test of the candidate's knowledge in the specialized field of research. The examining committee shall consist of at least four Caltech professorial faculty, at least three of whom shall be from the Division of Engineering and Applied Science, and at least two of whom shall be mechanical engineering faculty members. One member of the committee shall be from outside the student's area of Ph.D. research. The student's adviser shall act as chair of the committee.

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 program of courses must differ markedly from the major subject of study or research, and must consist of at least 54 units of advanced work. The student must also 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 option offers a program leading to the degree of Doctor of Philosophy. 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.

Students may choose between two major areas of specialization. One, the physics major, encompasses the traditional choices of experimental and theoretical physics. Caltech research opportunities for this major include high-energy physics, nuclear and particle physics, cosmic-ray and gamma-ray astronomy, infrared astronomy, submillimeter astronomy, condensed-matter physics, quantum optics, applied physics, gravitational physics, astrophysics, mathematical physics, and theoretical physics.

Students may alternatively elect a major in Physical Computation and Complex Systems (PCCS). The objective of this major is a unified approach to abstraction, modeling, and computation applied to the natural world. This approach is based on a systematic use of physical analogies and methods. The program involves fundamental education in mathematical physics, simple classical and quantum physical systems, fundamental properties of complex systems, physical optimization methods, and the appropriate computational techniques needed for large-scale problem solving on advanced-architecture computers.

A Master of Science degree may be awarded upon completion of what is typically a four-term program of courses. Students are not normally admitted to work toward the M.S. degree in physics unless they are 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 are strongly advised to 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 the student's 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 quantum-mechanics-based course.)

Physics electives These must be selected from Ph 103, Ph 118, Ph 127, Ph 129, Ph 135, Ph 136, Ph 151, Ph 161, Ph 176, Ph 203, Ph 205, Ph 209, Ph 220, Ph 222, Ph/APh 223, Ph 224, Ph 225, Ph 228, Ph 229, Ph 230, Ph 231, Ph 234, Ph 235, Ph 236, Ph 237, Ph 242.	81 units
Other electives These must be graduate courses from physics or any other option, including the humanities.	27 units

With the approval of the option representative, a student who has the proper preparation may substitute other graduate courses in science or engineering for some of the physics electives listed above. A master's is not offered in the PCCS major.

Doctor of Philosophy Degree in Physics or PCCS
In addition to the general Institute requirements for a Ph.D., the particular requirements for a doctorate in physics or PCCS include admission to candidacy as described below, passing 27 units of advanced courses in physics outside the student's research specialty, 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. Two requirements for admission to candidacy are the passing of an oral candidacy examination (described below) and the passing of two terms of Physics Seminar, Ph 242. In addition, a student must pass two written examinations covering fundamental classical and quantum physics.

The other particular requirements for admission to candidacy differ for the two majors, physics and PCCS. A physics 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 may substitute for one area, after consultation with the theoretical astrophysics faculty, part of the written astrophysics examination that is given yearly by the astronomy department. No course work other than Physics Seminar is specifically required for the written candidacy exams, but the typical student will profit from taking several of the basic graduate courses, such as Ph 106, Ph 125, Ph 129, Ph 135, Ph 136, and Ph 209.

A PCCS student must demonstrate proficiency as described above in two of the four areas: mathematical methods of physics at the level of Ph 129, and applications of classical physics at the level of Ph 136. In addition, the PCCS student must pass Ph 151 and Ph 161 with a grade of C or better.

A 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 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 registration for subsequent terms will be allowed. 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. The chair of the examination committee will be the professor the student plans to do research with, and normally a student will have already begun research (Ph 172 or Ph 173) on a definite topic with that professor. The examination will cover the student's research work and its relation to the 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 (three terms of the usual nine-unit course) of advanced physics courses outside a student's specialty may be satisfied by courses drawn from the following list: Ph 118, Ph 127, Ph 151, Ph 161, Ph 176, Ph 203, Ph 205, Ph 220, Ph 222, Ph/APh 223, Ph 224, Ph 225, Ph 228, Ph 229, Ph 230, Ph 231, Ph 234, Ph 235, Ph 236, Ph 237, APh 114, APh 156, APh 190, APh 214, Ay 121-128, 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 27-unit requirement for students in the PCCS major is an application specialization, which must be satisfied by courses covering an area of physics that is a focus of their PCCS research. In cases of doubt, students in the PCCS major must consult with the chairperson as to the appropriate courses to satisfy their application specialization. PCCS students should be aware that many courses in applied mathematics and in computer science, although not required, are highly relevant to their studies.

A student is expected to obtain a grade of C or better in each course. If the student 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 or PCCS.

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, with 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 may be required, and this should be arranged with the chairperson of the Physics Graduate Committee. This exam will include both academic topics and topics on current physics research areas. The oral exam may be waived if at least one term of Ph 242 has been taken successfully, or if all 45 units are in letter-graded (*not* pass-fail) courses.

Science, Ethics, and Society

Graduate students in science, mathematics, or engineering may take a minor in science, ethics, and society (SES). The minor provides students with a historical and philosophical education in the social, economic, ethical, and political problems that have arisen in the modern world in connection with the advance of science and technology. It provides opportunities for study of the development of science and technology since the Scientific Revolution, and for inquiry into the evolution of ethical and policy issues in areas such as research and development, technological innovation, energy supply and conservation, the environment, and biomedicine. Work in the minor concerns historical and/or philosophical examinations of subjects such as genetics and molecular biology, the birth of modern physics, the politics of research and development, the social uses of biological knowledge, the nature of scientific explanation, and the evolution of theories of cognition; but it may also include consideration of contemporary issues concerning science and technology treated in philosophical, ethical, and historical perspective. The minor thus focuses on the acquisition of broad basic knowledge about persistent issues in the affairs of science, technology, and society so as to enable students to deal with such issues in the future, whatever particular form they may take. It is thus a valuable supplement to a technical degree, since it helps equip students to meet the nontechnical social, economic, and political challenges that people in technical careers increasingly encounter. Students who successfully complete the SES minor will be recognized with official credit for the achievement on their transcripts.

SES Graduate Minor Requirements
Graduate students who take an SES minor are expected to complete SES 101 ab, SES 102 bc, at least three units of SES 103, and 18 units of additional work in SES. Students need not complete the requirements for the minor within the first two years of graduate study. Students who have completed work in SES subjects equivalent to SES 101 a or SES 101 b before coming to Caltech may be given credit toward the completion of the minor requirements.

Social Science

Aims and Scope of Graduate Study in Social Science
Over the past two decades, it has become ever more apparent that many of the most serious problems faced by the nation have both an economic *and* a political component. Graduate education, however, has remained largely compartmentalized, with most programs producing students who, while well trained in economics or in political science, are not trained in both. The Caltech Ph.D. program in social science is designed to graduate scholars who are well grounded in the theoretical perspectives, the quantitative techniques, and the experimental methods of economics *and* of political science and who also have been introduced to quantitative history and to law as well. In addition to providing students with a solid foundation in the underlying disciplines, the program has a substantial policy component that brings institutional design—an analysis that merges work in theory, experimentation, and history—to policy studies in a way that is done at no other institution.

Recent graduates of the program have taken positions in departments of economics, political science, and public policy, and in schools of business at major universities. A smaller number 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 option's 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 107.

Course Program

Within the first two years of residence, every student is expected to (a) demonstrate adequate competence in the core academic areas of economics, analytical politics, and econometrics; (b) satisfactorily pass 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 optionwide colloquium.

- The core curriculum consists of the following four three-quarter courses: SS 201 abc (analytical foundations of social science); SS 202 abc (political theory); SS 205 abc (foundations of economics); and SS 222 abc (econometrics).

  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 option's 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, economics, 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 earn at least a B in each. These research-oriented courses are designed to introduce students to independent research, and all require research papers, although the student, with the consent of the relevant instructors, may link two or three workshops and produce a single major paper. Under any conditions, a min-

imum of two papers must be completed during the second year. The six workshops should be chosen in consultation with the option's director of graduate studies and with faculty members who are working in the area in which the student wishes to do his or her thesis research and should be chosen 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 economics or politics, econometrics, or quantitative history. Students should also bear in mind that a major strength of the program is its multidisciplinary nature, and they are encouraged to sample a variety of fields. In each year there will be workshops in economic theory, applied economics, formal political theory, and some substantive area of political science. In addition, although all may not be offered each year, there will be workshops in law, econometrics, finance, 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 solely authored research project in an optionwide colloquium.

After the completion of the second year requirements, 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 faculty member.

Degree of Doctor of Philosophy in Social Science

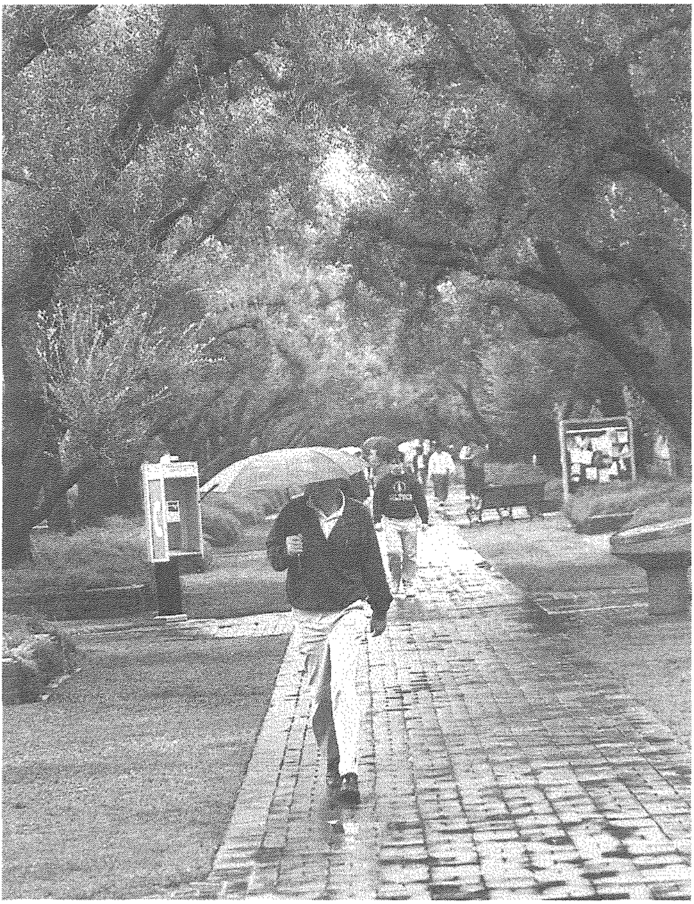
Requirements for the Ph.D. include: (1) passing, by the beginning of the second year, a written examination covering the core material in social science; (2) satisfactorily completing six research workshops; (3) completing a minimum of two research papers; (4) presenting a research seminar to the faculty by the end of that year; (5) gaining admission to candidacy; (6) writing a dissertation that reports the findings of independent research; and (7) passing a final oral examination based on the thesis and research. The dissertation is expected to represent publishable, original research with a coherent theme. At the end of each quarter during the third and fourth years, the thesis committee and the option's director of graduate studies will meet to determine whether the student is making sufficient progress in *research* to provide a reasonable expectation of completion within four years. 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



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. Students may not schedule two courses taught at the same hour.

Abbreviations

Ae	Aeronautics
An	Anthropology
AMa	Applied Mathematics
AM	Applied Mechanics
APh	Applied Physics
Art	Art History
Ay	Astronomy
Bch	Biochemistry
Bi	Biology
BEM	Business Economics and Management
ChE	Chemical Engineering
Ch	Chemistry
CE	Civil Engineering
CNS	Computation and Neural Systems
CS	Computer Science
CDS	Control and Dynamical Systems
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
ISP	Independent Studies Program
JP	Jet Propulsion
L	Languages
Law	Law
Lin	Linguistics
Lit	Literature
MS	Materials Science
Ma	Mathematics
ME	Mechanical Engineering
Mu	Music
PA	Performance and Activities
Pl	Philosophy
PCCS	Physical Computation and Complex Systems
PE	Physical Education
Ph	Physics
PS	Political Science
Psy	Psychology
SES	Science, Ethics, and Society
SS	Social Science

Ae 100. Research in Aeronautics. *Units to be arranged in accordance with work accomplished.* 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 of higher dimension. 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: Sturtevant.

Ae/AM/CE 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 such as, but not limited to, elastic stability, wave propagation, and introductory fracture mechanics. Instructor: Knauss.

Ae 103 abc. Aircraft Dynamics and Control. *9 units (3-0-6); first, second, third terms. Prerequisites: AMa 95 abc and CDS 110 a or equivalent.* The first and second terms cover performance and dynamic behavior of aircraft. Topics include elementary airfoil and wing theory, speed performance, climb and descent, range, takeoff and landing distances, static longitudinal and lateral stability, small amplitude unsteady motions, dynamic stability, responses to controls and disturbances. The third term will cover applications of classical and modern control theory to feedback control of longitudinal and lateral motions of rigid aircraft. Instructors: Hornung, Culick.

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, with data acquisition and processing systems. Experiments (second and third terms) in solid and fluid mechanics with emphasis on current research methods. Instructor: Ravichandran.

Ae 107. Case Studies in Engineering: "Mars Pathfinder." *9 units (3-0-6); second term. Prerequisite: graduate status or instructor's* *permission.* A detailed overview of the engineering design challenges associated with JPL's Mars Pathfinder Mission to Mars, featuring a low-cost lander and a micro-rover. This first return to the surface of Mars since the seventies will be described by staff of the Jet Propulsion Laboratory who have been key participants during its development. Subject matter focusing on Mars Pathfinder systems design and test will include precision navigation techniques, altitude control, power systems, entry, descent and landing systems design, multi-body dynamics and aerodynamics, thermal control, embedded real-time software development, rover mobility, and electronics systems. According to the present schedule of the Pathfinder Mission, this course will begin shortly after the actual launch and will end several months before the expected landing on Mars. Coursework will include relevant student projects. Instructor: Culick.

CE/Ae/AM 108 abc. Computational Mechanics. *9 units (3-0-6).* For course description, see Civil Engineering.

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/AM 160 abc. Continuum Mechanics of Fluids and Solids. *9 units (3-0-6); first, second, third terms.* Elements of Cartesian Tensors. Configurations and motions of a body. Kinematics—study of deformations, rotations and stretches, polar decomposition. Lagrangian and Eulerian strain velocity and spin tensor fields. Irrotational motions, rigid motions. Kinetics—balance laws. Linear and angular momentum, force, traction stress. Cauchy's theorem, properties of Cauchy's stress. Equations of motion, equilibrium equations. Power theorem, nominal (Piola-Kirchoff) stress. Thermodynamics of bodies. Internal energy, heat flux, heat supply. Laws of thermodynamics, notions of entropy, absolute temperature. Entropy inequality (Clausius-Duhem). Examples of special classes of constitutive laws for materials without memory. Objective rates, co-rotational, convected rates. Principles of materials frame indifference. Examples: the isotropic Navier-Stokes fluid, the isotropic thermoelastic solid. Basics of finite differences, finite elements, and boundary integral methods, and their applications to continuum mechanics problems illustrating a variety of classes of constitutive laws. Instructors: Bhattacharya, Ortiz.

EE/Ae 179 abc. Projects in Flight Control. *Units to be arranged in accordance with work accomplished.* For course description, see Electrical Engineering.

Ae 200. Advanced Research in Aeronautics. *Units to be arranged.* Ae.E. or Ph.D. thesis level research under the direction of the staff. A written research report must be submitted during finals week each term.

Ae 201 abc. Advanced Fluid Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ae/APh 101 abc or CE/ME 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 will include a selection from: physical properties of real gases; the equations of motion of viscous and inviscid fluids; the dynamical significance of vorticity; vortex dynamics; exact solutions; motion at high Reynolds numbers; hydro-dynamic stability; boundary layers; flow past bodies; compressible flow; subsonic, transonic, and supersonic flow; shock waves. Instructor: Dimotakis.

Ae 204 abc. Technical Fluid Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ae/APh 101 abc, CE/ME 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 the design of devices such as mixers, ejectors, diffusers, and control valves. Studies of flow-induced oscillations, wind effects on structures, vehicle aerodynamics. Not offered 1996–97.

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. Graded pass/fail only. Instructor: Gharib.

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 campus are intermixed with seminars given by invited lecturers from companies and other research institutions. Graded pass/fail only. Instructor: Staff.

Note: The following courses, with numbers greater than 210, are one-, two-, or three-term courses offered 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/AM/MS 213 abc. Mechanics and Materials Aspects of Fracture. *9 units (3-0-6); first, second, third terms. Prerequisites: Ae/AM/CE 102 abc (concurrently) or equivalent and instructor's permission.* Analytical and experimental techniques in the study of fracture in metallic and nonmetallic solids. Mechanics of brittle and ductile fracture; connections between the continuum descriptions of fracture and micromechanisms. Discussion of elastic-plastic fracture analysis and fracture criteria. Special topics include fracture by cleavage, void growth, rate sensitivity, crack deflection and toughening mechanisms, as well as fracture of nontraditional materials. Fatigue crack growth and life prediction techniques will also be discussed. In addition, "dynamic" stress wave dominated, failure initiation growth and arrest phenomena will be covered. This will include traditional dynamic fracture considerations as well as discussions of failure by adiabatic shear localization. Instructor: Rosakis.

Ae/AM 215. Dynamic Behavior of Materials. *9 units (3-0-6); third term. Prerequisites: AM 114 abc or AM 125 abc; Ae/AM/CE 102 abc or AM 135 abc.* Fundamentals of theory of wave propagation; plane waves, wave guides, dispersion relations; dynamic plasticity, adiabatic shear banding; dynamic fracture; shock waves, equation of state. Not offered 1996–97.

AM/Ae 220 ab. Elastic Stability of Structures and Solids. *9 units (3-0-6).* For course description, see Applied Mechanics.

Ae 221. Theory of Viscoelasticity. *9 units (3-0-6); second term. Prerequisites: Ae/AM/CE 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 1996–97.

Ae/AM 223. Plasticity. *9 units (3-0-6); first term. Prerequisite: Ae/AM/CE 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 1996–97.

Ae/AM 225. Special Topics in Solid Mechanics. *Units to be arranged.* 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 and composite materials; and nonlinear problems. Instructors: Ortiz, Phillips.

Ae/AMa 232 abc. Computational Fluid Dynamics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ae/APh 101 abc; AM 125 abc or equivalent; CE/ME 101 abc or equivalent; AM 114 abc or equivalent; AMa 104, AMa 105 ab or equivalent.* Introduction to the use of numerical methods in the solution of fluid mechanics problems. First term: Problem-oriented review of numerical methods for inviscid and viscous incompressible flows. Vortex methods in two and three dimensions. Vortex merging and roll-up. Free shear layers. Viscous effects. Aircraft wake vortices. Ring vortices. Separated flows. Second term: Survey of finite difference, finite element, and spectral approximations for solution of the Navier-Stokes equations in two and three dimensions. Numerical study of problems of hydrodynamic stability, transition, and turbulence. Third term: Methods for the numerical solution of the compressible Euler and Navier-Stokes equations in one, two, and three dimensions. Finite-difference and finite-volume methods. Methods based on solution of the Riemann problem. Flux-splitting. Shock-capturing methods and related stability problems. Kinetic-theory-based methods. Explicit and implicit artificial viscosity for the Euler equations. Total variation diminishing approximations. Implementation of algorithms on parallel architectures. Instructors: Leonard, Meiron.

Ae 234. Hypersonic Aerodynamics. *9 units (3-0-6); third term. Prerequisites: Ae/APh 101 abc, AM 125 abc, or instructor's permission.* An advanced course dealing with aerodynamic problems of flight at hypersonic speeds. Topics are selected from: hypersonic small-disturbance theory, blunt-body theory, boundary layers and shock waves in real gases, heat and mass transfer, testing facilities and experiment. Not offered 1996–97.

Ae 235. Rarefied Gasdynamics. *9 units; first term.* Molecular description of matter; distribution functions; discrete-velocity gases. Kinetic theory: free-path theory, internal degrees of freedom. Boltzman equation: BBGKY hierarchy and closure, H Theorem, Euler equations, transport equations, Chapman-Enskog procedure. Collisionless and transitional flows. Applications. Not offered 1996–97.

Ae 236. Separated Flows. *9 units (3-0-6); third term.* Topics include a review of boundary layer theory, Kirchhoff model of separation, triple-deck theory, Sychev model, effect of turbulence on separation, location of separation points in various practical applications, classes of three-dimensionality, separation in three-dimensional steady flow, topological structure of steady three-dimensional separation, open separation, local solutions, and shock-wave boundary-layer interaction. Not offered 1996–97.

Ae 237. Nonsteady Gasdynamics. *9 units (3-0-6); third term.* A selection from: Gasdynamic discontinuities in liquids, solids, and gases. Waves with phase change and nonadiabatic flows. Shock and detonation wave stability. Continuous nonsteady waves. Wave interactions in one- and two-dimensional flow. Boundary layers in nonsteady flow. Applications and shock tube techniques. Instructor: Hornung.

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, and body forces. Unorthodox boundary conditions. Vorticity production due to discretization errors in numerical computations. Not offered 1996–97.

Ae 239 ab. Fluid Dynamic Stability and Turbulence. *9 units (3-0-6); first, second terms. Prerequisites: Ae/APh 101 abc; AM 125 abc or AMa 101 abc (AM 125 or AMa 101 may be taken concurrently).* Convective and absolute instability. Local and global instability. Examples include Kelvin-Helmholtz, Rayleigh-Taylor instability. Rayleigh and Orr-Sommerfeld equations. Laminar stability of parallel shear flows as a guide to transition to turbulence. Stability of subsonic and supersonic shear flows. Acoustic modes for compressible shear flows. Scaling arguments for turbulent shear flows. Jets, mixing layers, and boundary layers. Homogeneous isotropic turbulence and structure of the fine scales. The problem of closure. Physical and spectral models. Vortex dynamics. Large-scale computation. Not offered 1996–97.

Ae 240. Special Topics in Fluid Mechanics. *Units to be arranged.* Subject matter changes depending upon staff and student interest. Instructor: Gharib.

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 1996–97.

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). Offered by announcement.* 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, or consent of instructor.* Lectures, reading, and student projects deal with current efforts of indigenous people to raise living standards while maintaining cultural integrity. To illustrate the issues involved, the principal requirement of the course is for students working in two groups to design a ten-year development program for the Navajo Nation within the United States. Instructor: Scudder.

AMa 95 abc. Introductory Methods of Applied Mathematics. *12 units (4-0-8); first, second, third terms. Prerequisites: Ma 1 abc, Ma 2, 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: Pullin, Cohen.

AMa 98 abc. Selected Topics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 2.*
a,b Introduction to nonlinear problems. Special methods for solving ordinary and partial differential equations. Applications to nonlinear oscillations, and dynamics, chaos, shock waves, solitons.
c Difference-differential equations. Applications to traffic flow, random walks, branching processes, birth and death processes. Not offered 1996–97.

AMa 101 abc. Methods of Applied Mathematics I. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 or Ma 109.* Analytical methods for the formulation and solution of initial and boundary value problems for ordinary and partial differential equations. Techniques include the use of complex variables, generalized eigenfunction expansions, transform methods and applied spectral theory, linear operators, nonlinear methods, asymptotic and approximate methods, Weiner-Hopf, and integral equations. Instructor: Saffman.

AMa 104. Matrix Theory. *9 units (3-0-6); first term. Prerequisite: AMa 95 or equivalent.* Matrices and determinants, linear algebra, matrix analysis of differential equations, eigenvalues, eigenvectors, and canonical forms. Variational principles and perturbation theory. AMa 104 may be taken concurrently with AMa 105 a. Instructor: Holst.

AMa 105 abc. Introduction to Scientific Computing. *11 units (3-2-6); first, second, third terms. Prerequisites: AMa 95 or equivalent and some programming experience.* A comprehensive introduction to numerical techniques used in scientific computation. Topics: error analysis, approximation theory and interpolation, numerical integration, direct and iterative solution of systems of linear equations, root finding and solution of nonlinear equations, eigenvalue problems, numerical solution of ordinary differential equations, introduction to numerical solution of partial differential equations. Computer assignments will be given. AMa 105 a may be taken concurrently with AMa 104. Instructors: Holst, Hou.

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 ab. Perturbation Methods. *9 units (3-0-6); 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. Not offered 1996–97.

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. Inverse scattering and the theory of solitons. Not offered 1996–97.

AMa 153 abc. Stochastic Processes. *9 units (3-0-6); first, second, third terms. Prerequisite: AMa 95 or Ma 108.* Basic probability and probabilistic approximations; applications to stochastic population theories and stochastic epidemics. Markov chains, random walks and discrete potentials, Brownian motion. Correlations, power spectra, and application to filtering and prediction of stationary processes. Stochastic differential equations, use of Fokker-Planck and Kolmogorov equations. Markov-process methods. Instructor: Franklin.

AMa 161 abc. Applied Functional Analysis. *9 units (3-0-6). Prerequisites: AMa 101 or equivalent.* Introduction to Hilbert and Banach spaces; Sobolev spaces. Distribution theory, spectral theory for self-adjoint operators, degree theory, bifurcation. Linear and nonlinear partial differential equations with applications in fluid dynamics and materials science. Reaction-diffusion equations, theory of shock waves, Navier-Stokes equations, homogenization theory, phase transitions, and numerical analysis. Not offered 1996–97.

AMa 181 ab. Mathematical Programming and Game Theory. *9 units (3-0-6); second, third terms. Prerequisite: AMa 104 or equivalent.* Computer algorithms for linear programming: simplex, Khachian, Karmarkar. Duality; perturbation 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 1996–97.

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

AMa 201 ab. Methods of Applied Mathematics II. *9 units (3-0-6); second, third terms. Prerequisite: AMa 101 or equivalent; may be taken concurrently with instructor's permission.* Integral equations. Volterra and Fredholm theory; Hilbert-Schmidt theory; variational characterization. Singular integral equations. Cauchy kernels; Hilbert transforms; Hilbert and Riemann problems. Special techniques. Applications to problems in physics. Not offered 1996–97.

AMa 204 abc. Numerical Methods for Differential and Integral Equations. *9 units (3-0-6); first, second, third terms. Prerequisites: AMa 95, AMa 104, and AMa 105, or equivalent.* Numerical solution of linear and nonlinear elliptic, parabolic, and hyperbolic differential equations. Finite difference, finite volume, and finite element discretization methods; linear and Krylov iterative methods for elliptic equations, multigrid, and domain decomposition; explicit and implicit methods for parabolic and hyperbolic equations; stability analysis for initial boundary value problems; shock capturing techniques for nonlinear hyperbolic equations. Not offered 1996–97.

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 studies of hydrodynamic instabilities; numerical simulation of turbulent flow. Not offered 1996–97.

AMa 210 abc. Microscopic Structure and Overall Behavior of Materials and Media. *9 units (3-0-6); first, second, third terms. Prerequisites: knowledge of basic elements of Fourier series, complex analysis, and probability.* This course treats the behavior of microscopically inhomogeneous media on length scales much larger than those of the inhomogeneities. Topics: Estimates and bounds for the effective properties of composite materials (elastic, electrical, thermal, dielectric). Effective viscosity of suspensions. Overall energies in ordered and disordered nonlinear systems exhibiting temperature-dependent shape-deforming phase transitions. Design of optimal structures and microstructures. A variety of mathematical techniques introduced in the course relate to partial differential equations, calculus of variations, homogenization, perturbation expansions as well as complex variable theory and probability. Third quarter includes advanced reading and/or computing projects. Instructor: Bruno.

AMa 220 abc. Path Following, Homotopies, and Bifurcation in Scientific Computing. *9 units (3-0-6); first, second, third terms. Prerequisite: some knowledge of differential equations.* Modern computational techniques for solving nonlinear problems are derived, studied, and applied. Homotopy theory, degree theory, and bifurcation theory are covered. Lupanov-Schmidt theory, Newton's polygons, Hopf bifurcation, chaos, perturbed bifurcations, and imperfection sensitivity are included. Applications to computational fluid dynamics, reaction-diffusion, and dynamical systems. Instructors: Keller, Holst.

Ae/AMa 232 abc. Computational Fluid Dynamics. *9 units (3-0-6).* For course description, see Aeronautics.

AMa 251 abc. Advanced Fluid Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ae/APh 101 abc or CE/ME 101 abc; AM 125 abc or AMa 101 abc (may be taken concurrently).* For course description, see Aeronautics, Ae 201.

AMa 260 ab. Special Topics in Stochastic Processes. *9 units (3-0-6); second, third terms. Prerequisites: AMa 153 abc or equivalent or instructor's permission.* Topics include measure theory, martingales, entropy distance and the dichotomy of Gaussian measures, stationary processes: Szego's theorem and Krein's alternative, entropy and prediction, infinitely divisible distributions and associated processes, properties of the Brownian sample path, Brownian local time, Brownian motion and potential/capacity, and the theory of large deviations. Instructor: Keich.

AMa 261 a. Special Topics in Nonlinear Wave Propagation. *9 units (3-0-6); first term. Prerequisites: AMa 101 and instructor's permission.* Modulation theory. Inverse scattering and related techniques for the study of nonlinear waves. Solitons and their interactions. Multiphase nonlinear waves. Recent developments in these areas. Not offered 1996–97.

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

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

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, and vibrating systems. Instructor: Hall.

AM 65. Mechanics of Materials. *9 units (3-0-6); second term. Prerequisites: AM 35 abc, Ma 2 ab.* Introduction to continuum mechanics, principles of elasticity, plane stress, plane strain, axisymmetric problems, stress concentrations, thin films, fracture mechanics, variational principles, frame structures, finite element methods, composites, and plasticity. Instructors: Bhattacharya, Ravichandran.

AM 66. Vibration. *9 units (3-0-6); third term. Prerequisites: AM 35 abc, Ma 2 ab.* Introduction to vibration and wave propagation in continuous and discrete multi-degree-of-freedom systems. Strings, mass-spring systems, mechanical devices, elastic continua. Equations of motion, Lagrange's equations, Hamilton's principle, and time-integration schemes. Instructor: Staff.

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

CE/Ae/AM 108 abc. Computational Mechanics. *9 units (3-0-6).* For course description, see Civil Engineering.

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. Not offered 1996–97.

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, 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: Staff.

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: Staff.

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. Not offered 1996–97.

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 1996–97.

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.

Ae/AM 160 abc. Continuum Mechanics of Fluids and Solids. *9 units (3-0-6).* For course description, see Aeronautics.

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 1996–97.

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, Poincaré 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. Not offered 1996–97, but see CDS 103 ab.

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/MS 213 abc. Mechanics and Materials Aspects of Fracture. *9 units (3-0-6).* For course description, see Aeronautics.

Ae/AM 215. Dynamic Behavior of Materials. *9 units (3-0-6).* For course description, see Aeronautics.

AM/Ae 220 ab. Elastic Stability of Structures and Solids. *9 units (3-0-6); second, third terms. Prerequisite: Instructor's permission.* Introduction to the notions of stability and bifurcation of elastic systems using simple examples. Koiter's general asymptotic theory for the buckling, post-buckling, mode interaction, and imperfection sensitivity in elastic systems. One-dimensional problems include the elastica, thin-walled beams, circular arches, trusses, and frames. Two-dimensional examples include flat plates with simple or multiple buckling loads and circular cylinders under lateral pressure or axial compression. Extension to continuum solid mechanics includes plane strain and simple three-dimensional problems. Not offered 1996–97.

Ae/AM 223. Plasticity. *9 units (3-0-6).* For course description, see Aeronautics.

Ae/AM 225. Special Topics in Solid Mechanics. *Units to be arranged.* For course description, see Aeronautics.

AM 250. 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 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 diodes, 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: Scherer.

APh 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: Goodwin.

APh 23. Demonstration Lectures in Optics. *6 units (2-0-4); first 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, and optical detection and heterodyning. System examples to be selected from optical communications, radar, and adaptive optical systems. Instructor: Shumate.

APh 24. Introductory Modern Optics Laboratory. *6 units; second term. Prerequisite: APh 23.* Laboratory experiments to acquaint students with the contemporary aspects of modern optical research and technology. Experiments encompass many of the topics and concepts covered in APh 23. Instructor: Shumate.

APh 25. Introductory Quantum Mechanics. *9 units (3-0-6); third term. Prerequisites: Ph 2 ab, Ma 2 ab, or equivalents.* Introduction to quantum mechanics: Schrödinger equation, uncertainty principle, postulates of quantum mechanics, wave packets, dispersion, abrupt potentials, harmonic oscillator, angular momentum. Instructor: Corngold.

APh 77 bc. Laboratory in Applied Physics. *9 units; second, third terms.* Selected experiments chosen to familiarize students with laboratory equipment, procedures, and characteristic phenomena in plasmas, fluid turbulence, fiber optics, X-ray diffraction, microwaves, high-temperature superconductivity, black-body radiation, holography, and computer interfacing of experiments. Instructor: Shumate and 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 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; critical phenomena; ideal classical and degenerate gases; theory of liquids; band theory of solids; fluctuations; noise. Instructor: Johnson, Corngold.

APh 107. Advanced Dynamics. *9 units (3-0-6); third term. Prerequisite: dynamics at level of Ph 106 ab.* Review of Hamilton and Hamilton-Jacobi formalisms; integrable systems; continuous and discrete dynamics (maps); the KAM analysis; solitons; dissipative systems and fractal sets; a variety of examples. Not offered 1996–97.

APh 110. Topics in Applied Physics. *2 units (2-0-0); first, second 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 25 and APh 125 ab 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 124. Advanced Modern Optics Laboratory. *9 units; third term. Prerequisites: APh 24, APh 130, APh 131 (or APh 190 ab).* Laboratory experiments covering both active and passive optical devices and topics relevant to their use in modern optical systems. Topics covered include propagation effects in optical fibers; fiber-optic traveling-wave amplifiers; gain saturation and saturation dynamics in optical amplifiers; sources for fiber-optic systems including semiconductor lasers and fiber lasers; direct modulation, external modulation of laser sources; noise in laser sources. Instructor: Shumate.

APh 125 abc. Quantum Mechanics of Matter. *9 units (3-0-6); first, second, third terms. Prerequisite: APh 25.* Quantum mechanics and applications to problems in solids, liquids, and gases. Topics: central force problems; hydrogen atom; multielectron atoms; approximation methods: time-independent and time-dependent perturbation theory, variational method, WKB approximation; eigenstates of molecules; theories for chemical bonding; optical transitions in matter; scattering: Born approximation, partial wave expansions, electron and photon scattering in matter; the electromagnetic field; quantum theory of crystalline solids. Instructors: Atwater, Vahala.

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 of optoelectronics. Gaussian beam propagation, optical resonators. Interaction of light and matter, laser rate equations, mode-locking, Q-switching; selected specific lasers. Instructor: Shumate.

APh/EE 131. Optoelectronic Devices. *9 units (3-0-6); second term. Prerequisite: APh/EE 130 or instructor's permission.* Semiconductor lasers; propagation of light in crystals; electro-optic effects and their use in the modulation of light; optical detectors and amplifiers; noise characterization of optoelectronic devices; introduction to nonlinear optics. System design considerations, with examples selected from optical communications, radar, and other applications. Instructor: Shumate.

APh/EE 132. Fourier Optics. *9 units (3-0-6); third 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 are discussed. Topics: scalar diffraction theory; the lens as a Fourier transforming element; coherent and incoherent imaging; optical information processing systems; holography. Instructor: Psaltis.

APh 133. Optical Computing. *9 units (3-0-6); second term. Prerequisite: APh/EE 132 or equivalent exposure to optics.* An introductory course in devices and techniques used for the optical implementation of information processing systems. Subjects to be covered include optical linear transformations, nonlinear optical switching devices, holographic interconnections, optical memories, photorefractive crystals, and optical realizations of neural computers. Offered in alternate years; not offered 1996–97.

APh/MS 140. Ion Beam Modification and Analysis of Materials. *6 units (2-0-4); first term.* Introduction to ion-solid interactions as applied to the modification of thin films and to the structural and compositional analysis of materials. Topics: collision kinematics, interatomic potentials, scattering cross sections, stopping cross sections, energy straggling, transport theory, ion ranges. Applications to backscattering spectrometry: energy and mass resolution, scattering geometry, evaluation of spectra, channeling. Applications to materials modification: ion implantation, mixing, sputtering, amorphization. Instructors: Atwater, Corngold.

APh/MS 141 abc. Ion Beam Analysis Laboratory. *5 units (0-4-1); first, second, third terms; no more than two terms for credit. Prerequisite or concurrently: APh 140.* Laboratory instruction in the use of backscattering spectrometry for the characterization of materials. Operation of solid-state detector and electronics chains. System calibration. Recording of spectra. Quantitative evaluation of spectra. Channeling in single crystalline films and bulk crystals. Instructor: Atwater.

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 156 abc. Plasma Physics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 106 abc or equivalent.* An introduction to the principles of plasma physics, including orbits of charged particles in electric, magnetic, and gravitational fields; continuum magnetohydrodynamics and elementary stability theory; transport processes such as conductivity and diffusion, Vlasov equation, waves, and oscillations in plasmas. Examples from plasmas used in controlled thermonuclear fusion research (e.g., tokamaks, mirrors, pinches). Instructor: Bellan.

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., pn 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: Staff.

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. Not offered 1996–97.

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 1996–97.

Ph/APh 223 abc. Advanced Topics in Condensed Matter Physics. *9 units (3-0-6).* For course description, see Physics.

APh 250. Advanced Topics in Applied Physics. *Units and term to be arranged.* Content will vary from year to year; topics are 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 HISTORY

These courses are open only to students who have fulfilled the freshman humanities requirement.

Art 101. Selected Topics in Art History. *9 units (3-0-6). Offered by announcement. Advanced credit to be determined on a course-by-course basis by the instructor.* Instructors: Staff.

Art 103. Ancient Art: From the Pyramids to the Colosseum. *9 units (3-0-6); third term.* A survey of the art of the earliest civilizations of the Ancient Near East and Mediterranean from the Bronze Age to approximately A.D. 300. The major monuments—architectural, sculptural, and pictorial—of Mesopotamia, Egypt, the Aegean, Greece, and Rome will be examined as solutions to problems of form and function presented by communal political, economic, and religious life. Emphasis will be placed on the creation of Graeco-Roman art, the foundation of the Western artistic tradition. The course will include one or more study trips to the Getty Museum. Instructor: Woods.

Art 106. The Age of the Great Cathedrals. *9 units (3-0-6); first term.* A study of the arts of Western Europe from the disintegration of the Roman Empire circa A.D. 476, to the 14th century. The diverse historical forces at work during this long period produced a correspondingly varied art. Emphasis will be on the later Middle Ages, from circa 1200–1350, a period marked by a synthesizing of inherited traditions into a comprehensive whole. Major monuments of architecture, such as the cathedrals of Notre Dame, Chartres, Reims, Cologne, Strasbourg, and Westminster, as well as sculpture, illuminated manuscripts, mosaics, panel painting, and stained glass will be examined within the aesthetic and social framework of countries as culturally diverse as France, Italy, Germany, Spain, and Britain. Instructor: Howard.

Art 108. Italian Renaissance Art. *9 units (3-0-6); first term.* 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. Not offered 1996–97. Instructor: Howard.

Art 109. Northern European Art: 1400–1650. *9 units (3-0-6); third term.* A comprehensive survey of artistic developments in Northern Europe from the late Middle Ages through the Renaissance and baroque periods. The course will focus upon the complexity of northern art, from its origins in the still forceful medieval culture of 15th-century Flanders, to its confrontation with Italian Renaissance humanism in the 16th century. The effects of this cultural synthesis and the eventual development of distinct national schools of painting in the 17th century are examined through the works of the period's dominant artists, including Van Eyck, Dürer, Brueghel, Holbein, Rubens, Van Dyck, Hals, and Rembrandt. Instructor: Howard.

Art 110. Baroque Art. *9 units (3-0-6).* 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, Velázquez, 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. Not offered 1996–97. Instructor: Howard.

Art 111. European Art of the 18th Century: From the Rococo to the Rise of Romanticism. *9 units (3-0-6).* Course will encompass 18th-century European painting, sculpture, architecture, and the decorative arts. During this period a variety of styles and subjects proliferated in the arts, as seen in the richly diverse works of artists such as Watteau, Boucher, Chardin, Fragonard, Tiepolo, Canaletto, Hogarth, Gainsborough, Blake, David, Piranesi, and Goya, which reflect a new multiplicity in ways of apprehending the world. Not offered 1996–97. Instructor: Bennett.

Art 112. British Art. *9 units (3-0-6); second term.* A survey course on British painting, sculpture, and architecture in the 17th, the 18th, and the 19th centuries. By examining the works of well-known British artists such as Hogarth, Blake, Gainsborough, Reynolds, Constable, and Turner, the class will focus on the multiplicity of styles and themes which developed in the visual arts in Britain from 1740 to 1840 and are part of the wider artistic phenomenon known as Romanticism. This introduction to the British visual arts will be enriched by several class meetings in the Huntington Art Gallery. Instructor: Bennett.

Art 115. Art of the 19th Century. *9 units (3-0-6).* A survey of 19th-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. Not offered 1996–97. Instructor: Bennett.

Art 118. Modern Art. *9 units (3-0-6); first term.* An in-depth survey of international painting and sculpture of the first half of the 20th century. Crucial movements, among them Fauvism, German Expressionism, Cubism, Dadaism, Surrealism, and American abstraction and realism between the two world wars, will be studied, and masterworks by a number of major artists of this period (e.g., Picasso, Matisse, Nolde, Duchamp, Magritte, Hopper) will be closely examined. Instructor: Lang.

Art 125. History of Western Architecture. *9 units (3-0-6).* A survey of major developments in Western architecture and urbanism from the classical civilizations of Greece and Rome to the 20th century. The course focuses upon the visual, spatial, and functional properties and the cultural significance of key building types ranging from Greek temples, Roman civil and administrative structures, Gothic cathedrals, Renaissance and baroque churches and city palaces, to the technology-based skyscrapers and other forms of 20th-century modernism. Not offered 1996–97. Instructor: Howard.

Art 150. The Arts of Dynastic China.* *9 units (3-0-6).* A survey of the development of Chinese art in which the major achievements in architecture, sculpture, painting, calligraphy, and ceramics will be studied in their cultural contexts from prehistory through the Manchu domination of the Qing Dynasty (1644-1911). Emphasis will be placed on the aesthetic appreciation of Chinese art as molded by the philosophies, religions, and history of China. Not offered 1996–97. Instructor: Wolfgram.

Art 151. Traditions of Japanese Art. *9 units (3-0-6); second term.* An introduction to the great traditions of Japanese art from prehistory through the Meiji Restoration (1868-1912). Students will examine major achievements of sculpture, painting, temple architecture, and ceramics as representations of each artistic tradition, whether native or adapted from foreign sources. Fundamental problems of style and form will be discussed, but aesthetic analysis will always take place within the conditions created by the culture. Instructor: Wolfgram.

** Advanced courses with credit toward the 36-unit humanities requirement. Other advanced courses receive credit toward the 36-unit H&SS requirement.* *See page 152.*

ASTRONOMY

Ay 1. The Evolving Universe. *9 units (3-3-3); third term. This course is intended primarily for freshmen not expecting to take more advanced astronomy courses and will satisfy the menu requirement of the Caltech core curriculum.* Introduction to modern astronomy that will illustrate the accomplishments, techniques, and scientific methodology of contemporary astronomy. The course will be organized around a set of basic questions, showing how our answers have changed in response to fresh observational discoveries. Topics to be discussed will include telescopes, stars, planets, and the search for life elsewhere in the universe, supernovae, pulsars, black holes, galaxies and their active nuclei, and the big bang. There will be a series of laboratory exercises intended to highlight the path from data acquisition to scientific interpretation. Students will also be required to produce a term paper on an astronomical topic of their choice. In addition, a field trip to Palomar Observatory will be organized. Instructor: Blandford.

Ay 20. Basic Astronomy and the Galaxy. *11 units (3-2-6); first term. Prerequisites: Ma 1 abc, Ph 1 abc, or for freshmen with a strong high-school background in math and physics.* 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 use of a telescope and CCD camera for astronomical measurements. Instructor: Djorgovski.

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

Ay 22. Solar System. *9 units (3-0-6); third term.* Physics of the sun. Surface phenomena of the sun, formation of spectral lines. Solar activity, sunspots, and flares. The solar corona and solar wind. Physics of the planetary system. Planetary magnetospheres and atmospheres, surface phenomena. Comets. Instructor: 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. Instructors: Staff.

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 78 abc. Senior Thesis. *9 units; first, second, third terms. Prerequisite: to register for this course, the student must obtain approval of the Astronomy Option Representative and the prospective thesis adviser.* Open only to senior astronomy majors. This research must be supervised by a faculty member, your thesis adviser. The written thesis must be completed and approved by the adviser before the end of the third term. Students wishing assistance in finding an adviser and/or a topic for a senior thesis are invited to consult with the Astronomy Option Representative. A grade will not be assigned in Ay 78 until the end of the third term. P grades will be given the first two terms, and then changed at the end of the course to the appropriate letter grade.

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. Nucleosynthesis in stars. Stellar oscillations. Instructor: McCarthy.

Ay 102. Physics of the Interstellar Medium. *9 units (3-0-6); second term. Prerequisite: Ay 20.* An introduction to fluid mechanics, sound waves, and shock waves. Introduction to magnetohydrodynamics, Alfvén 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. Instructors: Sargent, Phinney.

Ay 105. Optical Astronomy Instrumentation Lab. *9 units (1-6-2); third term. Prerequisite: Ay 20.* An opportunity for astronomy and physics undergraduates (juniors and seniors) to gain firsthand experience with the basic instrumentation tools of modern optical and infrared astronomy. The 10 weekly lab experiments are expected to include: radiometry measurements, geometrical optics, optical aberrations and ray tracing, spectroscopy, fiber optics, CCD electronics, CCD characterization, photon counting detectors, vacuum and cryogenic technology, and stepper motors and encoders. Instructor: McCarthy.

Ay 121. Radiative Processes. *9 units (3-0-6); first term. Prerequisites: Ay 101 (undergraduates); Ph 98 or equivalent.* The interaction of radiation with matter: radiative transfer, emission, and absorption. Compton processes, synchrotron radiation, collisional excitation, spectroscopy of atoms and molecules. Instructor: Readhead.

Ay 122. Astronomical Measurements and Instrumentation. *9 units (3-0-6); first term. Prerequisite: Ph 106 or equivalent.* 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: J. Cohen, Kulkarni.

Ay 123. Stellar Structure and Early Evolution. *9 units (3-0-6); second term. Prerequisites: Ay 101 (undergraduates); Ph 98 or equivalent.* Stellar structure and evolution. Polytropes, radiative transport, convection, nuclear energy generation, main sequence. Hayashi track, advanced stages of evolution, pulsations, rotation. Stellar atmospheres. Instructor: McCarthy.

Ay 124. Structure and Dynamics of Galaxies. *9 units (3-0-6); third term. Prerequisites: Ay 21 (undergraduates); Ph 106 or equivalent.* Stellar dynamics and properties of galaxies; kinematics and dynamics of our galaxy; spiral structure; stellar composition, masses, and rotation of external galaxies; star clusters; galactic evolution; binaries, groups, and clusters of galaxies. Instructors: Sargent, Steidel.

Ay 125. High-Energy Astrophysics. *9 units (3-0-6); second term. Prerequisites: Ay 21 (undergraduates); Ph 106 or equivalent.* High-energy astrophysics and the final stages of stellar evolution; supernovae, binary stars, accretion disks, pulsars; extragalactic radio sources; active galactic nuclei; black holes. Instructors: J. Cohen, Martin.

Ay 126. Interstellar Medium. *9 units (3-0-6); second term. Prerequisite: Ay 102 (undergraduates).* Physical processes in the interstellar medium. Ionization, thermal, and dynamic balance of interstellar medium, molecular clouds, hydrodynamics, magnetic fields, H II regions, supernova remnants, star formation, global structure of interstellar medium. Instructors: Phinney, Sargent.

Ay 127. Cosmology and Galaxy Formation. *9 units (3-0-6); third term. Prerequisites: Ay 21 (undergraduates) and Ph 106 or equivalent.* Cosmology; extragalactic distance determinations; relativistic cosmological models; galaxy formation and clustering; thermal history of the universe, microwave background; nucleosynthesis; cosmological tests. Instructors: Djorgovski, Goldreich.

Ay 128. Solar Physics. *9 units (3-0-6); third term. Prerequisites: Ay 22 (undergraduates); Ph 106 or equivalent.* The detailed structure and dynamics of the sun, including the solar interior, the neutrino problem, the photosphere, chromosphere, corona and solar wind, convection and the solar dynamo, sunspots and faculae, helioseismology, solar flares, and solar-terrestrial relations. Instructor: Zirin.

Ge/Ay 132. Atomic and Molecular Processes in Astronomy and Planetary Sciences. *9 units (3-0-6).* For course description, see Geology.

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 Caltech Submillimeter, 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/EE 144. Imaging at Radio, Infrared, and Optical Wavelengths by Interferometric and Adaptive Techniques. *9 units (3-0-6); second term.* The theory of coherence, interferometry, and aperture synthesis observations at radio and visible wavelengths. The technique of adaptive optics to overcome atmosphere blurring at visible wavelengths. Emphasis is given to the formation of images with limited spatial frequency coverage, to applications in astronomy, geodesy, and high-resolution imaging with large optical telescopes. Relative emphasis on interferometric imaging versus adaptive optics will vary from year to year. Instructors: J. Cohen, Kulkarni.

Ay/Ph 145. Signal Processing and Data Analysis. *9 units (3-0-6); second term.* Statistical analysis and signal processing essential to observational and to experimental science. Topics: calculus of probability, Bayes Theorem, distributions of single and multiple random variables, normal samples, parameter estimation, time series analysis of signals, Fourier transforms, convolution and correlation, sampling and digitizing, power spectrum measurement, digital filters. Examples from astronomy and physics. Instructor: Kulkarni.

Ay 211. Extragalactic Astronomy. *9 units (3-0-6); first term. Prerequisites: Ay 127, Ay 124, and Ay 123.* This year the course will review the formation and evolution of galaxies, including their heavy element abundances. Discussion will include the use of QSO absorption lines to study the evolution of the interstellar gas in galaxies. Students will each give a lecture on an assigned topic. Given in alternate years; not offered 1996–97.

Ay 212. Topics in Astronomy. *9 units (3-0-6); third term.* A course for graduate students in astronomy. This year the course will cover the evolution of the universe and the growth of structure from recombination to the appearance of the first galaxies and quasars. Instructors: Blandford, Readhead.

Ay 215. Planets and Brown Dwarfs. *9 units (3-0-6); second term.* Course for graduate students and seniors in astronomy and planetary science. Instructions via seminars by staff and students. We will review current theoretical ideas relevant to the formation of low mass stars, circumstellar disks, planets, and brown dwarfs. A sound theoretical understanding is required in order to interpret and make further progress in observations. Difficulties associated with calculating model atmospheres and cooling rates for brown dwarfs will be exposed, and observational signatures of these elusive objects sought. Strategies of ongoing and proposed searches for planets and brown dwarfs will be discussed. Instructors: Goldreich, Kulkarni.

Ay 218. High-Energy Astrophysics. *9 units (3-0-6); first term. Prerequisites: Ay 125, Ph 106, and Ph 125 or equivalent.* Topics covered vary from year to year. Given in alternate years; not offered 1996–97.

Ay 234. Seminar in Radio Astronomy. *6 units (2-0-4); third term. Prerequisite: Ay 125.* Recent developments in radio, infrared, optical, X-ray, and gamma-ray studies of active galactic nuclei and quasars. Discussion will include physical models, morphological and geometric characteristics, and unification. Given in alternate years; not offered 1996–97.

Ay 235. Research Seminar. *1 unit (1-0-0); first term.* Will present seminars on current research interests of the astronomy faculty to graduate students during the fall term. Instructors: Staff.

BIOCHEMISTRY

Bch/Bi/Ch 170. Principles of Three-Dimensional Protein Structure. *9 units (3-3-3); first term. Prerequisites: Bi/Ch 110.* The forces determining the folding of proteins into their unique tertiary structures. Protein structures will be classified by organization of the structural elements and structural motifs, and their influence on function will be explored. Topics will include enzyme and antibody structure and function, virus structures, protein-nucleic acid interactions, methods of macromolecular structure determination, and protein structure analysis. A computer graphics system will be used for the display and analysis of macromolecular structure.

Instructors: Bjorkman, Rees.

Bch 176. The Molecular Basis of Protein Function. *9 units (3-3-3); second term. Prerequisite: Bch/Bi/Ch 170.* Theory, mechanisms, and kinetics of protein-ligand interactions and enzyme catalysis, including the role of cofactors. The course will also cover the cooperativity characteristic of multi-subunit protein complexes and will emphasize the relationship between protein structure and function. Not offered 1996–97.

Bch 178. Fundamentals of Molecular Genetics. *9 units (3-3-3); third term. Prerequisite: Bch 176.* Principles and mechanisms of DNA repair and replication, transcription and splicing, and protein synthesis. Not offered 1996–97.

BIOLOGY

Bi 1. Fundamentals of Modern Biology. *9 units (3-0-6).* A one-term course designed to expose the students to the logic of biological experiments, the multiple scales at which issues must be analyzed, and the power of modern biological techniques. The course is not intended as a survey that offers a lecture on each of a multitude of issues/topics; instead, the course will present key aspects of modern biology by asking students to "solve" a major topical issue. By presenting the basic material as a means to understanding an engaging and topical issue, the course should help give the students a context in which to both organize and employ the principles of modern biology. Topics may vary from year to year; the topic for 1996–97 is AIDS. Instructors: Fraser, Revel.

Bi 2. Current Research in Biology. *6 units (2-0-4); first term. An elective course, open only to freshmen.* Current research in biology will be discussed, on the basis of reading assigned in advance of the discussions, with members of the divisional faculty. Graded pass/fail. Instructors: Abelson and staff.

Bi 8. Introduction to Molecular Biology; Organization and Expression of Genetic Information. *9 units (3-0-6); 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 the organization and expression of genetic information, including what is commonly called molecular biology, and introduces topics in developmental biology and immunology. Graded pass/fail. Instructor: Varshavsky.

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: Dunphy and staff.

Bi 10. Cell Biology Laboratory. *6 units (1-3-2); third term. Prerequisite: Bi 8; designed to be taken concurrently with Bi 9.* Introduction to basic methods in cell and molecular biological research, including polymerase chain reaction, molecular cloning, expression and purification of recombinant fusion proteins in bacteria, enzymology, and gel electrophoresis of proteins and nucleic acids. Instructor: Deshaies.

Bi 11. Organismic Biology. *9 units (3-3-3); first term. Prerequisite: Bi 1 or Bi 9.* Survey of the principal kinds of organisms and the 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; 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 80. Senior Thesis Seminar. *3 units (3-0-0); first term. Prerequisite: Concurrent registration with Bi 90.* Practice in the techniques of oral presentation, by individual presentations and discussion of thesis topics. Instructors: Revel, Schuman.

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, concurrent registration for Bi 80 during first term, 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.

Ph/Bi 103 c. Neuroscience for Physicists and Engineers. *Third term.* For course description, see Physics.

Bi/Ch 110. Introduction to Biochemistry. *12 units (4-0-8); first term. Prerequisite: Ch 41 abc or consent of instructor.* Lectures and recitation introducing the molecular basis of life processes, with emphasis on the structure and function of proteins. Topics will include the derivation of protein structure from the information inherent in a genome, biological catalysis, the intermediary metabolism that provides energy to an organism, and the use of DNA manipulations, cloning, and expression of proteins in foreign hosts to study protein structure and function. Instructors: Richards, Campbell.

Bi/Ch 111. Biochemistry of Gene Expression. *12 units (4-0-8); second term. Prerequisites: Bi/Ch 110; Bi 8 and Bi 122 recommended.* Lectures and recitation on the molecular basis of biological structure and function. Emphasizes the storage, transmission, and expression of genetic information in cells. Specific topics include DNA replication, recombination, repair and mutagenesis, transcription, RNA processing, and protein synthesis. Instructors: Campbell, Parker.

Bi/Ch 113. Biochemistry of the Cell. *12 units (4-0-8); third term. Prerequisite: Bi/Ch 110; Bi 9 recommended..* Lectures and recitation on the biochemistry of basic cellular processes in the cytosol and at the cell surface. The emphasis will be on signal transduction, membrane traffic, and control of cell division. Instructors: Kennedy, Dunphy.

Bi 114. Immunology. *12 units (4-0-8); second term. Prerequisites: Bi 8, Bi 9, Bi 122 or equivalent, and Bi/Ch 110 recommended.* The course will cover the molecular and cellular mechanisms that mediate recognition and response in the mammalian immune system. Topics include cellular and humoral immunity, the structural basis of immune recognition, antigen presentation and processing, developmental regulation of gene rearrangement, biochemistry of lymphocyte activation, lymphokines and the regulation of cellular responses, T and B cell development, and mechanisms of tolerance. Instructors: Bjorkman and Rothenberg.

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 1996–97. 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. Instructors: Meyerowitz, Sternberg.

Bi 123. Genetics Laboratory. *9 units (0-6-3); third term. Prerequisite: Bi 122.* Laboratory exercises illustrating the principles of genetics, with emphasis on Mendelian inheritance in multicellular eukaryotes, including *Drosophila melanogaster* and *Caenorhabditis elegans.*

Bi 125. Principles and Methods of Gene Transfer and Gene Manipulation in Eukaryotic Cells. *6 units (2-0-4); 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 1996–97. Instructor: Attardi.

Bi 127. Regulation of the Cell Cycle. *6 units (2-0-4); third term. Prerequisites: Bi 8, Bi 9, Bi/Ch 110, or graduate standing. Enrollment by permission of instructor.* An advanced seminar focusing on regulation of the cell cycle in eukaryotes. Genetic, biochemical, and molecular studies of cell cycle control in different biological systems including yeast, vertebrate and invertebrate embryos, and vertebrate cells in culture will be featured. The relationship of cell proliferation, and the signals that control it, to cellular differentiation will be a theme. Critical review of current literature will be central. Given in alternate years; not offered 1996–97. Instructor: Wold.

Bi/Ch 132. Biophysics of Macromolecules. *9 units (3-0-6); second term. Recommended: Bi/Ch 110 (or taken concurrently).* Structural and functional aspects of nucleic acids and proteins, including hybridization; electrophoretic behavior of nucleic acids; principles and energetics of folding of polypeptide chains in proteins; allostery and cooperativity in protein action; enzyme kinetics and mechanisms; and methods of structure determination, such as X-ray diffraction and magnetic resonance. Structure and function of metalloenzymes. Given in alternate years; not offered 1996–97. Instructors: Chan, Rees.

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; not offered 1996–97. Instructor: Revel.

Bi 145. Animal Physiology. *9 units (3-0-6); third term. Recommended prerequisites: Bi 9, Bi 11, Ch 24.* Selected topics in animal physiology. Mammalian systems will be emphasized, but information from other groups will be drawn upon where relevant. Particular focus on biophysical analysis and understanding of muscle contraction and its regulation; the supply of oxygen to muscle and other tissues; and the regulation of water and solute contents of cells and organisms. Given in alternate years; not offered 1996–97. Instructor: Brokaw.

Bi/CNS 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: Laurent, Zinn, Schuman.

Bi 152. Introduction to Neuroethology. *6 units (2-0-4); second term.* Introduction to the neurobiological study of natural behavior of animals. Topics include such questions as how animals recognize and localize signals in their natural environments, how animals move, how behavior develops, what and how animals learn, and how natural selection shapes the evolution of brain and behavior. Instructor: Konishi.

Bi 156. Molecular Neurobiology. *9 units (3-0-6); second 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 1996–97. Instructors: Patterson, Zinn.

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 1996–97. Instructor: Allman.

Bi 158. Vertebrate Evolution. *9 units (3-0-6); third term.* An integrative approach to the study of vertebrate evolution combining comparative anatomical, behavioral, embryological, genetic, paleontological, and physiological findings. Special emphasis will be given to: (1) the modification of developmental programs in evolution; (2) homeostatic systems for temperature regulation; (3) changes in the life cycle governing longevity and death; (4) the evolution of brain and behavior. Given in alternate years; not offered 1996–97. Instructor: Allman.

Bi/CNS 161. Cellular Neurobiology Laboratory. *9 units (0-6-3); 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 1996–97. Instructor: Lester.

Bi/CNS 162. Central Nervous System Laboratory. *10 units (0-8-2); second term. Prerequisite: Bi 150 or instructor's permission.* A laboratory-based introduction to experimental methods used to study the central nervous system electrophysiologically. Through the term, students investigate the physiological response properties of the mammalian cerebellum using various extracellular recording techniques. Students are instructed in all aspects of experimental procedures, including proper surgical techniques, microelectrode fabrication, stimulus presentation, and computer-based data analysis. Graded pass/fail. Given in alternate years; not offered 1996–97. 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.

Bch/Bi/Ch 170. Principles of Three-Dimensional Protein Structure. *9 units (3-3-3).* For course description, see Biochemistry.

CNS/Bi 172. Clinical Neuropsychology. *6 units (3-0-3).* For course description, see Computation and Neural Systems.

Bi 180. Methods in Molecular Genetics. *12 units (2-8-2); first term. Prerequisites: Bi 122 or instructor's permission.* An introduction to current molecular genetic techniques including basic microbiological procedures, transposon and UV mutagenesis, gene transfer, preparation of DNA, restriction, ligation, electrophoresis (including pulsed-field), electro-poration, Southern blotting, PCR, gene cloning, sequencing, and computer searches for homologies. The first half of the course involves structured experiments designed to demonstrate the various techniques. The second half is devoted to individual research projects in which the techniques are applied to original studies on an interesting, but not well studied, organism. Graded pass/fail. Instructor: Bertani.

CNS/Bi/Ph 185. Collective Computation. *9 units (3-1-5).* For course description, see Computation and Neural Systems.

CNS/Bi/EE 186. Vision: From Computational Theory to Neuronal Mechanisms. *12 units (4-4-4).* For course description, see Computation and Neural Systems.

Bi 189. 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 1996–97. Instructors: E. Davidson, Sternberg.

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.* Given in alternate years; offered 1996–97. Instructors: Sternberg, Meyerowitz.

Bi/Ch 202 abc. Biochemistry Seminar. *1 unit; first, second, third terms.* A seminar on selected topics and on recent advances in the field. Instructors: Chan, Rees.

Bi 204. Genetics Seminar. *2 units; first term. Prerequisites: graduate standing, or Bi 122 and instructor's permission.* Reports and discussion on special topics in genetics. Instructor: Meyerowitz.

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 molecular biology of ion channels, neurotransmitter receptors, transporters, and other molecules underlying the excitability of cell membranes. Given in alternate years; not offered 1996–97. Instructor: Lester.

Bi 212. Topics in Neuroethology. *6 units (2-0-4); second term.* Reading and discussions of original papers related to animal behavior and its analysis by neuroethological methods. Knowledge of neurophysiology is required. Given in alternate years; not offered 1996–97. Instructor: Konishi.

Bi 214. Control of Development and Function in Hematopoietic Cells. *6 units (2-0-4); first term. Prerequisites: Bi 114 or graduate standing.* An advanced seminar based on reading from the current literature. Mechanisms of cell fate determination and lineage commitment, cell activation, and physiological function will be discussed, with an emphasis on lymphocytes. Given in alternate years; offered 1996–97. Instructor: Rothenberg.

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 1996–97. Instructor: Allman.

Bi 218. Molecular Biology of Neural Development. *6 units (2-0-4); second term.* A graduate seminar course designed to cover selected topics in the development of the nervous system, studied at the molecular level. The material should complement that in Bi 219, which is offered in alternating years. Emphasis will be placed on the genetic analysis of invertebrate systems and on selected model systems in vertebrate neural development. Given in alternate years; not offered 1996–97. Instructor: Anderson.

Bi 219. Developmental Neurobiology. *12 units (3-0-9); second 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 the generation of specific synaptic connections and the molecular basis underlying it. Given in alternate years; offered 1996–97. Instructors: Patterson, Fraser.

Bi 220. Advanced Seminar in the Molecular Biology of Development. *6 units (2-0-4); second, third terms.* Discussion of current papers on various pertinent topics including nucleic acid renaturation, hybridization, and complexity studies; synthesis and turnover of transcripts, transcript prevalence, and the dynamics of gene expression; transcription-level regulation of gene function; molecular aspects of differentiation in certain more intensely studied systems, etc. Quantitative aspects and biophysical background of relevant measurement methods are emphasized. Given in alternate years; offered 1996–97. Instructor: E. Davidson.

CNS/Bi 221. Computational Neuroscience. *9 units (4-0-5).* For course description, see Computation and Neural Systems.

Bi 222. Structure and Function of the Synapse. *6 units (2-0-4); third term. Prerequisites: Bi 110 abc, Bi 150, graduate standing, or instructor's permission.* Lectures, reading, and discussion covering recent research on synaptic structure and function. Topics will include structure and function of synaptic proteins, emphasizing mechanisms of neurotransmitter release and regulation of post-synaptic receptors; the extracellular matrix and synaptic structure; protein kinase signalling cascades; and developmental and adult synaptic plasticity, emphasizing long-term potentiation and long-term depression. Reading and discussion will focus on evaluation of the primary research literature. Given in alternate years; offered 1996–97. Instructors: Kennedy and Schuman.

Bi 224. Principles of bioLOGICal Analysis. *6 units (2-0-4); second term.* A graduate seminar course designed to illustrate how basic principles of logic and scientific methodology are applied to resolve questions about the function and regulation of biological systems. This course will draw upon examples from research papers in cellular and molecular biology to demonstrate how fundamental issues such as necessity and sufficiency, direct and indirect action, cause and effect, etc., underlie the execution and interpretation of most experiments in biology. The point of this course will be to give students a "conceptual tool kit" that they can apply to the resolution of experimental problems in any area of modern molecular and cellular biology. Given in alternate years; offered 1996–97. Instructor: Deshaies.

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, and membrane physiology and assembly. Given in alternate years; not offered 1996–97. Instructor: Attardi.

Ch/Bi 231. Advanced Topics in Biochemistry. *6 units (2-0-4).* For course description, see Chemistry.

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.

CNS/Bi 246. Multicellular Recording. *9 units (2-6-1).* For course description, see Computation and Neural Systems.

Bi 250 ab. Issues and Principles in Modern Biology. *4 units (2-0-2); first, second terms.* The course presents an overview of current research in the biology division with an emphasis on the work going on in the laboratories of individual faculty members. Weekly meetings include specific reading and involve direct give-and-take between the instructors and the class. Instructors: Abelson and staff.

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, third terms.* Students may register for research units after consultation with their adviser.

BUSINESS ECONOMICS AND MANAGEMENT

BEM 101. Introduction to Accounting. *9 units (3-0-6); first term.* An introduction to accounting in business. Topics include: financial accounting, cost accounting. Instructors: Staff.

BEM 102. Topics in Management Science. *9 units (3-0-6). Prerequisite: Ec 11. Offered by announcement.* 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. Instructor: Camerer.

BEM 103. Introduction to Finance. *9 units (3-0-6); first term. Ec 11 recommended.* An introduction to corporate finance. Economic theory is used to study asset valuation and financial decision making in business. Topics include: financial decision making under certainty, introduction to valuation of risky assets (stocks and bonds), the corporate investment decision, dividend policy, and the corporate financing decision.

Instructor: Staff.

BEM 104. Investment Analysis. *9 units (3-0-6); third term. Prerequisites: BEM 103, some familiarity with statistics. Ec 11 recommended.* An introduction to investment analysis, portfolio management, and capital markets. Its focus is the application of modern financial theory to portfolio selection and asset pricing. Topics include asset pricing models, the term structure of interest rates, contingent claim valuation. Instructor: Bossaerts.

BEM 105. Options. *9 units (3-0-6); third term. Prerequisites: BEM 103, some familiarity with statistics. Ec 11 recommended.* An introduction to modern option pricing theory. The focus is the valuation of contingent claims. Both American and European options are considered. The Binomial and Black-Scholes option pricing models are derived. The theory is also applied to risky debt and portfolio choice. Instructor: Bossaerts.

BEM 110. Topics in Business Economics. *9 units (3-0-6). Prerequisite: consent of instructor. Offered by announcement.* Selected topics in business economics. Instructors: Staff.

BEM/Ec 146. Organization Design. *9 units (3-0-6); second term. Prerequisite: Ec 11.* An introduction to the analysis, design, and management of organizations with an emphasis on incentives and information. Principles from economics, political science, and game theory will be applied to problems in project and team management, in organizational computing, and in allocating and pricing shared facilities. Instructor: Camerer.

CHEMICAL ENGINEERING

ChE 10. Introduction to Chemical Engineering Systems. *9 units (3-3-3); third term; open to freshmen only.* An introduction to the breadth of chemical engineering through several short-term projects supervised by individual chemical engineering faculty. Areas covered include fluid mechanics, separations, catalysis, and materials properties. Not offered 1996–97.

ChE 63 ab. Chemical Engineering Thermodynamics. *9 units (3-0-6); first, second terms.* A comprehensive course in classical thermodynamics with engineering and chemical applications. First and second laws; closed and open systems. Equations of state. Thermochemical calculations. Properties of real fluids. Power generation and refrigeration cycles. Multicomponent systems, excess properties, fugacities, activity coefficients, and models of nonideal solutions. Chemical potential. Phase equilibria. Chemical reaction equilibria. Thermodynamics of surfaces. Instructor: Giapis.

ChE 64. Introductory Chemical Reaction Engineering. *9 units (3-0-6); third term. Prerequisite: ChE 63 ab.* Elements of chemical kinetics and chemical reactors. Ideal and nonideal reactors. Materials balances for reactors and separation units. Thermochemical calculations and energy balances. Instructor: Davis.

ChE 80. Undergraduate Research. *Units by arrangement.* Research in chemical engineering offered as an elective in any term other than in the senior year. Graded pass/fail.

ChE 90 ab. Senior Thesis. *9 units (0-4-5); second, third terms. Prerequisite: ChE 126 a.* A research project carried out under the direction of a chemical engineering faculty member. A grade will not be assigned to ChE 90 prior to completion of the thesis, which normally takes two terms. A P grade will be given for the first term and then changed to the appropriate letter grade at the end of the course. Instructor: Gavalas.

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 mass transfer. Instructors: Brady, Kornfield, Wang, Hubbell.

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. Instructors: Staff.

ChE 110 ab. Optimal Design of Chemical Systems. *9 units (3-0-6); 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. Instructor: Wagner.

ChE 126 ab. Chemical Engineering Laboratory. *9 units (1-6-2); first, second terms. Prerequisites: ChE 101, ChE 103 abc, and ChE 105, or concurrent registration.* Projects illustrative of problems in transport phenomena, unit operations, chemical kinetics, process control, and reactor design are performed. Instructors: Arnold, Hubbell.

Ch/ChE 140 ab. Principles and Applications of Semiconductor Photoelectrochemistry. *6 units (4-0-2).* For course description, see Chemistry.

Ch/ChE 147. Polymer Chemistry. *9 units (3-0-6).* For course description, see Chemistry.

ChE/Ch 148. Polymer Physics. *9 units (3-0-6); third term. Prerequisites: Ch/ChE 147 or with instructor's permission.* An introduction to the physics that govern polymer structure and dynamics in liquid and solid states, and to the physical basis of characterization methods used in polymer science. Topics include characterization, scaling, and dynamics of polymers in solutions and melts; polymer-polymer thermodynamics in blends and block-copolymers; rubber elasticity; the rubber-glass transition; crystallization and morphology of semi-crystalline polymers. Not offered 1996–97.

ChE 151 ab. Physical and Chemical Rate Processes. *12 units (3-0-9); first, second terms.* The foundations of heat, mass, and momentum transfer for single and multiphase fluids will be developed. Governing differential equations; laminar flow of incompressible fluids at low and high Reynolds numbers; forced and free convective heat and mass transfer, diffusion, and dispersion. Emphasis will be placed on physical understanding, scaling, and formulation and solution of boundary-value problems. Applied mathematical techniques will be developed and used throughout the course. Instructor: Brady.

ChE 152. Heterogeneous Kinetics and Reaction Engineering. *9 units (3-0-6); first term. Prerequisite: ChE 64 or equivalent.* Survey of heterogeneous reactions and reaction mechanisms on metal and oxide catalysts. Characterization of porous catalysts. Reaction, diffusion, and heat transfer in heterogeneous catalytic and noncatalytic systems. Instructor: Gavalas.

ChE/Ch 155. Chemistry of Catalysis. *9 units (3-0-6); third term.* Discussion of homogeneous and heterogeneous catalytic reactions, with emphasis on mechanistic principles and on the relationships between the two areas. Topics include homogeneous hydrogenation; catalysis by metals; homogeneous oxidation; catalysis by metal oxides; catalytic polymerization; acid-base catalysis. Instructors: Davis, Labinger.

ChE/Env 157. Sources and Control of Air Pollution. *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; control techniques for particulate and gaseous pollutants; solution of large-scale regional air pollution control problems. Not offered 1996–97.

ChE/Env 158. Air Pollution Aerosols. *9 units (3-0-6); first 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. Instructor: Flagan.

ChE/Env 159. Atmospheric Chemistry and Physics of Air Pollution. *9 units (3-0-6); second 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. Instructor: Cass.

ChE 162. Biomedical Engineering. *9 units (3-0-6); third term. Prerequisites: Bi 9 and Ch 41 abc.* An introductory course in chemically oriented biomedical engineering, including biomaterials, controlled drug delivery, pharmacodynamics, and cell- and tissue-based therapeutics. Not offered 1996–97.

ChE 163. Fundamentals of Biochemical Engineering and Protein Biotechnology. *9 units (3-0-6); third term. Prerequisites: Bi/Ch 110 a or instructor's permission.* Introductory course in biochemical engineering and industrial biotechnology, including biocatalysis and fermentation processes, enzyme kinetics, protein engineering, and biochemical separations. Instructor: Arnold.

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: Wang.

ChE 165. Chemical Thermodynamics. *9 units (3-0-6); first term. Prerequisite: ChE 63 ab or equivalent.* Review of first and second laws and engineering applications. Intermolecular forces and virial coefficients. Equations of state and thermodynamic properties of pure substances. Thermodynamics of gaseous and liquid mixtures. Theories of solutions. Phase and chemical equilibria. Instructor: Gavalas.

ChE 174. Special Topics in Transport Phenomena. *9 units (3-0-6); third term. Prerequisite: AM 113 or AMa 95, ChE 151 ab. May be repeated for credit.* Advanced problems in heat, mass, and momentum transfer. Introduction to mechanics of complex fluids; physicochemical hydrodynamics; microstructured fluids; selected topics in hydrodynamic stability theory; transport phenomena in materials processing; turbulence. Other topics may be discussed depending on class needs and interests. Not offered 1996–97.

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 Two.

Ch 1 ab. General Chemistry. *6 units (3-0-3) first term; 9 units (4-0-5) second term.* 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, hybridization and resonance, bonding in solids. Second term: chemical equilibria, oxidation and reduction, thermodynamics, kinetics, introduction to organic chemistry and the chemistry of life. Graded pass/fail. Instructors: Lewis, Barton, Rees.

Ch 3 a. Fundamental Techniques of Experimental Chemistry. *6 units; first, second terms.* Introduces the basic principles 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 or Ch 21, or by permission of the instructor. Graded pass/fail. Instructors: 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: Staff.

Ch 4 ab. Synthesis and Analysis of Organic and Inorganic Compounds. *9 units (1-6-2). Prerequisite: Ch 1 (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 emphasizes spectroscopic methods of analysis; Ch 4 b stresses applications of chromatography in addition to more classical separation techniques. Ch 4 a, first and third terms; Ch 4 b, second term only. Instructors: Staff.

Ch 5 ab. Advanced Techniques of Synthesis and Analysis. *9 units (1-6-2); second, third 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: Bercaw, Myers.

Ch 6 ab. Application of Physical Methods to Chemical Problems. *10 units (0-6-4); second, third terms. Prerequisites: Ch 1, 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 X-ray crystallography, laser Raman spectroscopy, microwave spectroscopy, electron spin resonance, ultraviolet photoelectron spectroscopy, and Fourier transform 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. Instructors: Beauchamp, Okumura.

Ch 7. Advanced Experimental Methods in Bioorganic Chemistry. *9 units (1-6-2); third term. Prerequisites: Ch 41 abc, and Bi/Ch 110. Enrollment by permission of instructor. Preference will be given to students who have taken Ch 5 a or Bi 10.* This advanced laboratory course will provide experience in the powerful contemporary methods for polypeptide and oligonucleotide synthesis. Experiments will address nucleic acid and amino acid protecting group strategies, biopolymer assembly and isolation, and product characterization. A strong emphasis will be placed on understanding the chemical basis underlying the successful utilization of these procedures. In addition, experiments to demonstrate the application of commercially available enzymes for useful synthetic organic transformations will be illustrated. Instructor: Imperiali.

Ch 10 abc. Frontiers in Chemistry. *3 units (2-0-1); first, second terms. 6 units (1-4-1); third term. Open for credit to freshmen and sophomores. Prerequisites: Ch 10 c prerequisites are Ch 10 ab, Ch 3 a, and either Ch 1 ab, Ch 41 ab, or Ch 21 ab, and permission of instructor.* Ch 10 ab is a weekly seminar by a member of the chemistry department on a topic of current research; the topic will be presented at an informal, introductory level. The other weekly session will acquaint students with the laboratory techniques and instrumentation used on the research topics. Ch 10 c is a research-oriented laboratory course, which will be supervised by a chemistry faculty member. Weekly class meetings will provide a forum for participants to discuss their research projects. Graded pass/fail. Instructors: Barton, Lewis.

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: Richards, Anson.

Ch 15. Chemical Equilibrium and Analysis Laboratory. *10 units (0-6-4); first term. Prerequisites: Ch 1 ab, 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 is on determinations of chemical composition, measurement of equilibrium constants, evaluation of rates of chemical reactions, and trace-metal analysis. Instructors: Anson, Chan.

Ch 21 abc. The Physical Description of Chemical Systems. *9 units (3-0-6); first, second, third terms. Prerequisites: Ch 1 ab, Ph 2 ab, Ma 2 ab.* Atomic and molecular quantum mechanics, spectroscopy, thermodynamics, statistical mechanics, and chemical kinetics. Instructors: McKoy, Baldeschwieler, Beauchamp.

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 ab.* 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. Instructors: Chan, staff.

Ch 41 abc. Organic Chemistry. *9 units (3-0-6); first, second, third terms. Prerequisite: Ch 1 ab or instructor's permission.* The synthesis, structures, and mechanisms of reactions of organic compounds. Instructors: Grubbs, Carreira.

Ch 80. Chemical Research. *Offered to B.S. candidates in chemistry. Prerequisite: consent of research supervisor.* Experimental and theoretical research requiring a report containing an appropriate description of the research work.

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.

Ch 90. Oral Presentation. *2 units (1-0-1); second term.* Training in the techniques of oral presentation of chemical and biochemical topics. Practice in the effective organization and delivery of technical reports before groups. Graded pass/fail. Instructors: Anson, Richards.

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 1996–97.

Bi/Ch 110. Introduction to Biochemistry. *12 units (4-0-8).* For course description, see Biology.

Bi/Ch 111. Biochemistry of Gene Expression. *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: Bercaw.

Bi/Ch 113. Biochemistry of the Cell. *12 units (4-0-8).* For course description, see Biology.

Ch 117. Introduction to Electrochemistry. *6 units (2-0-4); second 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 1996–97.

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). Prerequisites: General exposure to quantum mechanics (e.g., Ph 2 ab, Ph 12 abc, or equivalent).* Modern ideas of chemical bonding, with an emphasis on qualitative concepts and how they are used to make predictions of structures, energetics, excited states, and properties. Part a: The quantum mechanical basis for understanding bonding, structures, energetics, and properties of materials (polymers, ceramics, metals alloys, semiconductors, and surfaces). The emphasis is on explaining chemical, mechanical, electrical, and thermal properties of materials in terms of atomistic concepts. Part b: The quantum mechanical basis for understanding transition metal systems with a focus on chemical reactivity. There will be an emphasis on organometallic complexes, on homogeneous catalysis, and on heterogeneous catalysis. Part c: The student does an individual research project using modern quantum chemistry computer programs to calculate wavefunctions, structures, and properties of real molecules. Ch 120 a is identical to MS 131. It is part of the Ch 120 ab sequence in chemistry and is also part of the MS 131, MS 132, MS 133 sequence in Materials Science. Part b will not be offered in 1996–97. Instructor: Goddard.

Ch 121 ab. Atomic Level Simulations of Materials and Molecules. *Part a, 9 units (3-1-5) second term; Part b, 6 units (1-1-4) third term. Prerequisites: Ma 2 ab, Ph 2 ab, Ch 1 ab, or equivalent. Recommended: Ch 41 abc, Ch 21 a.* Methods for predicting the structures and properties of molecules and solids. The course will highlight theoretical foundations and applications to current problems in: biological systems (proteins, DNA, carbohydrates, lipids); polymers (crystals, amorphous systems, copolymers); semiconductors (group IV, III-V, surfaces, defects); inorganic systems (ceramics, zeolites, superconductors, and metals); and organometallics and catalysis (heterogeneous and homogeneous). Both terms will involve the use of computers for building and calculating systems of interest. Part a covers the basic methods. Part b is a laboratory course where the student uses the techniques of the course to carry out the project. Ch 120 a is recommended but not required for Ch 121 a. Instructor: Goddard. Not offered 1996–97.

Ch 122 abc. 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), nuclear magnetic resonance (second term), and mass spectrometry (third term). All three terms can be taken independently. Part c not offered 1996–97. Instructors: Baldeschwieler, staff.

Ch 125 abc. The Elements of Quantum Chemistry. *9 units (3-0-6); first, second, third terms. Prerequisite: Ch 21 abc or an equivalent brief introduction to quantum mechanics.* A first course in molecular quantum mechanics consisting of a quantitative treatment of quantum mechanics with applications to systems of interest to chemists. The basic elements of quantum mechanics, the electronic structure of atoms and molecules, the interactions of radiation fields and matter, scattering theory, and reaction rate theory. Instructors: Kuppermann, McKoy, Weitekamp.

Ch 126. Molecular Spectra and Molecular Structure. *9 units (3-0-6); first term. Prerequisite: Ch 21 and Ch 125 a taken concurrently, or permission of instructor.* Quantum mechanical foundations of the spectroscopy of molecules. Topics include quantum theory of angular momentum, rovibrational Hamiltonian for polyatomic molecules, molecular symmetry and permutation-inversion groups, electronic spectroscopy, interaction of radiation and matter. Instructor: Okumura.

Ge/Ch 127. Nuclear Chemistry. *9 units (3-0-6).* For course description, see Geology.

Ge/Ch 128. Cosmochemistry. *9 units (3-0-6).* For course description, see Geology.

Ch 130. Spectroscopy. *9 units (3-0-6); third term.* Discussion of various topics in lasers and their applications. Group theory with applications to molecular structure and spectroscopy will also be discussed. Instructor: Zewail.

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

Ch 135 ab. Chemical Dynamics. *9 units (3-0-6); part a, third term; part b, second term. Prerequisites: Ch 21 abc and Ch 41 abc, or equivalent, or consent of instructor.* Part a: Introduction to the dynamics of chemical reactions. Topics include scattering cross sections, rate constants, intermolecular potentials, reactive scattering, nonadiabatic processes, statistical theories of unimolecular reactions, and the application of laser and molecular beam techniques to the study of reaction mechanisms. Part b: The quantum description of chemical reactions. The scattering matrix. The calculation of reaction cross sections, probabilities, and rate constants. Collision lifetimes and resonances. Classical trajectories. The two terms can be taken independently. Instructors: Okumura, Kuppermann. Taught second term only, 1996–97.

Ch/ChE 140 ab. Principles and Applications of Semiconductor Photoelectrochemistry. *6 units (4-0-2); second, third terms. Prerequisite: APh 9 or permission of instructor.* The properties and photoelectrochemistry of semiconductors and semiconductor/liquid junction solar cells will be discussed. Topics include: optical and electronic properties of semiconductors; electronic properties of semiconductor junctions with metals, liquids, and other semiconductors, in the dark and under illumination, with emphasis on semiconductor/liquid junctions in aqueous and non-aqueous media. Problems currently facing semiconductor/liquid junctions and practical applications of these systems will be highlighted. The course will meet for four one-hour lectures per week and will be in a tutorial format with instruction predominantly from graduate students and postdoctoral fellows with expertise in the field. Given in alternate years; not offered 1996–97. Instructor: Lewis.

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 1996–97.

Ch 143. Basic FT NMR Spectroscopy. *9 units (3-2-4); second term. Prerequisite: Ch 41 abc.* In 1996–97, will cover NMR basics and applications, with emphasis on FT NMR and the principles of multipulse NMR techniques used in structural analysis, including determination of relaxation times, INEPT, DEPT, NOSEY, and COSY. A number of NMR techniques will be illustrated with the Chapman-Russell *FT NMR Problems* video-disc-based computer program, which features on-screen spectra at a variety of magnetic fields with, and without, decoupling, 2D spectra, and so on. The practical use of NMR will be further demonstrated by laboratory exercises using modern pulse FT NMR techniques with high-field spectrometers for structural analysis. Instructors: Roberts and staff.

Ch 144 ab. Advanced Organic Chemistry. *9 units (3-0-6); first, 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. Instructors: Dougherty, staff.

Ch 145. Bioorganic Chemistry of Proteins. *9 units (3-0-6); second term. Prerequisites: Ch 41 abc and Bi/Ch 110.* This course aims to define the information that can be derived on the structure and function of enzymes through the use of affinity labeling reagents, mechanism-based inactivators, and transition-state analog inhibitors. While the focus will be on selected classes of enzymes, the material covered is intended to give insight into general rules for the investigation of enzyme mechanisms and inhibitor design. Instructors: Imperiali, Dougherty.

Ch 146. Bioorganic Chemistry of Nucleic Acids. *9 units (3-0-6); third term. Prerequisite: Ch 41 ab.* Will examine the bioorganic chemistry of nucleic acids, including DNA and RNA structures, molecular recognition, and mechanistic analyses of covalent modification of nucleic acids. Topics such as synthetic methods for the construction of DNA and RNA; separation techniques; recognition of duplex DNA by peptide analogs, proteins, and oligonucleotide-directed triple helical formation; RNA structure and RNA as catalysts (ribozymes) will be discussed. Given in alternate years; not offered 1996–97. Instructor: Dervan.

Ch/ChE 147. Polymer Chemistry. *9 units (3-0-6); second term. Prerequisite: Ch 41 abc.* An introduction to the chemistry of polymers, including synthetic methods, mechanisms and kinetics of macromolecule formation, and characterization techniques. Instructor: Grubbs. Not offered 1996–97.

ChE/Ch 148. Polymer Physics. *9 units (3-0-6).* For course description, see Chemical Engineering.

Ch 153. Advanced Inorganic Chemistry. *9 units (2-0-7); second term. Prerequisites: Ch 112 and Ch 21 abc or concurrent registration.* Topics in modern inorganic chemistry. Electronic structure, spectroscopy, and photochemistry with emphasis on examples from the modern research literature. Instructor: Gray.

Ch 154. Organometallic Chemistry. *9 units (3-0-6); second term. Prerequisite: Ch 112 or equivalent.* A general discussion of the reaction mechanisms, and synthetic and catalytic uses of transition metal organometallic compounds. Instructors: Bercaw, Grubbs.

ChE/Ch 155. Chemistry of Catalysis. *9 units (3-0-6).* For course description, see Chemical Engineering.

Ch 163. Lectures-Seminars in Physical Chemistry. *6 units (2-0-4); third term. Prerequisites: None.* This course involves lectures by the instructor and seminars by the students, centered upon a particular theme in current physical chemistry and in its application to inorganic chemistry, electrochemistry, theoretical chemistry, chemical reaction rates, chemical dynamics, or some combination of these fields. Examples of topics are "Electron Transfer Reactions in Chemistry and Biology," "Chemical Reaction Rates and Dynamics," and "Electron Transfers and Related Processes at Interfaces." Open to all students. Students are also encouraged to propose a theme. In 1996–97, the second of the above topics has been selected. Instructor: Marcus.

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.

Bch/Bi/Ch 170. Principles of Three-Dimensional Protein Structure. *9 units (3-3-3).* For course description, see Biochemistry.

Env/Ch/Ge 175 ab. Environmental Organic Chemistry. *9 units (3-0-6).* For course description, see Environmental Engineering Science.

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. Bioinorganic Chemistry. *9 units (3-0-6); third term. Prerequisites: Ch 112 and Bi/Ch 110 or equivalent.* Current topics in bioinorganic chemistry will be discussed, including metal storage and regulation, metalloenzyme structure and reactions, biological electron transfer, metalloprotein design, and metal-nucleic acid interactions and reactions. Given in alternate years; not offered 1996–97. Instructor: Barton.

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 221. Electron Transfer Reactions in Chemistry and Biology. *3 units; third term. Prerequisite: Ch 21 abc.* Fundamentals of electron transfer reactions. Molecular (statistical) theory, dielectric continua, electronic matrix elements, Franck-Condon principle, relevant thermodynamics, reorganization energy, quantum effects, charge transfer spectra, solvent dynamics. Reactions in solution, at metal electrode-liquid, modified electrode-liquid, semiconductor electrode-liquid, and liquid-liquid interfaces. STM theory. Reactions in photosynthetic reaction centers and in other proteins. Given in alternate years; not offered 1996–97. Instructor: Marcus.

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);*

part a second term; part b first term. Prerequisite: Ch 125 abc or Ph 125 abc or equivalent. The general quantum mechanical theory of molecular collisions will be presented in detail. Quasi-classical, semi-classical, and other approximations. Applications to inelastic and reactive molecule-molecule and inelastic electron-molecule collisions. Not offered 1996–97. Instructor: Kuppermann.

Ch 228. The Dynamics of the Chemical Bond. *9 units (3-0-6); third term. Prerequisite: Ch 21 abc.* Fundamentals of time-dependent phenomena will be discussed with particular focus on the primary processes important to molecular reaction dynamics. Topics such as reaction dynamics, nonradiative decay, coherence, energy redistribution, and wave packet dynamics will be covered. Instructor: Zewail.

Ch/Bi 231. Advanced Topics in Biochemistry. *6 units (2-0-4); third term.* Transcriptional Regulation in Eukaryotes. Topics: The subunit structure of eukaryotic RNA polymerases and their role in transcriptional reaction; the composition of eukaryotic promoters, including regulatory units; general and specific transcription factors; developmental regulatory circuits and factors; structural motifs involved in DNA binding and transcriptional initiation and control. Instructor: Parker.

Ch 242 abc. Chemical Synthesis. *9 units (3-0-6); third term. Prerequisite: Ch 41 abc.* An integrated approach to synthetic problem solving featuring an extensive review of modern synthetic reactions with concurrent development of strategies for synthesis design. Part a will focus on the application of modern methods of stereocontrol in the construction of stereochemically complex acyclic systems. Part b will focus on strategies and reactions for the synthesis of cyclic systems. Part c is an intensive development of the tools of mechanistic problem solving in organic chemistry and their application to problems in chemical synthesis. Parts b and c not offered 1996–97. 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 1996–97.

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 1996–97.

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.

CE 90 abc. Structural Analysis and Design. *9 units (3-0-6); first, second, third terms. Prerequisite: AM 35 abc.* Structural loads; influence lines for statically determinate beams and trusses; deflection of beams; moment area and conjugate beam theorems; approximate methods of analysis of indeterminate structures; slope deflection and moment distribution techniques. Generalized stiffness and flexibility analyses of indeterminate structures. Design of selected structures in timber, steel, and reinforced concrete providing an introduction to working stress, load and resistance factor, and ultimate strength approaches. In each of the second and third terms a design project will be undertaken involving consideration of initial conception, cost-benefit, and optimization aspects of a constructed facility. Instructor: Staff.

CE 95. Introduction to Soil Mechanics. *9 units (2-3-4); second term. Prerequisite: AM 35 ab.* A general introduction to the physical and engineering properties of soil, including origin, classification and identification methods, permeability, seepage, consolidation, settlement, slope stability, and lateral pressures and bearing capacity of footings. Standard laboratory soil tests will be performed. Instructor: Scott.

ME/CE 96. Mechanical Engineering Laboratory. *6 or 9 units as arranged with instructor.* For course description, see Mechanical Engineering.

CE/ME 97. 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, first-year graduate students who have not had an equivalent course can take it under CE 100. Not offered 1996–97.

CE 100. Special Topics in Civil Engineering. *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.

CE/ME 101 abc. Fluid Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisites: ME 19 abc or equivalent; AMa 95 abc or AM 114 abc (may be taken concurrently).* First quarter: kinematics of flow fields; general equations of fluid motion; control volume analysis; vorticity transport; two- and three-dimensional potential flow. Second quarter: creeping flows; viscous flow; laminar boundary layer theory; stability and transition to turbulence; introduction to turbulence; engineering prediction of turbulent shear flows. Third quarter: one-dimensional gas dynamics; shock waves; expansion fans; acoustic waves; fluid amplitude waves and the method of characteristics; linear and nonlinear water waves; waves in stratified flows. Instructor: Brennen.

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

CE/Ae/AM 108 abc. Computational Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisite: instructor's permission.* Numerical analysis by the finite element method covering fundamental concepts and computer implementation. Solution of systems of linear equations and eigenvalue problems. Solution of the partial differential equations of heat transfer, solid and structural mechanics, and fluid mechanics. Transient and nonlinear problems. Instructor: Staff.

CE 110. Analysis and Design of Hydraulic Projects. *6 or more units as arranged; any term. Prerequisite: ME 19 abc.* 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.

CE 113 ab. Coastal Engineering. *9 units (3-0-6); first, second terms. Prerequisites: ME 19 abc and CE 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 1996–97.

CE 115 ab. Soil Mechanics. *9 units (3-0-6); second term. 9 units (2-3-4); third term. Prerequisite: instructor's permission.* 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. Not offered 1996–97.

CE 160 abc. Structural and Earthquake Engineering. *9 units (3-0-6); first, second, third terms. Prerequisite: CE 90 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. Not offered 1996–97.

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. Instructor: Staff.

CE/Ge 181. Engineering Seismology. *9 units (3-0-6); second 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. Instructor: Heaton.

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 203. Advanced Work in Hydraulic Engineering. *Units to be based upon work done; any term.* Special course to meet the needs of advanced graduate students.

ES/CE 204 abc. Hydrodynamics of Free Surface Flows. *9 units (3-0-6).* For course description, see Engineering Science.

CE 210 ab. Hydrodynamics of Sediment Transport. *9 units (3-0-6); second, third terms. Prerequisites: AMa 95 abc, Env 112 abc, and CE 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. Instructor: Staff.

CE 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.

CE 212. 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.

CE 213. Advanced Coastal Engineering. *9 units (3-0-6); third term. Prerequisites: CE 101 abc and CE 113 ab.* Selected topics in coastal engineering such as harbor resonance, mooring and berthing of ships, and structural forces due to waves, tsunamis, and other impulsive wave systems. Not offered 1996–97.

CE 300. Research in Civil Engineering. *Hours and units by arrangement.* Research in the field of civil engineering. By arrangements with members of the staff, properly qualified graduate students are directed in research.

For courses in Environmental Engineering Science, see that section.

COMPUTATION AND NEURAL SYSTEMS

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CNS 100. Introduction to Computation and Neural Systems. *3 units (3-0-0); second term.* This course is designed to introduce first-year CNS students to the wide variety of research being undertaken by CNS faculty. Topics from all the CNS research labs are discussed and span the range from biology to engineering. Instructors: CNS faculty.

CNS/EE 124. Pattern Recognition. *9 units (3-0-6); third term. Prerequisite: Ma 2 or equivalent.* An introduction to pattern recognition from a fundamental mathematical and statistical viewpoint with an emphasis on classic results in the field from the 1950s to the present.

Methods and techniques discussed will include optimal Bayesian discrimination, discriminant functions, basic principles of estimation, linear discriminants (including Fisher's method and the perceptron), parametric models such as multivariate Gaussian classifiers, mixture and kernel density methods, nearest neighbor classifiers, feedforward neural network models, decision tree methods, as well as general techniques for unsupervised learning (clustering), dimensionality reduction, and performance estimation such as cross-validation. Instructors: To be announced.

EE/CNS 148. Selected Topics of Computational Vision. *9 units (3-0-6).* For course description, see Electrical Engineering.

Bi/CNS 150. Neurobiology. *10 units (4-0-6).* For course description, see Biology.

CS/CNS/EE 156 ab. Learning Systems. *9 units (3-0-6).* For course description, see Computer Science.

Bi/CNS 161. Cellular Neurobiology Laboratory. *9 units (0-6-3).* For course description, see Biology.

Bi/CNS 162. Central Nervous System Laboratory. *10 units (0-8-2).* For course description, see Biology.

CNS/Bi 172. Clinical Neuropsychology. *6 units (3-0-3); second term. Prerequisite: Bi 150 or instructor's consent.* Lecture course discussing the relationship between cerebral cortex and behavior, in particular, with respect to the clinical literature. Cerebral functions are considered in light of acquired behavioral deficits such as aphasia, apraxia, agnosia, callosal syndrome (split-brain), hemineglect, dementia, amnesia, and anosognosia. Instructor: Bogen.

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

CNS/Ph 175. Artificial Life. *9 units (3-0-6); second term. Prerequisites: Ph 12 or equivalent; programming skills.* Introduction to the study of simple living systems using the paradigm of self-replicating code evolving in a noisy environment replete with information, implemented on a computer. Applications to the evolution of complexity, adaptive computation, self-organized criticality, thermodynamical and statistical theories of evolution, population biology, and the "directed" mutation hypothesis. Instructor: Adami.

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 precandidacy 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 physics, circuit, and system techniques for designing large-scale CMOS analog systems. Devices covered include the MOS transistor above and below threshold, the floating gate MOS transistor (including Fowler-Nordheim tunneling and hot electron injection), and silicon phototransducers (photodiodes and phototransistors). Static circuits studied include the current mirror, the differential pair, and the operational transconductance amplifier. Time-varying circuits studied include linear and nonlinear filters of first and second order, and monostable and astable relaxation oscillators. System examples from feedback control systems, vision, and audition. In-depth laboratory work on elementary circuits and subsystems is an integral part of the course. Instructor: CNS faculty.

CNS/CS/EE 184 abc. Analog Integrated Circuits Project Laboratory. *9 units (2-2-5); second, third, first terms. Prerequisite: CNS 182 abc; may be taken concurrently.* Analog integrated circuits design class. Course material covers the methodology, tools, and techniques of analog integrated circuit design. Each student will define, design, verify, and submit for fabrication analog or mixed analog/digital CMOS or BiCMOS integrated circuits. A mini-circuit shall be designed and submitted for fabrication the second quarter (184 a); testing of the mini-circuit and submission of a larger project shall be completed by the end of the third quarter (184 b). Testing and characterization of the larger project shall be done in the first quarter of the following year (184 c). A two-term version of the course can be made available by arrangement with the instructor. Graded on a pass/fail basis. Instructor: CNS faculty.

CNS/Bi/Ph 185. Collective Computation. *9 units (3-1-5); 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, combinatorial problems, sequences; systems that learn; self-organizing maps and development; oscillations; spike-based computing. Course work includes some hardware laboratory and work in the CNS simulation facility. Instructors: Hopfield, Koch.

CNS/Bi/EE 186. Vision: From Computational Theory to Neuronal Mechanisms. *12 units (4-4-4); second term.* Lecture, laboratory, and discussion course aimed at understanding visual information processing, in both machines and the mammalian visual system. The course will emphasize an interdisciplinary approach aimed at understanding vision at several levels: computational theory, algorithms, psychophysics, and hardware (i.e., neuroanatomy and neurophysiology of the mammalian visual system, analog VLSI circuits). The course will focus on early vision processes, in particular motion analysis, binocular stereo, brightness, color and texture analysis, and boundary detection. Students will be required to hand in approximately three homeworks as well as complete one project (mathematical analysis, computer modeling, psychophysics, or hardware implementation). Instructors: Koch, Perona, Andersen.

CNS/CS/EE 188 ab. Computation Theory and Neural Systems. *9 units (3-0-6); second, third terms. Prerequisite: Ma 2.* Introduction to computational models and methods that are inspired by, and related to, neural systems as well as relevant mathematical techniques developed in computer science and engineering. Specific topics include: computing with circuits, feedback and computation, associative memories, analog computing, fault tolerance, learning and elements of parallel and distributed computing. Instructor: Bruck.

CNS/Bi 221. Computational Neuroscience. *9 units (4-0-5); third term. Prerequisites: Bi/CNS 150, CNS 185; or instructor's consent.* Lecture and discussion aimed at understanding computational aspects of information processing within the nervous system. The course will emphasize single neurons and how their biophysical properties relate to neuronal coding, i.e., how is information actually represented in the brain at the level of action potentials. Topics include biophysics of single neurons, signal detection and signal reconstruction, information theory, population coding and temporal coding in sensory systems of invertebrates and in primate cortex. Students are required to hand in three homeworks, discuss one set of papers in class, and participate in the debates. Instructors: Koch, Gabbiani, Bower.

CNS/Bi 246. Multicellular Recording. *9 units (2-6-1); first term. Prerequisite: Bi 150 or equivalent.* Laboratory course in techniques and applications of multi-neuron recording in the central nervous system. The course will cover (1) methods for collecting single-cell data, (2) the analysis of multi-neuron data including spike sorting, and (3) scientific issues addressed by multicellular recording, including population coding and functional connectivity. Students are required to attend a two-hour laboratory lecture/discussion once a week, and complete one project. Multidisciplinary approaches are encouraged which combine engineering principles for data collection and analysis with experimental and theoretical approaches to understanding the nervous system. To this end, students will be encouraged to work in pairs, with one student coming from an engineering laboratory, and one from a neurobiology laboratory. Instructor: Andersen.

CNS/EE 248. Sensory Information Processing Laboratory. *9 units (1-2-6); third term. Prerequisite: any of CNS/EE 124, CNS 186, EE/CNS 148 or equivalent.* Laboratory course in real-time applications of sensory processing. Students will be guided through the construction of working systems performing recognition, tracking, and navigation using vision, audition, and other sensors. Examples: vehicle navigation, face recognition, signature verification, fingerprint identification, and voice classification. At the beginning of the term a number of lectures will introduce the materials and methods involved in the experiments. Instructors: Psaltis, Perona.

CS/CNS 257 abc. Simulation. *9 units (3-3-3) first; (3-5-1) second; (3-5-1) third term.* For course description, see Computer Science.

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

CNS 286. Special Topics in Computation and Neural Systems. *Units to be arranged; first, second, and third terms. Students may register with permission of the responsible faculty member.*

COMPUTER SCIENCE

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CS 1. Introduction to Sequential Programming. *6 units (1-4-1); first term. No prerequisites.* Optional course for students who have not seen programming before or who wish to learn C. Basic information on syntax and the central programming ideas: data types, simple linked data structures, assignment, conditional and sequential execution, iteration, and recursion. Involves homeworks and laboratory work to introduce the basic ideas. Instructor: Taylor.

CS 2. Problem Solving and Computing Lab. *9 units (3-4-2); second term. Prerequisite: CS 1 or equivalent.* Methodical programming and problem solving. Weekly laboratory exercises, programming in C, and homeworks in problem solving and program design. Data structures: stacks, queues, heaps, graphs, and trees. Complexity, invariants, and metrics. Simple algorithms: sorting, searching, and hashing.

Students who have not encountered programming before should take CS 1 in the first term. Instructor: Taylor.

CS 3. Introduction to Concurrent Programming. *9 units (3-4-2); third term. Prerequisite: CS 2.* Introduction to concurrent programming concepts and basic techniques, hands-on use of Caltech multicomputers. Builds on programming methods used in CS 2 but focuses on concurrent programming. Nontrivial programming problems from fluid mechanics and game playing. Instructor: Taylor.

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.

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

CS/EE 11. Digital Electronics Laboratory. *6 units (0-3-3); second term. Prerequisites: CS/EE 4. 6 units credit allowed toward freshman labo-*

ratory 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 20 abc. Computation, Computers, and Programs. *9 units (3-3-3); first, second, third terms. Prerequisite: CS 2 or equivalent.* An introduction to computation and computing science. The representation and implementation of computations as programs and machines. Relationships between physical computing machines and abstract processes. Representation of data. Abstraction and composition. Algorithms, complexity, and efficiency. Limitations of computations. Correctness concerns. Nondeterminism. Reversible computations. Concurrent computing. Design of computers and programs. Laboratory work using UNIX workstation computers to explore computations and programs. Instructors: Staff.

EE/CS 51. Principles of Microprocessor Systems. *9 units (3-0-6).* For course description, see Electrical Engineering.

EE/CS 52. Microprocessor Systems Laboratory. *12 units (1-11-0).* For course description, see Electrical Engineering.

EE/CS 53. Microprocessor Project Laboratory. *9 units (0-9-0) or 12 units (0-12-0) as arranged with the instructor.* For course description, see Electrical Engineering.

EE/CS 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 Electrical Engineering.

CS 80 abc. Undergraduate Research in Computer Science. *Units in accordance with work accomplished. Consent of both research adviser and course supervisor required before registering.* 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 81 abc. Undergraduate Laboratory in Computer Science. *Units in accordance with work accomplished. Consent of both research adviser and course supervisor required before registering.* Supervised experimental 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.

Ma/CS 117 abc. Computability Theory. *9 units (3-0-6).* For course description, see Mathematics.

CS/EE/Ma 129 abc. Information and Complexity. *9 units (3-0-6), first and second terms; (1-4-4) third term. Prerequisite: Basic knowledge of* *probability and discrete mathematics.* A basic course in information theory and computational complexity with emphasis on fundamental concepts and tools that equip the student for research and provide a foundation for pattern recognition and learning theory. *First term:* What is information and what is computation; entropy, source coding, Turing machines, uncomputability. *Second term:* Topics in information and complexity; Kolmogorov complexity, channel coding, circuit complexity, NP completeness. *Third term:* Theoretical and experimental projects on current research topics. Not offered 1996–97. Instructor: Abu-Mostafa.

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

CS 138 abc. Computer Algorithms. *9 units (3-0-6); first, second, third terms. Prerequisite: CS 2 or equivalent.* Design, analysis, and proofs of correctness of computer programs. Program specification, methods of proving program correctness, and computational complexity. NP-completeness. Models of parallel, concurrent, and distributed computation. Searching, sorting, string matching. Graph, geometric, algebraic, and matrix algorithms. Linear programming. Heuristic search. Discrete-event simulation. Algorithms for distributed systems. Part of the third term is spent studying applications in one branch of science or engineering. Given in alternate years; not offered 1996–97. Instructor: Chandy.

CS 139 abc. Concurrency in Computation. *9 units (3-0-6); first, second, third terms. Prerequisite: CS 20 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. Given in alternate years. Instructor: Martin.

CS 140 abc. Programming Laboratory. *9 units (3-4-2); first, second, third terms.* An introduction to object-oriented, functional, and logic programming, with laboratory exercises and a full-scale project. Each of these programming paradigms affords its own benefits in particular application domains. C++ and Cosmic C will be used to explore object-oriented and communicating-process programming, Lisp and Scheme to explore functional programming, and Prolog and Strand to explore logic programming. The second term of the course gives students the opportunity to develop, under close guidance, a programming project whose complexity is at the scale of a compiler, using one of the paradigms presented in the first term. The emphasis in the project is not only in achieving the task, but presenting a clear problem specification, a modular design, and a maintainable implementation. Instructors: Staff.

CS 141 abc. Distributed Computation Laboratory. *9 units (3-3-3); first, second, third terms. Prerequisites: CS 20 or equivalent.* This laboratory course deals with applications of systematic design methods and theories for reasoning about the correctness and performance of concurrent programs. The theories include temporal logics, computational complexity analysis, probabilistic models, statistics, and discrete-event simulation. The first two terms require program development carried out individually or in groups of two, and the third term has a larger project carried out by a team. Concurrent programs are developed using object-oriented languages and methods for single address space and multiple address space systems. User-interface designs are considered within the narrow scope of designing reliable concurrent systems that include human interaction. Aspects of communication protocols for static and mobile systems, distributed operating systems, and fault-tolerant systems are studied with a focus on systematic design to achieve reliability and performance. Students will select programming projects using tools such as (but not limited to) Java and the World Wide Web, Unix processes, pipes and sockets, TCP/IP, and multicast protocols, object request brokers such as CORBA, C++ and its extensions such as CC++, and discrete-event simulation packages. Given in alternate years. Instructor: Chandy.

CS 142 abc. Decision Support Systems. *9 units (3-3-3); first, second, third terms. Prerequisite: Programming experience using PASCAL. Permission of the instructor required.* The building of conceptual models as an expression of the patterns perceived in the analysis of data. Database systems, discrete simulation, decision support systems, and expert systems. Small group projects and extensive use of the computer. Not offered 1996–97. Instructor: Thompson.

CS/CNS/EE 156 ab. Learning Systems. *9 units (3-0-6); first, second terms. Prerequisites: Ma 2 and CS 2, or equivalent.* Introduction to the theory, algorithms, and applications of automated learning. How much information is needed to learn a task, how much computation is involved, and how it can be accomplished. Special emphasis will be given to unifying the different approaches to the subject coming from statistics, function approximation, optimization, pattern recognition, and neural networks. Offered in 1996–97. Instructor: Abu-Mostafa.

CS/CNS 174 abc. Computer Graphics Laboratory. *9 units (3-3-3); first, second, third terms. Prerequisites: Ma 2 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: Schröder.

CS 180. Master's 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.* Digital integrated system design, with projects involving the design, verification, and testing of high-complexity CMOS microcircuits. First-term lecture and homework topics emphasize disciplined design, and include CMOS logic, layout, and timing; computer-aided design and analysis tools; and electrical and performance considerations. Each student is required in the first term to complete individually the design, layout, and verification of a moderately complex integrated circuit. Advanced topics second and third terms include self-timed design, computer architecture, and other topics that vary year by year. Projects are large-scale designs done by teams. Instructor: Martin.

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

CNS/CS/EE 184 abc. Analog Integrated Circuits Project Laboratory. *9 units (2-2-5).* For course description, see Computation and Neural Systems.

CS 185 abc. Asynchronous VLSI Design Laboratory. *9 units (3-3-3); first, second, third terms. Prerequisite: CS 139.* The design of digital integrated circuits whose correct operation is independent of delays in wires and gates. (Such circuits do not use clocks.) Emphasis is placed on high-level synthesis, design by program transformations, and correctness by construction. The first term introduces delay-insensitive design techniques, description of circuits as concurrent programs, circuit compilation, standard-cell layout and other computer-aided design tools, and electrical optimizations. The second term is reserved for advanced topics, and for the presentation and review of mid-size projects, which will be fabricated in CMOS or GaAs technologies, and tested. Given in alternate years; not offered 1996–97. Instructor: Martin.

CNS/CS/EE 188 ab. Computation Theory and Neural Systems. *9 units (3-0-6).* For course description, see Computation and Neural Systems.

CS 237 abc. Compiler Design Laboratory. *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. Not offered 1996–97.

CS/CNS 257 abc. Simulation. *9 units (3-3-3) first; (3-5-1) second; (3-5-1) third term. Permission of the instructor required.* Mathematical and computational modeling methods. First term: the mathematical foundations of simulation, such as Eulerian equations of motion, tensor analysis, applied 3-D geometry, and the mathematics of continuum dynamics. Second term: the numerical methods of simulation, such as the numerical solution of differential equations, the finite element method, and Monte Carlo techniques. Third term: case studies applying these techniques to selected three-dimensional problems in the physical sciences. Term projects for the third term will involve implementing a case study or other computational application of the methods. Some experience with vector and raster graphics would be helpful. Instructor: Barr.

CS 274 abc. Topics in Computer Graphics. *9 units (3-3-3); first, second, third terms. Prerequisite: CS 174, or permission of instructor.* Each term will focus on some topic in computer graphics, such as geometric modeling, rendering, animation, human-computer interaction, or mathematical foundations. The topics will vary from year to year. May be repeated for credit with permission of instructor. Not offered every year.

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. Computer Science Seminar on Mathematics of Program Construction. *9 units (3-0-6); first, second, third terms. Prerequisite: CS 20 or permission of instructor.* This course addresses the mathematical basis of programming. First term: predicate calculus, lattice theory, sequential programming. Second term: relational calculus, programs as trace-sets, temporal properties. Third term: models of concurrency and concurrent programming. Not offered 1996–97. Instructors: Staff.

CS 286 abc. Seminar in Computer Science. *3, 6, or 9 units, at the instructor's discretion. Permission of the instructor required.*

CDS 101. Applied Operator Theory. *9 units (3-0-6); first term.* Invariant subspaces, Jordan form, Cayley-Hamilton theorem, matrix exponential, singular value decomposition, L_p spaces, Banach and Hilbert spaces, operators, duals, adjoints, induced norms, spectral theory. Instructor: Staff.

CDS 102. Geometry of Nonlinear Systems. *9 units (3-0-6); second term. Prerequisite: CDS 101.* Basic differential geometry, oriented toward applications in control and dynamical systems. Topics include: Smooth manifolds and mappings, tangent and normal bundles, transversality. Vector fields and flows. Distributions and Frobenius's theorem. Matrix Lie groups and Lie algebras. Exterior differential forms, Stokes's theorem. Instructor: Staff.

CDS 110 ab. Introduction to Control of Physical Systems. *9 units (3-0-6); first, second terms. Prerequisites: AMa 95 abc.* Application of feedback analysis and design to physical systems, including classical control theory in the frequency and time domains. Stability; performance; methods based on Bode, Nyquist, and root-locus diagrams. Representation in state space. Analog and discrete dynamical systems. Introduction to multivariable control. Instructor: Staff.

CDS 111. Applications of Control Technology. *9 units (3-3-3); third term. Prerequisite: CDS 110 or equivalent.* Application of modern control design techniques to physical systems. The goal of this course is to teach students how to design and implement feedback controllers on physical systems, and to allow students to evaluate different control design methodologies on experimental hardware. Instructor: Murray.

CDS 112. Introduction to Modern Control. *9 units (3-0-6); first term. Prerequisite: AM 114 or equivalent; CDS 110 and 111 desirable.* Self-contained introduction to control systems with emphasis on the role of control in overall system analysis and design. Examples drawn from throughout engineering and science. Open versus closed loop control. State-space methods, time and frequency domain, stability and stabilization, realization theory. Time-varying and nonlinear models. Uncertainty and robustness. Optimization, optimal control, variational methods, and dynamic programming. System identification from data. Instructor: Doyle.

CDS 113 ab. Robust Control. *12 units (3-3-6); second, third terms. Prerequisites: CDS 112, CDS 101.* Linear systems, realization theory, time and frequency response, norms and performance, stochastic noise models, robust stability and performance, linear fractional transformations, structured uncertainty, optimal control, model reduction, μ analysis and synthesis, real parametric uncertainty, Kharitonov's theorem, uncertainty modeling, fuzzy set theory and control. Instructor: Doyle.

CDS 121. Nonlinear Systems and Adaptive Control. *9 units (3-0-6); third term. Prerequisites: CDS 102, CDS 113 a.* Methods for analysis and design of nonlinear control systems emphasizing Lyapunov theory. Second-order systems, describing functions, direct and indirect method of Lyapunov, I/O stability. Model reference adaptive control, self-tuning regulators, sufficient excitation, parameter convergence, stability and robustness issues. Instructor: Staff.

CDS 122. Geometric Nonlinear Control Theory. *9 units (3-0-6); third term. Prerequisites: CDS 102, CDS 113 a.* Study of the differential geometric approach to nonlinear control theory. Controllability, observability, feedback linearization, invariant distributions, disturbance decoupling, Lagrangian and Hamiltonian control systems, exterior differential systems. Instructor: Staff.

CDS 131. Computational Methods in CDS. *9 units (3-3-3); first term.* Applications of symbolic manipulation, linear and nonlinear programming, graphics. Use of software: MATHEMATICA, MAPLE, MINOS, GAMS. Instructor: Staff.

CDS 132. System Identification and Estimation. *9 units (3-0-6); second term. Prerequisites: CDS 101, CDS 113 a (may be taken concurrently).* Review of probability, statistics, and stochastic processes. Optimal predictors for input-output and state-space models. Nonparametric, prediction-error, and correlation methods. Asymptotic analysis. Computational aspects. Recursive identification. Experiment design. Model validation and closed-loop identification. Instructor: Staff.

CDS 140. Introduction to Dynamics. *9 units (3-0-6); first term. Prerequisite: AMa 95 (or AM 114), CDS 101 (may be taken concurrently).* Basic topics in dynamical systems in Euclidean space, including equilibria, stability, Liapunov functions, periodic solutions, Poincaré-Bendixon theory, Poincaré maps. Attractors and structural stability. The Euler-Lagrange equations, energy as a Liapunov function, conservation laws. Introduction to simple bifurcations; eigenvalue crossing conditions. Discussion of bifurcations in applications. Instructor: Marsden.

CDS 142. Hamiltonian Dynamics. *9 units (3-0-6); third term. Prerequisites: CDS 103, CDS 141.* Hamiltonian stability and bifurcation theory, Poincaré-Birkhoff normal forms, KAM theory, Nekhoroshev theory, Arnold diffusion. Instructor: Wiggins.

CDS 143 ab. Nonlinear Dynamical Systems and Chaos. *9 units (3-0-6); second, third terms. Prerequisite: CDS 140, CDS 102 (may be taken concurrently).* Normal form theory, center manifold theory, codimension two and larger bifurcation theory, normally hyperbolic invariant manifolds, nonlinear resonance, the KAM theorem, method of averaging, symbolic dynamics, the Smale horseshoe, Melnikov's method, homoclinic and heteroclinic orbits, chaos, Liapunov exponents, strange attractors, global bifurcations. Instructor: Wiggins.

CDS 241 ab. Geometric Mechanics. *9 units (3-0-6); first, second terms. Prerequisites: CDS 102, CDS 140.* The geometry and dynamics of Lagrangian and Hamiltonian systems, including symplectic and Poisson manifolds, variational principles, Lie groups, momentum maps, rigid-body dynamics, Euler-Poincaré equations, stability, and an introduction to reduction theory. More advanced topics will include reduction theory, fluid dynamics, the energy momentum method, geometric phases, bifurcation theory for mechanical systems, and nonholonomic systems. Offered alternate years; not offered 1996–97.

CDS 270. Advanced Topics in Systems and Control. *Prerequisite: CDS 102.* Topics dependent on class interests and instructor. Can be repeated for credit.

CDS 280. Advanced Topics in Dynamical Systems Theory. *Prerequisite: consent of instructor.* Topics will vary according to student and instructor interest. Examples include chaotic transport theory, invariant manifold techniques, multidimensional geometric perturbation theory, the dynamics of coupled oscillators, rigid-body dynamics, numerical methods in dynamical systems theory. Can be repeated for credit.

CDS 300 abc. Research in Control and Dynamical Systems. *Hours and units by arrangement.* Research in the field of control and dynamical systems. By arrangement with members of the staff, properly qualified graduate students are directed in research. Instructors: Staff.

ECONOMICS

Ec 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. Instructors: Page, Plott.

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 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.

Ec 101. Selected Topics in Economics. *9 units (3-0-6). Offered by announcement.* Instructors: Staff, visiting lecturers.

Ec 105. Industrial Organization. *9 units (3-0-6); first term. Prerequisite: Ec 11 or equivalent.* A study of how technology affects issues of market structure and how market structure affects observable economic outcomes, such as: prices, profits, advertising, and research and development expenditures. Emphasis will be on how the analytic tools developed in the course can be used to examine particular industries in detail. Instructor: Wilkie.

Ec 116. Contemporary Socioeconomic Problems. *9 units (3-0-6); third term. Prerequisites: Ec 11 and PS 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: Dubin.

Ec 118. Environmental Economics. *9 units (3-0-6); first term. Prerequisite: Ec 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. Instructor: Ledyard.

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. Instructors: Staff.

Ec 121 ab. Theory of Value. *9 units (3-0-6); second, third terms. Prerequisites: Ec 11 and Ma 2 (may be taken concurrently).* 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. Instructor: Border.

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. Instructor: Dubin.

Ec 124 abc. Mathematical Methods of Economics. *9 units (3-0-6); third term. Prerequisites: Ma 107 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. Not offered 1996–97. Instructor: Border.

Ec 126. Computational Economics and Complex Systems. *9 units (3-0-6); third term. Prerequisites: Ec 11, ability to write computer programs in C or Pascal.* An introduction to computational economics and complex systems. This course encourages students to explore problems from economics by constructing computational models. The course will provide an introduction to the field of complex systems and to computational techniques relevant to the social sciences. These techniques will include, but not be limited to: genetic algorithms, simulated annealing, spinglasses. A substantial portion of the student's time will be devoted to the construction and critical analysis of computer models, such as Conway's Game of Life. Particular emphasis will be placed on the interplay between the micro-level incentives of individual agents and the resulting macro-level behavior of the system. Not offered 1996–97. Instructor: Page.

Ec/SS 128. Economic and Financial Development in the 19th and 20th Centuries. *9 units (3-0-6); second term. Prerequisite: Ec 11 or SS 13.* Economic analysis of financial and industrial development of various regions of the world from 1800 to the present. Topics may include agrarian reform and the end of serfdom; capital markets and financial institutions and their role in industrialization; bank panics, market crashes, and hyperinflation; and the rise and fall of communism in Eastern Europe. Instructor: Fohlin.

Ec/SS 129. Economic History of the United States. *9 units (3-0-6); second term. Prerequisite: Ec 11 or SS 13.* An examination of certain analytical and quantitative tools and their application to American economic development. Instructor: Davis.

Ec/SS 130. Economic History of Europe from the Middle Ages to the Industrial Revolution. *9 units (3-0-6); second term. Prerequisite: Ec 11 or SS 13.* Employs the theoretical and quantitative techniques of economics to help explore and explain the development of the European cultural area between 1000 and 1850. Topics include the rise of commerce, the demographic transition, the industrial revolution, and changes in property rights and capital markets. Not offered 1996–97. Instructor: Hoffman.

Ec 131. Labor Economics. *9 units (3-0-6); first term. Prerequisite: Ec 11 or equivalent.* Modern theory of labor markets. Uses empirical evidence to supplement theoretical results. Instructors: Staff.

PS/Ec 134. The Political Economy of Urban Areas. *9 units (3-0-6).* For course description, see Political Science.

Ec 135. Economics of Uncertainty and Information. *9 units (3-0-6); first term. Prerequisites: Ec 11, Ma 2.* An analysis of the effects of uncertainty and information 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, and the value of information. Instructor: Palfrey.

Ec 138. Introduction to Welfare Economics. *9 units (3-0-6). Prerequisite: Ec 11.* Economic efficiency of various market arrangements; modern developments in the theories of decentralization and informational efficiency. Not offered 1996–97. Instructors: Staff.

Ec 145. Public Finance. *9 units (3-0-6). Prerequisite: Ec 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. Not offered 1996–97. Instructor: Ledyard.

BEM/Ec 146. Organization Design. *9 units (3-0-6).* For course description, see Business Economics and Management.

Ec 155. Decision Theory. *9 units (3-0-6); third term. Prerequisite: Ma 2.* Course will discuss the formal analysis of individual decision making from normative and descriptive standpoints. Topics to be covered include choice under certainty, under risk (von Neumann and Morgenstern) and under certainty (Anscombe-Aumann and Savage), conditional preferences and probabilities, independence and de Finetti's theorem on exchangeability, dynamic decision making, non-expected utility models, non-additive probabilities, and multiple priors. Instructor: Ghirardato.

Ec/PS 160 abc. Laboratory Experiments in the Social Sciences. *9 units (3-3-3).* 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. Students are required to design and conduct experiments. Instructor: Plott.

Ec 161. Business Cycles. *9 units (3-0-6); third term. Prerequisite: Ec 11.* The role of dynamic decision making in economic fluctuations and growth. Topics include: labor supply decisions and unemployment, behavior of inventories, real investment behavior, productivity, and real capital markets. Not offered 1996–97. Instructors: Staff.

Ec 162. Monetary Theory. *9 units (3-0-6); first term. Prerequisite: Ec 11.* The role of money and the payments mechanism in the U.S. economy. Topics include: behavior of the Federal Reserve and the commercial banking system, determination of interest rates and the term structure of interest rates, empirical analysis of the demand and supply of money, and financial markets. Instructor: Fohlin.

PS/Ec 172. Noncooperative Games in Social Sciences. *9 units (3-0-6).* For course description, see Political Science.

PS/Ec 173. Cooperation and Social Behavior. *9 units (3-0-6).* For course description, see Political Science.

ELECTRICAL ENGINEERING

EE 1. Introduction to Electrical Engineering. *9 units (3-3-3); third term.* Major themes in the EE core courses are introduced through demonstration lectures and home-laboratory experiments. This course is suitable for both EE's and non-EE's, being a head-start for the former and a brief encounter for the latter. Topics: elementary electrical circuits in both time and frequency domains; the electromagnetic spectrum; generating and radiating electromagnetic waves; signals, noise, and information, and how they interact; power conditioning and transmission; characteristics of electronic devices; elementary opto-electronic devices and systems; measurement techniques. This course complements the digital courses CS/EE 4 and CS/EE 11, stressing the analog side of EE. Application of electronic fundamentals to systems such as cellular radio and satellite communications will be treated at an introductory level. The home-laboratory provides hands-on experience. Graded pass/fail. Instructor: Bridges.

CS/EE 4. Introduction to Digital Electronics. *6 units (2-0-4).* For course description, see Computer Science.

CS/EE 11. Digital Electronics Laboratory. *6 units (0-3-3).* For course description, see Computer Science.

EE 20 ab. Analog Electronics. *12 units (3-2-7); first, second terms. Prerequisites: Ma 1 ab, Ph 1 abc.* Fundamentals of electronics through the progressive construction of a radio transceiver—batteries, components, filters, op amps, transistors, amplifiers, oscillators, and mixers. Circuit analysis and theorems. Transceiver measurements and transmission lines. Instructor: Rutledge.

EE 32 ab. Introduction to Linear Systems. *9 units (3-0-6); first, second terms. Prerequisites: Ma 1, Ma 2, and EE 14.* 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: McEliece.

EE 40. Fundamentals of Energy Processing Systems. *9 units (3-0-6); third term. Prerequisites: Ma 2, Ph 2, EE 14 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.

EE 50. Advanced Digital Design. *9 units (3-0-6); third term. Prerequisite: CS/EE 11 or permission of instructor.* Advanced digital design as it applies to the design of ASICs, in particular gate arrays and standard cells. The course emphasizes the practical aspects of ASIC design such as timing, testing, and fault grading. Topics include: synchronous design, state machine design, design for testability, PALs, FPGAs, Standard Cells, timing considerations, fault vectors, and fault grading. Instructor: George.

EE/CS 51. Principles of Microprocessor Systems. *9 units (3-0-6); first term.* The principles and design of microprocessor-based computer systems. Covers both hardware and software aspects of microprocessor system design, including interfacing techniques. The homework emphasis is on software development, especially hardware interfacing, in assembly language. Instructor: George.

EE/CS 52. Microprocessor Systems Laboratory. *12 units (1-11-0); second term. Prerequisite: EE/CS 51 or equivalent.* The student will design, build, and program a specified microprocessor-based system. This structured laboratory is organized to familiarize the student with electronic circuit construction techniques, modern development facilities, and standard design techniques. Instructor: George.

EE/CS 53. Microprocessor Project Laboratory. *9 units (0-9-0) or 12 units (0-12-0) as arranged with the instructor; third term. Prerequisite: EE/CS 52 or equivalent.* A project laboratory to permit the student to select, design, and build a microprocessor-based system. Instructor: George.

EE/CS 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. The laboratory is for the experienced student who can work independently and who has taken or has had experience equivalent to EE/CS 53. Instructor: George.

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. Not offered on pass/fail basis; not offered 1996–97. Instructor: Potter.

EE 80 abc. Senior Thesis. *9 units; first, second, third terms. Prerequisite: instructor's permission, which should be obtained during the junior year to allow sufficient time for planning the research.* Individual research project, carried out under the supervision of a member of the electrical engineering faculty. Written report required. Open only to senior electrical engineering majors. Not offered on a pass/fail basis. Instructor: Potter.

EE 90. Analog Electronics Project Laboratory. *9 units (1-8-0); third term. Prerequisites: EE 14 abc.* A structured laboratory course which gives the student the opportunity to design and build a sequence of simple analog electronics projects. The goal is to gain familiarity with circuit design and construction, component selection, CAD support, and debugging techniques. Text: Literature references. Instructor: Megdal.

EE 91 ab. Experimental Projects in Electronic Circuits. *Units by arrangement; first, second terms. 6 units minimum each term. Prerequisites: EE 14 abc. Recommended: EE/CS 51 and 52, and EE 114 abc (may be taken concurrently). Open to seniors; others only with consent of instructor.* An opportunity to do advanced original projects in analog or digital electronics and electronic circuits. Selection of significant projects, the engineering approach, modern electronic techniques, demonstration and review of a finished product. DSP/microprocessor development support and analog/digital CAD facilities available. Text: Literature references. Instructor: Megdal.

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.* Projects may be done for joint credit with EE 91 if approved by both instructors. EE/Mu 107 projects may be continued into a second year. Instructor: Boyk.

EE 112. Digital Signal Processing Principles. *9 units (3-0-6); first term. Prerequisites: EE 32 ab or equivalent.* Course deals with deterministic signal processing topics. Classical filter approximations, IIR digital filters, optimal FIR filters, advanced structures for digital filter implementations, stability test procedures, fast transforms, fast convolutions, allpass filters, frequency transformations, lattice filters, state-space descriptions, freedom from limit cycles, structural passivity and low-sensitivity structures, roundoff noise minimization in digital filters, elements of array signal processing. Possible additional topics: complex-cepstrum and applications, magnitude-only reconstruction, and minimum-phase systems. 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) first term; (3-2-4) second 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 ab. Information Theory. *9 units (3-0-6); first, second terms. Prerequisite: Ma 2.* Shannon's mathematical theory of communication, 1948–present. Entropy, relative entropy, and mutual information for discrete and continuous random variables. Shannon's source and channel coding theorems. Mathematical models for information sources and communication channels, including memoryless, first-order Markov, ergodic, and Gaussian. Calculation of capacity-cost and rate-distortion functions. Kolmogorov complexity and universal source codes. Side information in source coding and communications. Network information theory, including multi-user data compression, multiple access channels, broadcast channels, and multi-terminal networks. Discussion of philosophical and practical implications of the theory. This course, when combined with EE/Ma 127 ab, EE 161, EE 166, and/or EE 167 should prepare the student for research in information theory, coding theory, wireless communications, and/or data compression. Instructor: Effros.

EE/Ma 127 ab. Error-Correcting Codes. *9 units (3-0-6); second, third terms. Prerequisite: Ma 2.* 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, Fire; convolutional codes; concatenated codes; and the associated encoding and decoding algorithms. Self-contained introduction to the theory of finite fields. Instructor: Staff.

EE 128. Multirate Systems, Filter Banks, and Wavelets. *9 units (3-0-6); second term. Prerequisites: EE 112 or equivalent.* Sampling rate alterations in discrete time systems, decimation, interpolation, fractional alteration of sampling rate, multistage implementations, efficient implementations using polyphase decompositions, Nyquist filtering, maximally decimated filter banks, theory of perfect reconstruction systems, efficient design and implementations based on paraunitary polyphase matrices and lossless lattices, unconventional sampling, wavelet transforms in the context of multirate and paraunitary filter banks, applications in signal compression, digital audio, and speech. Instructor: Vaidyanathan.

CS/EE/Ma 129 abc. Information and Complexity. *9 units (3-0-6) first and second terms; (1-4-4) third term.* 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.

Ay/EE 144. Imaging at Radio, Infrared, and Optical Wavelengths by Interferometric and Adaptive Techniques. *9 units (3-0-6).* For course description, see Astronomy.

EE/CNS 148. Selected Topics of Computational Vision. *9 units (3-0-6); third term. Prerequisites: Familiarity with basic calculus, linear algebra, and geometry. Some proficiency in computer programming.* The focus is on three-dimensional vision: motion analysis, shape recovery and recognition, vision-based navigation, attention. There will be 2–4 homework assignments, including computer simulations and a final project on a vision topic chosen by the student. Instructor: Perona.

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. Electromagnetic Engineering. *12 units (3-2-7); first term. Prerequisite: EE 14 ab.* Foundations of circuit theory. Transmission lines, electric fields, magnetic fields, and Maxwell's equations. Instructor: Bridges.

EE 152. Guided Wave Circuits. *12 units (3-2-7); second term. Prerequisite: EE 151 or equivalent.* Wave propagation in metal waveguides and dielectric waveguides; optical fibers, optical integrated circuits, and applications to optoelectronic systems. Selections from periodic propagating structures, and coupled mode devices. Offered every other year; not offered 1996–97. Instructor: Bridges.

EE 153. Microwave Circuits and Antennas. *12 units (3-2-7); third term.* High-speed circuits for wireless communications, radar, and broadcasting. Design, fabrication, and measurements of microstrip filters, directional couplers, low-noise amplifiers, oscillators, detectors, and mixers. Design, fabrication, and measurements of wire antennas and arrays. Offered every other year; not offered 1996–97. Instructor: Rutledge.

CS/CNS/EE 156 ab. Learning Systems. *9 units (3-0-6).* For course description, see Computer Science.

EE/Ge 157 abc. Introduction to the Physics of Remote Sensing. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 2 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. 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, and data. Instructor: Goldsmith.

EE 161. Wireless Communications. *9 units (3-0-6); second term. Prerequisite: EE 160.* This course will cover the fundamentals of wireless channels and channel models, wireless communication techniques, and wireless networks. Topics include statistical models for time-varying narrowband and wideband channels, fading models for indoor and outdoor systems, macro-and microcellular system design, channel access and spectrum sharing using TDMA, FDMA, and CDMA, time-varying channel capacity and spectral efficiency, modulation and coding for wireless channels, antenna arrays, diversity combining and multi-user detection, dynamic channel allocation, and wireless network architectures and protocols. Instructor: Goldsmith.

EE 162. Random Processes for Communication and Signal Processing. *9 units (3-0-6); first term. Prerequisite: Some familiarity with probability.* Introduction to single-parameter random processes: stationarity; correlation functions; power spectral density; Gaussian processes. Response of linear systems to random processes. Instructor: Simon.

EE 163 ab. Communication Theory. *9 units (3-0-6); second, third terms. Prerequisite: EE 32 ab; EE 162 or equivalent.* Least mean square error linear filtering and prediction. 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 digital baseband and carrier communication systems. Instructor: Simon.

EE 164. Adaptive Filters 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 subbands, Wiener 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 cancellation, interference minimization, and antenna arrays. Instructors: Staff.

EE 165. Introduction to Spacecraft Telecommunications Engineering. *9 units (3-0-6); third term. Prerequisites: EE 160 or equivalent, or EE 163 ab.* This course will cover topics in both earth-orbiting satellite and deep-space communications with respect to both ends of the communications link (i.e., the spacecraft and the ground station). Instructor: Antsos.

EE 166. Optimal Signal Processing, Quantization, and Compression. *9 units (3-0-6); third term. Prerequisites: EE 112 or equivalent, EE 162 or equivalent, and elementary matrix algebra. EE 128 will help.* Course deals with optimal (statistical) signal processing topics. Optimal subband coders and transform coders, optimal bit-allocation, discrete-time Karhunen-Loeve transforms, DCT, generality of unitary transforms, linear predictive coding, DPCM, coding gain optimization, information theoretic bounds, autoregressive modeling, detection of sinewaves in noise. Instructor: Vaidyanathan.

EE 167. Data Compression. *9 units (3-0-6); second term. Prerequisite: EE 126 or instructor's permission.* An introduction to the basic results, both theoretical and practical, of data compression. Review of relevant background from information theory. Fixed model and adaptive Huffman and Arithmetic codes. The Lempel-Ziv algorithm and its variants. Scalar and vector quantization, including the Lloyd-Max quantizers, and the generalized Lloyd algorithm. Transform Coding. Karhuenen-Loeve and discrete cosine transforms. The bit allocation problem. Sub-band coding. Practical algorithms for image and video compression. Instructor: Effros.

EE/Ae 179 abc. Projects in Flight Control. *Units to be arranged in accordance with work accomplished.* Multidisciplinary projects using radio-controlled helicopters and airplanes as test beds for experiments in aerodynamics and flight control. Design, construction, and flight test of sensor, actuator, signal-processing, telemetry, airframe, and propulsion systems. Modeling of vehicle dynamics and the use of an automatic control system. Problems of autonomous vehicles, including guidance and navigation. Projects using land and water vehicles are also possible. Instructors: Doyle, Culick, Murray.

EE/APh 180. Solid-State Devices. *9 units (3-0-6); second term.* Starting with the phenomenological statement of physical processes, the operation of a device and its representation in terms of an equivalent circuit are 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, the pn junction, the junction transistor, the Schottky diode, and the field-effect transistor. Instructor: Scherer.

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.

CNS/CS/EE 184 abc. Analog Integrated Circuits Project Laboratory. *9 units (2-2-5).* For course description, see Computation and Neural Systems.

EE 185 ab. Microfabrication Technology for Solid-State Devices. *9 units (3-0-6); first, second terms. Prerequisites: APh 9, EE/APh 180, or instructor's permission.* Course in advanced (silicon) microfabrication technology. Topics: lithography; oxidation; diffusion; ion implantation; thin-film deposition; wet and dry etching; metalization. The use of these techniques to fabricate a wide variety of solid-state devices, including MOSFETs, microsensors, and microactuators will be discussed. Practical equipment for these processes will also be included. Instructor: Tai.

CNS/Bi/EE 186. Vision: From Computational Theory to Neuronal Mechanisms. *12 units (4-4-4).* For course description, see Computation and Neural Systems.

CNS/CS/EE 188 ab. Computation Theory and Neural Systems. *9 units (3-0-6).* 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.

CNS/EE 248. Sensory Information Processing Laboratory. *9 units (1-2-6).* For course description, see Computation and Neural Systems.

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)

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E 2. Engineering and Entrepreneurship. *2 units (1-0-1); first term.* Reflections on engineering and entrepreneurship by co-founder of TRW, Dr. Simon Ramo. Items to be covered include: the nature of practical engineering; entrepreneurship; financing a company; manufacturing; the role of government; the international economy; environment, safety, and liability; and large versus small companies. Discussion will center around a number of current issues, such as electric vehicles, supersonic transports, the information superhighway, interactive television, genetic engineering, and others. Graded pass/fail. Not offered 1996–97. Instructor: Ramo.

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 blackboards, overhead projectors, and slide projectors. Instructors: Staff.

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)*

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ENGINEERING SCIENCE

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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/CE 204 abc. Hydrodynamics of Free Surface Flows. *9 units (3-0-6); first, second, third terms. Prerequisites: CE/ME 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 the 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; not offered 1996–97. Instructor: Staff.

ES 250 abc. Research in Engineering Science. By arrangement with members of the staff, properly qualified graduate students are directed in research in Engineering Science. Hours and units by arrangement.

ENGLISH

En 1 ab. English as a Second Language. *9 units (3-0-6 or 4-0-5); first, second terms.* A program in the fundamentals of English composition for non-native speakers of English, required for foreign students in need of supplementary instruction before entering freshman humanities courses. Students will be assigned to either En 1 b or the two-quarter sequence of En 1 ab on the basis of a diagnostic examination. *Not available for credit toward the humanities-social science requirement.* Instructors: Fonseca, Linden-Martin.

En 2. Basic English Composition. *9 units (2-2-5); first, second terms.* A course in the fundamentals of English composition for native speakers of English, required for students in need of supplementary instruction before entering freshman humanities courses. Students will be assigned to En 2 on the basis of a diagnostic examination. *Not available for credit toward the humanities-social science requirement.* Instructor: Fonseca.

ENGLISH AS A SECOND LANGUAGE (ESL)

Please see pages 197 and 198 for requirements regarding English competency. All of the following courses are open to international graduate students only. None are available for credit.

ESL 101 ab. Oral Communication and Pronunciation. *Noncredit;*

first and second terms. Communication and pronunciation in spoken English. Development of pronunciation, vocabulary, listening comprehension, and accuracy and fluency in speaking. Aspects of American culture will be discussed. The first quarter is required for all first-year international students designated by the ESL screening process. Instructors: Linden-Martin and staff.

ESL 102. Advanced Spoken English for Academic Purposes. *Noncredit; first and third terms.* Development of fluency and communication strategies. Emphasis on presentation skills and interpersonal communication on scientific topics. Strongly recommended for first-time international graduate teaching assistants. Instructors: Linden-Martin and staff.

ESL 103. English in Everyday Life. *Noncredit; first, second, and third terms.* Expressions, vocabulary, slang, and idioms used in daily life. Conversation and discussion, with feedback from instructors. Occasional grammar and pronunciation review. Comprehension of newspaper and magazine articles, as well as films and television programs. Instructors: Linden-Martin and staff.

ESL 104. Pronunciation Improvement and Accent Reduction. *Noncredit; second term only.* Aspects of American English pronunciation. Vowels and consonants, word and syllable stress, sentence stress and rhythm, intonation, and linking. Intensive practice and techniques for achieving correct pronunciation through self-monitoring. Instructors: Linden-Martin and staff.

ESL 105. Oral Presentation and Public Speaking. *Noncredit; second and third terms.* Oral presentation in a variety of settings, including oral exams, seminars, conferences, and the classroom. Focus on the organization of ideas, delivery techniques, pronunciation, grammar, and vocabulary. Frequent in-class presentations by students based on their current research interests, followed by critiques. Improvement of confidence and delivery skills. Instructors: Linden-Martin and staff.

ESL 106. Writing Seminar. *Noncredit; third term only.* Strategies for improving academic writing. Emphasis on grammar, word choice, organization, logical connectors, and punctuation. Classroom exercises and editing practice based on student writing samples. Instructors: Linden-Martin and 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: Staff.

Ge/Env 2. Global Change. *9 units (3-0-6).* For course description, see Geological and Planetary Sciences.

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 114 abc (may be taken concurrently); ME 19 ab; 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 hydraulic models. Transport and dispersion of solutes, sediments, and heat; turbulent plumes and buoyant jets; surface heat transfer, evaporation, and density stratification in natural waters. Engineering of outfalls. Flow and pollutant transport through porous media; groundwater problems. Instructor: List.

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. Given in alternate years; offered 1996–97. Instructor: Flagan.

Env 142 ab. Chemistry of Natural Water Systems. *9 units (3-0-6); first, second terms. Prerequisite: Ch 1 ab and Ch 14, or Ch 21 ab, or Ch 24 ab, or permission of the instructor.* Principles of inorganic and physical chemistry applied to quantitative description of processes in natural waters: Thermodynamic and kinetic aspects of electrolyte solutions, carbon dioxide/carbonate systems, dissolution and precipitation, metal-ligand complexes, electron transfer, surface chemistry of aquatic particles, and particle aggregation and stabilization processes in water. Instructor: Hering.

Env 143. Water Chemistry Laboratory. *9 units (0-6-3); third term. Prerequisite: Env 142 ab.* Laboratory experiments dealing with the major and minor constituents of natural waters. Topics include seawater chemistry, heterogeneous equilibria, redox processes, adsorption, and particle coagulation. Instructor: 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. Instructor: North.

Env 146. Chemical Reaction Engineering for Water Quality Control. *9 units (3-0-6); third term. Prerequisite: Env 142 ab.* 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. Given in alternate years; not offered 1996–97. Instructor: Morgan.

Env/Ge 148 abc. Global Environmental Science. *Prerequisites: Ch 1, Ma 2, Ph 2, or equivalent.* Global change on time scales of years to centuries.
Env/Ge 148 a. Weather and Climate. *9 units (3-0-6); first term.* Atmospheric radiation, greenhouse effect, ice ages, ozone hole, atmospheric and oceanic circulation and chemistry, numerical modeling of weather and climate. Instructor: Ingersoll.
Env/Ge 148 b. Global Biogeochemical Cycles. *9 units (3-0-6); second term.* Global biogeochemical cycles, fluxes, and chemical reservoirs in the solid earth, atmosphere, and oceans. Instructor: Andreae.
Env/Ge 148 c. Terrestrial Surface System. *9 units (3-2-4); third term.* Natural surficial processes, soils, vegetation, fresh water, and their modification by human interactions. Present in context of Holocene and Pleistocene. Remote sensing applications. Instructor: Murray.

Env/Ge 149. Marine Geochemistry. *9 units (3-0-6); third term.* Major element composition of seawater and its controls. Solution chemistry. Redox processes in seawater and sediments. Nutrient distributions and relationship to biota. Trace metal distributions. Radioactive elements and their applications. Air–sea exchange, ventilation, and carbon dioxide system. Overview of tracer oceanography. Instructor: Farley.

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 given to work at the Institute. Graded pass/fail. Instructor: Hoffmann.

Env/Ge 152 abc. Physics and Chemistry of Atmospheres and

Oceans. *9 units (3-0-6); first, second, third terms. Prerequisite: Env/Ge 148 abc or instructor's permission.* Physical and chemical processes in the earth's fluid envelope, presented at an intermediate level. First term: dynamics of large-scale motions in atmospheres and oceans, introduction to numerical modeling. Second term: atmospheric radiative transfer and remote sensing. Third term: global atmospheric chemistry and photochemistry. Instructors: Ingersoll (first term), Yung (second term), Yung and Hoffmann (third term).

ChE/Env 157. Sources and Control of Air Pollution. *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; control techniques for particulate and gaseous pollutants; solution of large-scale regional air pollution control problems. Given in alternate years; not offered 1996–97. Instructor: Cass.

ChE/Env 158. Air Pollution Aerosols. *9 units (3-0-6); first 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. Instructor: Flagan.

ChE/Env 159. Atmospheric Chemistry and Physics of Air Pollution. *9 units (3-0-6); second 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. Instructor: Cass.

Env/Bi 166. Microbial Physiology. *9 units (3-0-6); second term; alternate years. 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. Given in alternate years; not offered 1996–97.

Env/Bi 168. Microbial Diversity. *9 units (3-0-6); third term. 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 1996–97.

Env/Ch/Ge 175 ab. Environmental Organic Chemistry. *9 units (3-0-6); first and second terms.* A detailed analysis of the important chemical reactions and physico-chemical processes governing the behavior and fate of organic compounds in the surface and subsurface aquatic environments. The course is focused on physical organic chemistry relevant to natural waters. Fundamental aspects of thermodynamics, kinetics, mechanisms, and transport are stressed. Instructor: Hoffmann.

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 208. Special Topics in Microbiology. *6 units (2-0-4); second term; alternate years. Prerequisite: Env/Bi 168 and 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: bioremediation, genetics in unusual microorganisms; risk assessment and the release of genetically engineered organisms to the environment; environmental molecular biology. Given in alternate years; not offered 1996–97; topic: bioremediation.

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. Not offered 1996–97.

Env 214 abc. Advanced Environmental Fluid Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisites: CE/ME 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. Not offered 1996–97. Instructor: List.

Env 250. Advanced Environmental Seminar. *Units by arrangement, not to exceed 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, Civil Engineering, Mechanical Engineering, Biology, Geology, 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. Earth and Environment. *9 units (3-3-3); third term.* An introduction to the ideas and approaches of earth and environmental sciences, including both the special challenges and viewpoints of this kind of science as well as the ways in which basic physics, chemistry, and biology relate to these sciences. In addition to a wide-ranging lecture-oriented component, there will be a required field trip component (two weekend days), and a special research topic (often lab-oriented) chosen from many alternatives and to be carried out in small groups each led by a professor. The lectures and topics cover such issues as solid earth structure and evolution, plate tectonics, oceans and atmospheres, climate change, and the relationship between geological and biological evolution. Instructors: Stevenson, staff. *Satisfies the menu requirement of the Caltech core curriculum.*

Ge/Env 2. Global Change. *9 units (3-0-6); first term.* Global change on time scales of years to centuries. Weather and climate, greenhouse effect, ice ages, ozone hole, atmospheric and oceanic circulation and chemistry. Instructors: Ingersoll and Hoffmann.

Ge 3. Introduction to Earth and Planetary Sciences. *9 units (3-3-3); first term.* Broad, up-to-date view of the earth as an interconnected system. Convection in the earth's solid interior causes plate tectonics, earthquakes, and volcanic eruptions. The biosphere (including human society) evolves at the boundary between the surface of the solid earth and the envelopes of water and atmosphere, participating in, and perturbing, the geological cycles. The main integrating theme is whether the dinosaurs became extinct because of climate change caused by impact of an asteroid/comet, or immense volcanic eruptions, or slow continental drift. Topics vary with the instructor. Students must be prepared to spend three weekend days on field trips, including overnight camping. Not offered 1996–97. Instructor: Wyllie.

Ge 5. Geobiology. *9 units (3-3-3); third term.* Impact of life on the physical and chemical processes of the earth. Topics include the origin of life, diversification of prokaryotes, impact of oxygenic conditions on biochemical evolution, global glaciation and metazoan radiation, biomineralization and the Precambrian-Cambrian boundary, and evolutionary events during the Phanerozoic. Given in alternate years; not offered 1996–97. Instructor: Kirschvink.

Ge 10. Frontiers in Geological and Planetary Sciences. *3 units (2-0-1); third term. Open for credit to sophomores, juniors, and seniors; the course may be taken multiple times. Prerequisites: Ge 1, 2, or 4 (enrollment* *can be concurrent), or consent of instructor.* Weekly seminar by a member of the Division of Geological and Planetary Sciences or a visitor to discuss a topic of his or her current research at an introductory level. A second hour is used to discuss proposals written by class members for future research projects in the area of each seminar topic. The course is designed to introduce students to research and research opportunities in the division and to help students find faculty sponsors for individual research projects. Graded pass/fail. Instructors: Stolper, Wyllie.

Ge 11 ab. General Geology. *9 units (3-3-3); first and second terms. Prerequisites: Ch 1 or 2, Ma 1, Ph 1, or equivalents.* Systematic introduction to the earth and its history: the processes by which the earth and its biota have developed through time, and the observable products of these processes — rock materials, land forms, fossils. Plate tectonics. Igneous activity including plutonism and volcanism. Weathering, erosion, sedimentation, and sedimentary rocks. Stratigraphy and geologic time; development of sedimentary basins and the evolution of life as recorded in the rocks. Metamorphism and metamorphic rocks. Rock deformation, continental tectonics, and mountain building. Role of aqueous, atmospheric, glacial, and tectonic processes in shaping the earth's surface. History of the ice ages. Earth resources. Field trips, interpretation of geologic maps, and laboratory study of earth materials (minerals, rocks, fossils). Instructors: Wyllie, 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 counselors, Professors Rossman and Kirschvink. Graded pass/fail.

Ge 44. Introduction to Planetary Science. *9 units (3-0-6); third term. Prerequisites: none.* A broad introduction to what is known about the origin, evolution, and present state of the solar system. Observations on young solar mass stars, disks, and extra-solar planets, as well as meteorite properties and planet formation models, are the constraints on solar-system origin. Based on data from earth-based observations, planetary spacecraft, and extraterrestrial materials, the evolution and present states of planetary objects are addressed systematically by considering small bodies (comets and asteroids), the terrestrial planets, the giant planets, and finally, the icy bodies of the outer solar system. Instructor: Burnett.

Ge 66. Planet Earth. *9 units (3-0-6); second term. Prerequisites: Ma 2, Ph 2.* An introduction to the geophysics of the solid earth. Formation of planets. Structure and composition of the earth. Interactions between crust, mantle, and core. Surface and internal dynamics. Mantle convection. Imaging of the interior. Seismic tomography. Instructor: Anderson.

Ge 100 abc. 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 105 abc. The Geological and Planetary Sciences. *12 units (4-0-8); first and second terms. 12 units (3-3-6); third term. Prerequisites: Ch 1, Ma 2, Ph 2 or equivalents, or consent of instructor. Students with Ge 11 ab take Ge 104 ab instead of Ge 105 bc.* First term: The planets; their probable composition, physical state, and likely origin. Characterization of planets via ground-based and spacecraft observations. Theories of atmospheric structure, surface processes, and internal history in planetary bodies. The present internal structure of the earth, theories of the origin and evolution of the earth, and the earth's gravity and magnetic field. Second term: 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. Deformation of the earth in plate tectonics; surface processes and products. Physical and chemical manifestations of igneous, sedimentary, and metamorphic processes. Origin of the elements and their classification; the partitioning of major and trace elements in the earth. Third term: Evolution of land masses and oceans and their biota. Basic principles of physical stratigraphy, biostratigraphy, magnetostratigraphy, isotope geochemistry, tectonics, and biogeochemical cycles, focused on the understanding of tectonic, geochemical, and biological processes and events which have influenced earth history. One or two weekend field trips to important geological and geobiological sites in the southern California region. Instructors: Blake, Farley, Goldreich, Gurnis, Kirschvink, Wernicke.

Ge 106. Structural Geology and Tectonics. *9 units (3-3-3); second term. Prerequisite: Ge 11 ab.* 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 seafloor spreading. Field trips for study of structural features. Instructors: Saleeby, Kamb.

Ge 107. Introduction to Field Geology. *9 units (1-7-1); third term. Prerequisite: Ge 11 ab.* The rationale and techniques of geologic mapping, and their application in making a geologic map of a terrane of moderately deformed, stratified rocks. Synthesis and interpretation in a geologic report of the results of the field work, including structural and stratigraphic sections. One- or two-day field trips; total of seven days in the field. Instructor: Kamb.

Ge 108. Applications of Physics to the Earth Sciences. *9 units (3-0-6); second 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. Graded pass/fail. Instructor: Murray.

Ge 110. Sedimentary Geology. *9 units (3-3-3); second term. Prerequisite: Ge 11 ab.* 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. Instructors: Murray, staff.

Ge 114. Mineralogy. *12 units (3-6-3) or 9 units (3-4-2); first term.* 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 and geochemistry 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. Prerequisite: Ge 114.* 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: Stolper.

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 the light of chemical equilibrium and experimental studies. Detailed consideration of structure, phase relations, composition, and determination of the major metamorphic minerals. Instructor: Albee.

Ge 120. Summer Field Geology. *15 units (0-15-0); summer. Prerequisites: Ge 11 ab, Ge 106, Ge 107, Ge 110; or consent of instructor.*

Intensive course in techniques of field observation. Course includes two and one-half weeks of mapping in a well-exposed area of the southwestern United States and the preparation of a report, in September prior to registration week. Instructors: Saleeby, staff.

Ge 121 abc. Advanced Field and Structural Geology. *12 units (0-9-3); first, second, third terms. Prerequisites: Ge 11 ab, 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 rocks. Instructors: Stock (first term); Sieh (second term); Saleeby (third term).

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 1996–97. Instructor: Kirschvink.

124 a. *9 units (3-3-3); first term. Prerequisite: Ge 11 ab.* The principles of rock magnetism and physical stratigraphy; emphasis on the detailed application of paleomagnetic techniques to the determination of the history of the geomagnetic field.

124 b. *6 units (0-0-6); second 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. The Past Million Years. *12 units (3-4-5); third term. Prerequisites: Ge 11 ab, Ge 106, and Ge 110 or equivalent.* An introduction to the history of the earth's surface during the past million years and the processes that have sculpted it, as evidenced by its landforms and stratigraphy. Stratigraphic, geomorphologic, and geochronologic methods employed in the study of recent climate and tectonic history. Field trips, laboratory exercises, and term paper. Instructor: Sieh. (Alternating years with Ge 177, Geology of Earthquakes.)

Ge/Ch 127. Nuclear Chemistry. *9 units (3-0-6); second 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. Given in alternate years; offered 1996–97. Instructor: Burnett.

Ge/Ch 128. Cosmochemistry. *9 units (3-0-6); third 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 that attempt to describe the chemical state and history of cosmological objects in general and the early solar system in particular. Given in alternate years; offered 1996–97. Instructor: Blake.

Ge 131. Origin of the Solar System. *9 units (3-0-6). Offered by announcement. 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. Instructor: Stevenson.

Ge/Ay 132. Atomic and Molecular Processes in Astronomy and Planetary Sciences. *9 units (3-0-6); second term. Prerequisite: instructor's permission.* Fundamental aspects of atomic and molecular spectra that enable one to infer physical conditions in astronomical, planetary, and terrestrial environments. Topics will include the structure and spectra of atoms, molecules, and solids; transition probabilities; photoionization and recombination; collisional processes; gas-phase chemical reactions; and isotopic fractionation. Each topic will be illustrated with applications in astronomy and planetary sciences, ranging from planetary atmospheres and dense interstellar clouds to the early universe. Given in alternate years; not offered 1996–97. Instructor: Blake.

Ge 135. Regional Geology of Southern California (Seminar). *6 units (3-0-3); second term. Prerequisite: Ge 11 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 the Southwestern United States. *9 units (1-0-8); third term. Prerequisites: Ge 11 ab or instructor's permission.* Includes at least nine days of weekend field trips into areas of the 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. Instructor: Sharp.

Ge 140 ab. Introduction to Isotope Geochemistry. *9 units (2-0-7); first, second terms. 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: Taylor.

140 b. *first 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. Instructor: Wasserburg.

Ge 147. Tectonics of Western North America. *9 units (4-0-5); first term. Prerequisite: Ge 11 ab.* Major tectonic features of western North America, including adjacent craton and Pacific Ocean basin. Active plate junctures, igneous provinces, crustal uplift, and basin subsidence. Tectonic evolution from late Precambrian to recent time, and modern analogues for paleotectonic phenomena. Not offered 1996–97. Instructors: Saleeby and staff.

Env/Ge 148 abc. Global Environmental Science. *9 units (3-0-6).* For course description, see Environmental Engineering Science.

Env/Ge 149. Marine Geochemistry. *9 units (3-0-6).* For course description, see Environmental Engineering Science.

Ge 150. The Nature and Evolution of the Earth. *Units to be arranged. Offered by announcement only.* Advanced-level discussions 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); second term.* Review of processes responsible for the 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. Techniques of studying planetary surfaces are also covered in laboratory exercises and lectures. Instructors: Murray, Muhleman.

Env/Ge 152 abc. Physics and Chemistry of Atmospheres and Oceans. *9 units (3-0-6).* For course description, see Environmental Engineering Science.

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; not offered 1996–97. Instructor: Muhleman.

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. *First, second, third terms.* Presentation of current research in geophysics by students, staff, and visitors. Graded pass/fail. Instructor: Kanamori.

Ge 164 ab. Fluid Mechanics in the Earth Sciences. *9 units (3-0-6); first, second terms.* A unified presentation of the principles of fluid mechanics, with applications taken from the earth sciences. After each unit of fluid mechanics is complete, a faculty member from GPS will provide perspective with an application from the earth sciences. Fluid mechanics topics chosen from: control volume analysis, conservation equations. Bernoulli equation. Viscous flow; Stokes flow, boundary-layers, jets, chaotic mixing. Rotating fluids; geostrophic motion. Buoyancy-driven flows; buoyant plumes, stratified flow. Turbulence; turbulent structure, turbulent mixing. Two-phase flow; particle-laden flows, erosion, sedimentation, bubbly flows, foams. Flow in porous media. Compressible flow; supersonic flow, shock waves, shock Hugoniot, refraction. Earth science applications chosen from: mantle convection, geodynamics, terrestrial and solar dynamo, solar turbulence, atmospheric dynamics, geomorphology, volcanology, geochemical and geothermal systems, mineral physics. Not offered 1996–97. Instructors: Sturtevant and GPS staff.

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 the 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. Not offered 1996–97. Instructor: Goldreich.

Ge 174. Mechanics of Geologic Structure. *6 units (2-0-4); third term. Prerequisites: Ma 2 and Ge 106.* Rock deformation by brittle and ductile mechanisms and its analysis in terms of tensor stress and finite strain. Application to structures formed by folding and faulting in the earth. Not offered 1996–97. Instructor: Kamb.

Env/Ch/Ge 175 ab. Environmental Organic Chemistry. *9 units (3-0-6).* For course description, see Environmental Engineering Science.

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. Geology of Earthquakes. *9 units (3-0-6); third term. Prerequisite: Ge 106 or equivalent.* 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. Given in alternate years; not offered 1996–97. Instructor: Sieh.

Ge 180. Plate Tectonics. *9 units (3-0-6); third term. Prerequisites: Ge 11 ab and AM 113 or equivalent.* Geophysical and geological observations related to plate tectonic theory. Instantaneous and finite motion of rigid plates on a sphere; marine magnetic and paleomagnetic measurements; seismicity and tectonics of plate boundaries; reference frames and absolute plate motions. Interpretation of geologic data in the context of plate tectonics; plate tectonic evolution of the ocean basins. Given in alternate years; offered in 1996–97. Instructor: Stock.

CE/Ge 181. Engineering Seismology. *9 units (3-0-6).* For course description, see Civil Engineering.

Ge 203. Special Topics in Atmospheres and Oceans. *9 units (3-0-6); third 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 1996–97. 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 1996–97. Instructor: Taylor.

Ge 213. Special Topics in the Earth and Planetary Sciences. *Units and prerequisites dependent upon topics. Usually offered for letter grade; offered by announcement only.* A course 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 1996–97. 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 recommended.*

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; not offered 1996–97. Instructor: Taylor.

215 b. Advanced Igneous Petrology. *9 units (3-3-3); third term.* Lectures, seminars, and laboratory studies on igneous petrogenesis and rocks, emphasizing experimental studies. Given in alternate years; not offered 1996–97. Instructor: Wyllie.

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 1996–97. Instructor: Morrison.

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); second 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 (during the course) will be required at the telescope. Given in alternate years; not offered 1996–97. Instructor: Westphal.

Ge 229. Glaciology. *9 units (3-0-6); third term.* Characteristics of existing glaciers and ice sheets; ice-age glaciers; glacier flow and fracture mechanics in relation to ice physics; mass and energy balance and response to climatic change; glacial erosion and deposition; causes of glaciation. Given in alternate years; offered 1996–97. Instructor: Kamb.

Ge 232. Chemistry of the Solar System. *9 units (3-0-6); second 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; not offered 1996–97. Instructor: Burnett.

Ge 236. Applications of Rare Gases to Earth Science Problems. *9 units (3-0-6); offered by announcement only; third term. Prerequisite: instructor's approval.* Discussion of the principles, applications, and limitations of rare gases as records of terrestrial processes. Origin and behavior of rare gases in natural systems. Specific areas to be considered include: K/Ar and $^{40}Ar/^{39}Ar$ dating; Ar thermochronology; surface-exposure dating; rare gas constraints on mantle evolution and models of atmosphere formation; additional applications in geology, hydrology, paleoclimatology, and oceanography. Instructor: Farley.

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. Instructor: Wasserburg.

Ge 242. Metal Pathways Through Terrestrial and Marine Ecosystems. *6 units (2-0-4); offered by announcement only; 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: Staff.

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 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; offered 1996–97. Instructor: Gurnis.

Ge 260. Physics of Earth Materials. *9 units (3-2-4); first term. 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, high-pressure electrical properties of minerals, and application of shock and ultrasonic equation-of-state data to earth and planetary interiors. Given in alternate years; offered 1996–97. Instructor: Ahrens.

Ge 261 a. Advanced Seismology I. *9 units (3-0-6); second term. Prerequisites: Ge 176 or AMa 95, or consent of instructor.* Covers essential material in modern broadband seismology; elastic wave propagation and methods for computing synthetic seismograms; applications to the determination of earth structure at various wave lengths; special applications to modeling the broadband data from TERRAscope. Instructor: Helmberger.

Ge 261 b. Advanced Seismology II. *9 units (3-0-6); third term.* Continuation of Advanced Seismology I with special emphasis on particular complex problems; includes high-frequency (finite-difference methods) to low-frequency (free oscillations), construction of earth models using tomographic methods and synthetics; requires a class project. Instructors: Helmberger and staff.

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 extrapolation operators, migration methods, velocity estimation, multiple suppression, statics, slant stacks, and inversion methods. Instructor: Clayton.

Ge 270. Continental Tectonics. *9 units (3-0-6); third term. Prerequisites: AMa 95 or AMa 113; Ge 11 ab, Ge 106, Ge 166, Ge 180 or Ge 176.* Nature of non-plate, finite deformation processes in the evolution of the continental lithosphere using the Alpine orogen as an example. Rheological stratification; isostatic and flexural response to near-vertical loads; rifting and associated basin development; collision and strike-slip tectonics; deep crustal processes. Not offered 1996–97. Instructor: Wernicke.

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. Not offered 1996–97. Instructor: Sieh.

Ge 282 abc. Division Seminar. *1 unit; first, second, third terms.* Presentation of papers by invited investigators. In charge: Sieh.

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

These courses 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 division. 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 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 1996–97. Instructor: Fay.

H 110. Early Modern Europe.* *9 units (3-0-6).* Topics in the 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. Not offered 1996–97. Instructor: Hoffman.

H 113. The Great War 1914–1945.* *9 units (3-0-6); third term.* How and why "The Great War" (as the two World Wars will probably come to be known) began, was fought, recessed in 1919, resumed in 1939, and ended at last, leaving Europe cruelly transformed and deeply divided. Attention will be equally divided between society, politics (including the Russian Revolution and Hitler), and the war itself. Instructor: Fay.

H 116. Population and Economy in Pre-industrial England.* *9 units (3-0-6).* Population and resources within Europe and the wider world, and within England. The course of population change in England: patterns of marriage and change over time, natural and controlled fertility, patterns of mortality and change over time, the significance of illegitimacy and the impact of demography on family and household, the escape of England from the shadow of famine in the past. Not offered 1996–97. Instructors: Staff.

H 120. Europe and Asia, 1500–1900.* *9 units (3-0-6); third term.* Episodes in Asia's penetration by Europeans in the course of these four centuries, and Asia's response; from Cairo to Canton; but with special attention to India. Instructor: Fay.

H 122. British India.* *9 units (3-0-6).* Indian politics and society since the Sepoy Rebellion (1857), with particular attention to Gandhi and the winning of independence (1947). Not offered 1996–97. Instructor: Fay.

H 124. Population and Family History.* *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." Not offered 1996–97. Instructor: Lee.

SES/H/Lit 128. British Science Fiction.* *9 units (3-0-6).* For course description, see Science, Ethics, and Society.

H/Hum 130 ab. Cinema and Society.* *9 units (2-2-5); second, third terms.* A two-term course that covers the history of world cinema from the 1890s to today. Focus will be on technological innovation, film language, stylistic change, and historical importance of film as it has developed in Europe, Hollywood, and the Third World. First term will cover from the origins of film through the 1940s, with emphasis on works from Hollywood, Germany, the Soviet Union, France, and Italy. Second term will cover from World War II to the present, and will include sections on Asia, East Europe, the Third World, and American independents. Students will view at least one feature film a week. Though the course is designed as a sequence, students may take a single term. Not offered 1996–97. Instructor: Rosenstone.

H/Hum 131. History on Film.* *9 units (2-2-5). Offered by announcement.* 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 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. Not offered 1996–97. 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. Not offered 1996–97. Instructor: Lee.

H 136. Family, Friendship, and Love in Chinese Culture.* *9 units (3-0-6); third term.* The nature of human relations in China. The purpose of the class is twofold: first, to introduce a number of selected texts on family, friendship, and love in Chinese culture; second, to provide a broad conceptual framework on self and society in traditional and contemporary China. Classes are organized around specific themes. Readings include anthropological, historical, and literary texts. Instructor: Lee.

H 140. History of Los Angeles.* *9 units (3-0-6); third term.* A course that examines the 200-year history of Los Angeles through fiction, film, scholarship, and photography. Instructors: Deverell, Flamming.

H 141. The 20th-Century American City.* *9 units (3-0-6).* A survey course that examines the history of modern American urban development. Emphasis will be placed upon the social history of 20th-century American cities. Not offered 1996–97. Instructor: Deverell.

H 142. History of California.* *9 units (3-0-6).* This course examines the history of California from the 16th century through the 20th century. Attention will be paid to demographic patterns of Native American and other peoples, exploration, colonization, extractive industries, and the political development of the state. Not offered 1996–97. Instructor: Deverell.

H 143. Western Environmental History.* *9 units (3-0-6); second term.* This course examines the history of the American West through the prism of environmental history. From discussion of Native American peoples and their interaction with the California environment through the demographic expansion of Anglo America in the 19th century and the environmental history of the 20th century, the course ranges broadly across time and California space. Instructor: Deverell.

H 144. Topics in the History of American Immigration.* *9 units (3-0-6).* A course that examines the history of American immigration from the 18th through the 20th centuries. This course will explore the impact of immigration upon American politics, culture, and law. Not offered 1996–97. Instructors: Deverell, Flamming.

H 146. American Biography.* *9 units (3-0-6); first term.* Leading Americans as seen through the best of their biographies, with an examination of the changing methods in the art of biography. Not offered 1996–97. 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. Not offered 1996–97. Instructor: Ridge.

H/PS 148 ab. The Supreme Court in U.S. History.* *9 units (3-0-6); second, third terms.* The development of the Supreme Court, its doctrines, personalities, and role in U.S. history through analyses of selected cases. The first half of the course, which is a prerequisite for the second half, but may also be taken by itself, will deal with such topics as federalism, economic regulation, political rights, and free speech. The second half will cover such issues as the rights of the accused, equal protection, and privacy. Instructor: Kousser.

H 150 ab. African American History.* *9 units (3-0-6).* This two-part course will explore the history of African Americans from 1600 to the present. Generally part *a* of the course will cover the African diaspora through Reconstruction; part *b* will cover the period since 1877. The first term is not a prerequisite of the second term. Not offered 1996–97. Instructor: Flamming.

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 1996–97. 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. Not offered 1996–97. Instructors: Kevles, Rosenstone.

H 153 ab. America Since World War II.* *9 units (3-0-6).* Topics in the recent social, cultural, and political history of the United States. First term is not a prerequisite for second term. Not offered 1996–97. Instructor: Kevles.

H 154. American Social History.* *9 units (3-0-6); second term.* The evolution of American society since 1800, with particular emphasis on class, gender, race, and ethnicity. Instructor: Flamming.

H 155. The American Worker.* *9 units (3-0-6); third term.* Examines the development of the American working class in the 19th and 20th centuries, with emphasis on radicalism, class consciousness, working-class culture, and unionization. Instructor: Flamming.

SES/H 156. The History of Modern Science.* *9 units (3-0-6).* For course description, see Science, Ethics, and Society.

SES/H 157. Science in America, 1865–Present.* *9 units (3-0-6).* For course description, see Science, Ethics, and Society.

SES/H 158. The Scientific Revolution.* *9 units (3-0-6).* For course description, see Science, Ethics, and Society.

SES/H 159. Science and Society.* *9 units (3-0-6).* For course description, see Science, Ethics, and Society.

SES/H 160 ab. History of the Modern Physical Sciences.* *9 units (3-0-6).* For course description, see Science, Ethics, and Society.

H 161. Selected Topics in History. *9 units (3-0-6). Offered by announcement. Advanced credit to be determined on a course-by-course basis by instructor.* Instructors: Staff and visiting lecturers.

SES/H 162. Social Studies of Science.* *9 units (3-0-6).* For course description, see Science, Ethics, and Society.

SES/H 163. Gender in the History of Science, Technology, and Medicine.* *9 units (3-0-6).* For course description, see Science, Ethics, and Society.

SES/H 164. Sciences of Mind from the French Revolution to the Great War.* *9 units (3-0-6).* For course description, see Science, Ethics, and Society.

SES/H 165. History of Technology in the United States.* *9 units (3-0-6).* For course description, see Science, Ethics, and Society.

SES/H 166. The History of Environmentalism.* *9 units (3-0-6).* For course description, see Science, Ethics, and Society.

SES/H 168. The History of Modern Medicine.* *9 units (3-0-6).* For course description, see Science, Ethics, and Society.

SES/H 169. Selected Topics in Science, Ethics, and Society. *9 units (3-0-6).* For course description, see Science, Ethics, and Society.

H 201. Reading and Research for Graduate Students. *Units to be determined for the individual by the division.*

** Advanced courses with credit toward the 36-unit humanities requirement. Other advanced courses receive credit toward the 36-unit H&SS requirement. See page 152.*

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 requirement.

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. Not offered 1996–97. Instructors: philosophy and literature staff.

Hum 2 ab. Europe: The Roman Empire to the Industrial Revolution. *9 units (3-0-6); first and second terms.* Introduction to European religions and religious change, to value systems, and to the changing structure of political life and its economic base, from the Roman empire to the beginning of the industrial revolution. Instructors: history staff.

Hum 3 ab. Early European Literature. *9 units (3-0-6); first and second or second and third terms.* Critical exploration of a number of texts fundamental to our culture. The time-span will be from the beginnings to the late 17th century; but the precise chronological range, the emphases, and the selection of texts to be read and studied will be determined for each of the two quarters by the instructors teaching these courses. Instructors: literature staff.

Hum 5 ab. Enlightenment to Revolution: History, Thought, Culture. *9 units (3-0-6); first and second or second and third terms.* This two-term sequence will survey the transformation of European culture from the late 17th century through the middle of the 19th century, beginning with the "Scientific Revolution" and the Enlightenment critique of the old regime in Europe and continuing with the Romantic response to Enlightenment rationalism and the "age of revolution." Readings in history, philosophy, and literature; authors may include Descartes, Locke, Newton, Defoe, Rousseau, Goethe, Wollstonecraft, Marx, and Engels. Not offered 1996–97. Instructors: history and literature staff.

Hum 6 ab. The Modern Age: History, Thought, and Culture. *9 units (3-0-6); first and second or second and third terms.* This two-quarter sequence will introduce students to those aspects of the politics and culture of modernity that have profoundly transformed Western society and consciousness since the middle of the 19th century. A variety of literary, historical, philosophical, scientific, and artistic works will be examined, among them those of Marx and Weber, Nietzsche and Freud, James Joyce, Picasso, and Einstein. 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 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 20th-century political movements and culture. Instructors: history staff.

Hum 8 ab. American Literature and Culture. *9 units (3-0-6); first and second or 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, which may be taken to stretch from Beirut to Beijing and beyond, contains a variety of peoples whose only common property is that they have been defined in opposition to what is "European." This two-term sequence will attempt to introduce students to the history, culture, and present state of *some* of these peoples.

The choice, varying from year to year, will generally be made from East Asia, South Asia, or the Middle East. Instructors: history and literature staff.

Hum 10 ab. Morality, Society, and Politics. *9 units (3-0-6); first and second or second 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 17th 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 12 ab. Belief, Truth, and Knowledge. *9 units (3-0-6); first and second or second and third terms.* An introduction to two central areas of philosophy: epistemology (theories of knowledge) and metaphysics (theories about the ultimate nature of reality). Readings will be drawn from both historical and contemporary philosophical texts. The first quarter will deal with issues in epistemology. Particular topics may include various forms of skepticism; the nature of knowledge, belief and rationality; paradoxes about knowledge; the nature of scientific knowledge; probability; and logic. The second quarter will address some central questions in metaphysics. Topics to be covered may include the following: the relation between the mind and the body; the existence of God; the existence of a mind-independent reality; the nature of time; freedom and determinism; personal identity; and the nature of right and wrong. Instructors: philosophy staff.

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

SES/Hum 121. Freud.* *9 units (2-0-7).* For course description, see Science, Ethics, and Society.

H/Hum 130 ab. Cinema and Society.* *9 units (2-2-5).* For course description, see History.

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

Hum 132. Humanities on Film. *3 units (1-1-1). Offered by announcement.* A mini-course centered around a series of films (usually five) screened as part of the Caltech Film Program. Students will be required to attend prefilm lectures and postfilm discussions, to do some reading, and to produce a short paper. Instructor: Rosenstone.

Hum 133. Topics in Film History.* *9 units (2-2-5). Offered by announcement.* Will focus each quarter on one kind of motion picture — either a film genre, or films made by an individual director, or from a single nation or region of the world or particular historical era. Included are weekly screenings, readings on film, a weekly discussion meeting, and a term paper. Instructor: Rosenstone.

Hum 140 ab. The History of the Book.* *9 units (3-0-6). Offered by announcement.* A chronological survey of the evolution and cultural role of printed materials — specifically the book — in Western society from the 14th century to the present day. Instructors: Staff.

Hum 141 a. Offensive Literature.* *9 units (3-0-6). Offered by announcement.* A survey of literature deemed at various historical periods to have been seditious, blasphemous, obscene, or libelous. 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 152.*

INDEPENDENT STUDIES PROGRAM

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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 183 for complete details.

JAPANESE *(See Languages)*

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JET PROPULSION

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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 spaceflight 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, and inlets and diffusers. Instructor: Shepherd.

JP 131. Combustion Technology. *9 units (3-0-6); third term. Prerequisites: APh/ME 17 and ME 19.* Application of fluid dynamic and chemical principles to the study of combustion processes, including the theoretical and experimental treatment of laminar and turbulent flames; the combustion of liquid droplets and solid particles; and technical aspects of gas, oil, and coal combustion. Instructor: F.E.C. Culick. Not offered 1996–97.

JP 213. Dynamics of Reacting Gases. *9 units (3-0-6); each term. Prerequisites: APh/ME 17 abc; APh 101 abc or CE/ME 101 abc or equivalent.* Application of gas dynamic and chemical principles to the 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. Instructors: Culick, Goodwin, Shepherd. Not offered 1996–97.

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.

LANGUAGES

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 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. Instructor: Orcel.

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. Literary readings and writing are emphasized in the second and third quarters. Instructor: Orcel.

L 105. French Literature.* *9 units (3-0-6); second term. 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. Instructor: Orcel.

L 106 abc. Elementary Japanese. *10 units (5-1-4); first, second, third terms.* Emphasis on oral-aural skills, and understanding of basic grammar. Immediate introduction of the native script — *hiragana, katakana* — and gradual introduction to 300 to 500 characters. Instructor: Hirai.

L 107 abc. Intermediate Japanese. *10 units (5-1-4); first, second, third terms. Prerequisite: L 106 or equivalent.* Continued instruction and practice in conversation, building up vocabulary, and understanding complex sentence patterns. The emphasis, however, will be on developing reading skills. Recognition of approximately 1000 characters. Instructor: Hirata.

L 108 abc. Technical Japanese. *10 units (3-1-6); first, second, third terms. Prerequisite: L 107 or equivalent. (Not available for humanities and social science credit.)* Primarily reading and translation of technical texts in the natural and applied sciences. Recognition of the 1850 "general-use characters," as well as more specialized technical vocabulary. Instructor: Hirata.

L 110 abc. Elementary Spanish. *10 units (3-1-6); first, second, third terms.* Grammar fundamentals and their use in understanding, speaking, reading, and writing Spanish. Students who have had Spanish in secondary school or college must consult with the instructor before registering. Instructor: Staff.

L 112 abc. Intermediate Spanish. *9 units (3-0-6); first, second, third terms. Prerequisite: L110 or equivalent.* Grammar review, vocabulary building, practice in conversation, and introduction to relevant history, literature, and culture. Literary reading and writing is emphasized in the second and third terms. Students who have studied Spanish elsewhere must consult with the instructor before registering. Not offered 1996–97. Instructor: Staff.

L 121 abc. Elementary Latin. *9 units (3-0-6); first, second, third terms.* The course aims to prepare students to read classical Latin. Not offered 1996–97. Instructor: Pigman.

L 130 abc. Elementary German. *10 units (3-1-6); first, second, third terms.* Grammar fundamentals and their use in aural comprehension, speaking, reading, and writing. Students who have had German in secondary school or college must consult with the instructor before registering. Instructor: Aebi.

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 drills and exercises, expansion of vocabulary, and practice in reading, writing, and conversational skills. Second and third quarters will emphasize written expression, technical/scientific translation, and literary readings. Students who have studied German elsewhere must consult with the instructor before registering. Instructor: Washburn.

L 140 abc. German Literature. *9 units (3-0-6); first, second, third terms. Prerequisite: L 132 abc or equivalent. Advanced humanities credit to be determined by the instructor.* The reading and discussion of works by selected 19th- and 20th-century authors. Conducted in German. Not offered 1996–97. 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 152 ab. French Literature in Translation: Classical and Modern. *9 units (3-0-6). Offered by announcement. Advanced humanities credit to be determined by the instructor.* First term: French "classical" literature of the 17th and 18th centuries; second term: from 1939 to the present, with literary responses to "the Absurd." Readings are in English, but students may read French originals. Instructors: Staff.

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 literature, culture, and history. Writing is emphasized in the second and third quarters. Instructor: Cheron.

L/Lit 154. French Literature in Translation: The French Novel. *9 units (3-0-6). Offered by announcement. Advanced humanities credit to be determined by the instructor.* Famous novels of the 16th to the 20th century are read against their historical, sociological, and philosophical background. Readings and discussions are in English, but students may read the French originals. Instructors: Staff.

L/Lit 160 ab. German Literature in Translation.* *9 units (3-0-6).* First term: German literature of the 19th century—Biedermeier, Young Germany, Realism, and Naturalism; second term: "Tales of Hollywood," German Exile Literature 1933–45. Instructor: Washburn.

L/Lit 162. Latin American Literature in Translation. *9 units (3-0-6); second term.* This class is an introduction to the literary masterworks of the Latin American republics. The course is designed to acquaint students with the diverse panorama of prose works (short stories and novels) associated with some of the most widely recognized Latin American writers of the second half of the 20th century. While the majority of the readings represent the explosion of literary productivity known as "The Boom" (1960s and early 1970s), other significant works of the pre- and post-Boom period will also be included in order to show the evolution and confluence of artistic tendencies over time. Readings and discussions in English. Instructors: Staff.

L/Lit 165 abc. Russian Literature in Translation.* *9 units (3-0-6); first, second, third terms.* The development of Russian literature in its socio-historical context from the Classical period to contemporary texts. Authors will range from Pushkin to Solzhenitsyn. All readings in English. Not offered 1996–97. Instructor: Cheron.

L 166 abc. Russian Literature. *9 units (3-0-6); first, second, third terms. Prerequisite: L 153 or equivalent and permission of the instructor. Advanced humanities credit to be determined by the instructor.* 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. Instructor: Cheron.

L 167 abc. Latin Literature. *9 units (3-0-6); first, second, third terms. Prerequisite: L 121 abc or equivalent. Advanced humanities credit to be determined by the instructor.* Major works of Latin literature, usually one per term. No work will be studied more than once in four years, and students may repeat the course for credit. Instructor: Pigman.

L 168 abc. Elementary Ancient Greek. *9 units (3-0-6); first, second, third terms.* The course aims to prepare students to read Attic Greek (5th century B.C.). Not offered 1996–97. Instructor: Pigman.

* *Advanced courses with credit toward the 36-unit humanities requirement. Other advanced courses receive credit toward the 36-unit H&SS requirement. See page 152.*

LATIN (See Languages)

LAW

Law 33. Introduction to the Law. *9 units (3-0-6); third term.* An introduction to Anglo-American law from both the legal and the social-scientific points of view. Subject can vary from year to year. Available for introductory social science credit. Instructor: Spitzer.

Law 133. Topics in Anglo-American Law. *9 units (3-0-6); second term.* 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: McCaffery. *May be taken more than once if the topic is different.*

LINGUISTICS

Lin 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.

LITERATURE

These courses are open only to students who have fulfilled the freshman humanities requirement.

Lit 30. Reading in English. *Units to be determined for the individual by the division.* 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 division. Graded pass/fail. Instructors: Staff. *Not available for credit toward humanities-social science requirement.*

Lit 98. Tutorial for Literature Majors. *9 units (2-0-7). Prerequisite: instructor's permission.* An individual program of directed reading and research for literature majors in an area not covered by regular courses. Instructors: Staff.

Lit 99. Senior Seminar.* *9 units (2-0-7); second term.* Students will study research methods and plan, present in class, and write a research paper. Required of students in the literature option. Instructors: Staff.

Lit 100. Introduction to Poetry. *9 units (3-0-6); third term.* 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 illustrate the nature, functions, and resources of poetry, a wide-ranging selection of poems will be read and discussed. Instructor: Mandel.

Lit 103 ab. The Epic of Return.* *9 units (3-0-6); third term.* The *Odyssey* and its transformations. First term: the *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 108 abc. Seminar in Creative Writing. *9 units (3-0-6); first, second, third terms.* Students will develop their writing skills chiefly through their own creative efforts. Lecturers will provide guidance and direction, supervise class discussions of students' works, and assign outside reading as needed. Specifically, the subject for any quarter may be fiction, autobiography, poetry, the essay, or other forms. Information on each quarter's focus will be provided by the Registrar. Enrollment is limited and upperclass undergraduates will be given priority. Students may apply one quarter of Lit 108 to the 36-unit H&SS requirement. Instructors: Staff.

Lit 110. Chaucer.* *9 units (2-0-7).* Chaucer's major works, *Troilus and Criseyde*, and selections from *The Canterbury Tales*. Not offered 1996–97. Instructor: Pigman.

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. Not offered 1996–97. Instructors: La Belle, Pigman.

Lit 114 ab. Shakespeare.* *9 units (3-0-6). Offered by announcement. Not open to freshmen.* 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 three or four of Shakespeare's major plays. The first term is not a prerequisite for the second. Instructor: La Belle.

Lit 116. Milton.* *9 units (2-0-7).* Milton's major works — *Paradise Lost, Paradise Regained*, and *Samson Agonistes* — and some of the prose and shorter poems. Not offered 1996–97. Instructor: Pigman.

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. Instructors: Staff.

Lit 125 ab. British Romantic Literature.* *9 units (3-0-6).* A selective survey of English writing in the late 18th and early 19th centuries. Major authors may include Blake, Wordsworth, Coleridge, Byron, Keats, Percy Shelley, Mary Shelley, and Austen. Particular attention will be paid to intellectual and historical contexts and to new understandings of the role of literature in society. Not offered 1996–97. Instructor: Gilmartin.

Lit 126. Gothic Fiction.* *9 units (3-0-6); first term.* The literature of horror, fantasy, and the supernatural, from the late 18th century to the present day. Particular attention will be paid to gothic's shifting cultural imperative, from its origins as a qualified reaction to Enlightenment rationalism, to the contemporary ghost story as an instrument of social and psychological exploration. Issues will include atmosphere and the gothic sense of space; gothic as a popular pathology; and the gendering of gothic narrative. Fiction by Walpole, Shelley, Brontë, Stoker, Poe, Wilde, Angela Carter, and Toni Morrison. Film versions of the gothic may be included. Instructor: Gilmartin.

Lit 127. 19th-Century English Literature and Social Change.* *9 units (3-0-6).* Course will explore literary responses to some of the central issues confronting English society in the 19th century: industrialization, the growth of cities, class tension, and shifting gender roles. Authors to be considered may include Shelley, Dickens, Gaskell, Eliot, Carlyle, Arnold, and Ruskin. Not offered 1996–97. Instructor: Gilmartin.

SES/H/Lit 128. British Science Fiction.* *9 units (3-0-6).* For course description, see Science, Ethics, and Society.

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. Not offered 1996–97. Instructors: Staff.

Lit 131 ab. Modern European Fiction.* *9 units (2-0-7); third term.* French, German, and Italian novels and shorter fiction from the first half of the 20th century by authors such as Broch, Gide, Hesse, Kafka, Malraux, Thomas Mann, Musil, Proust, Schnitzler, and Svevo. Instructor: Pigman.

Lit 132. American Literature Until the Civil War.* *9 units (3-0-6).* Will analyze the literature of this period, from the Puritans through Melville, to determine how various writers understood their relationship to a new world of seemingly unlimited possibility. Authors covered may include: Mary Rowlandson, Benjamin Franklin, Hannah Foster, Harriet Jacobs, Emerson, Thoreau, Harriet Beecher Stowe, Hawthorne, and Melville. Not offered 1996–97. Instructor: Weinstein.

Lit 133. 19th-Century American Women Writers.* *9 units (3-0-6); third term.* This course will analyze many of the most popular novels written in the 19th century. How might we account for their success in the 19th century and their marginalization (until recently) in the 20th century? Why were so many of these texts "sentimental"? How might we understand the appeal of "sentimental" literature? What are the ideological implications of sentimentalism? Authors may include: Stowe, Warner, Cummins, Alcott, Phelps, Fern, etc. Instructor: Weinstein.

Lit 134. The Career of Herman Melville.* *9 units (3-0-6).* Will focus on Melville's works from *Typee* through *Billy Budd.* Special emphasis will be placed on Melville's relations to 19th-century American culture. Not offered 1996–97. Instructor: Weinstein.

Lit 138. Twain and His Contemporaries.* *9 units (3-0-6); third term.* Will study the divergent theories of realism that arose in the period after the Civil War and before WW I. Authors covered may include: Howells, James, Charlotte Perkins Gilman, Twain, Sarah Orne Jewett, Jacob Riis, Stephen Crane, and W. E. B. DuBois. Instructor: Weinstein.

Lit 140 ab. The Modern American Novel.* *9 units (3-0-6).* A two-term seminar that examines the development of the American novel from approximately 1915–1940. Authors covered may include:

Wharton, Cather, Fitzgerald, Yezierska, Hemingway, Steinbeck, and Wright. First term is not a prerequisite to second term. Not offered 1996–97. Instructor: Jurca.

Lit 145 ab. James Joyce and Modern Literature.* *9 units (3-0-6); third term.* 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 147. American Assimilation Narratives.* *9 units (3-0-6); first term.* Will focus on 20th-century novels, short stories, and autobiographies that address the meaning and value of assimilation to American culture. Authors covered may include Abraham Cahan, Langston Hughes, Maxine Hong Kingston, Richard Rodriguez, Frank Chin, and Toni Morrison. Instructor: Jurca.

Lit 149. Colonial Encounters.* *9 units (3-0-6); first term.* The literature and history of contact between Western European culture and those it defines as other, from Christopher Columbus to the present day. Attention to religion, race, and gender, and to European self-definitions in terms of other cultures. There will be readings also in non-European responses to colonization and empire. Authors may include Columbus, Cortés, Shakespeare, Rousseau, Kipling, Conrad, Aimé Césaire, David Henry Hwang, and Toni Morrison; films by Spike Lee and others. Instructor: Gilmartin.

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 162. Latin American 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.

Lit 170 abc. From Mysteries to Absurdism: A Survey of Drama. *9 units (3-0-6). Offered by announcement.* First term: origins of "modern" drama, from the Middle Ages to the Classical Age in 17th-century France. Second term: theater from 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 1950s. Not offered on a pass/fail basis. Instructor: Mandel.

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.

**Advanced courses with credit toward the 36-unit humanities requirement. Other advanced courses receive credit toward the 36-unit H&SS requirement.* *See page 152.*

MATERIALS SCIENCE

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MS 15 ab. Principles of Materials. *9 units (3-0-6); first, second terms.* The principles involved in the structure and properties of materials. Metallic materials, with some consideration given to ceramics and polymers. Emphasis on the utilization of phase transformations and strengthening mechanisms to obtain desired properties. Instructor: Fultz (MS 15 a).

MS 90. Materials Science Laboratory. *9 units (1-6-2); third term. Prerequisite: MS 15 ab.* An introductory laboratory in relationships between the structure and properties of materials. Experiments involve structure determination by x-ray diffraction, mechanical property measurements, crystal defect observation by chemical etching, and failure analysis. Individual projects may be performed, depending upon the student's interests and abilities.

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. Phase Transformations. *9 units (3-0-6); third term. Prerequisites: APh 105 b or ChE/Ch 164, or instructor's permission.* Thermodynamics and kinetics of phase transformations. Phase diagrams for decomposition and ordering. Nucleation, spinodal decomposition, microstructural morphologies. Role of strain energy in solid-solid phase transformations. Thermomechanical processing of selected materials. Instructor: Johnson.

MS 110 abc. Materials Research Lectures. *1 unit (1-0-0); first, second, third terms.* A seminar course designed to introduce advanced undergraduates and graduate students to modern research in materials science. Instructors: Kornfield, Atwater, Fultz.

MS 124. Mechanical Behavior of Materials. *9 units (3-0-6); second term. Prerequisite: MS 131.* Mechanical behavior of structural materials. The micromechanics of engineering metals will continue from MS 120, but a wide variety of other materials will be studied, including metallic glasses, polymers, ceramics, and composites. The focus of the course will be on the micromechanics of deformation and their relationship to macroscopic behavior. The course will be based on original work in the literature. A previous or concurrent course in continuum mechanics is recommended.

MS 125. Advanced Transmission Electron Microscopy. *9 units (1-6-2); third term. Prerequisite: MS 132.* Diffraction contrast analysis of crystalline defects. Phase contrast imaging. Physical optics approach to dynamical electron diffraction and imaging. Microbeam methods for diffraction and imaging. Chemical analysis by energy dispersive x-ray spectrometry and electron energy loss spectrometry. Instructor: Ahn.

MS 131. Structure and Bonding in Materials. *9 units (3-0-6); first term. Prerequisite: General exposure to quantum mechanics (e.g., Ph 2 ab, Ph 12 abc, or equivalent).* Modern ideas of chemical bonding, with an emphasis on qualitative concepts and how they are used to make predictions of structures, energetics, excited states, and properties. The quantum mechanical basis for understanding bonding, structures, energetics, and properties of materials (polymers, ceramics, metals alloys, semiconductors, and surfaces). The emphasis is on explaining chemical, mechanical, electrical, and thermal properties of materials in terms of atomistic concepts. Instructor: Goddard.

MS 132. Diffraction and Structure of Materials. *12 units (3-3-6); second term. Prerequisites: MS 131 or instructor's permission.* Principles of electron and x-ray diffraction, with applications for characterizing materials. Topics include scattering and absorption of electrons and x-rays by atoms. The transmission electron microscope (TEM) and the x-ray diffractometer. Kinematical theory of diffraction: effects of strain, size, disorder, and temperature. Crystal defects and their characterization. A weekly laboratory will complement the lectures. Instructors: Fultz and Ahn.

MS 133. Kinetic Processes in Materials. *9 units (3-0-6); third term. Prerequisites: APh 105 b or ChE/Ch 164, or instructor's permission.* Kinetic master equation, uncorrelated and correlated random walk, diffusion. Mechanisms of diffusion and atom transport in solids, liquids, and gases. Coarsening of microstructures. Nonequilibrium processing of materials. Instructors: Fultz and Kornfield.

APh/MS 140. Ion Beam Modification and Analysis of Materials. *6 units (2-0-4).* For course description, see Applied Physics.

APh/MS 141 abc. Ion Beam Analysis Laboratory. *5 units (0-4-1).* For course description, see Applied Physics.

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.

Ae/AM/MS 213 abc. Mechanics and Materials Aspects of Fracture. *9 units (3-0-6).* For course description, see Aeronautics.

MS 300. Thesis Research.

MATHEMATICS

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Ma 1 abc. Probability and Calculus of One and Several Variables. *9 units (4-0-5); first, second, third terms. Prerequisites: high school algebra, trigonometry, and calculus.* Review of calculus; basic probability. Complex numbers, Taylor polynomials, infinite series, basic linear algebra. Derivatives of vector functions, multiple integrals, line and path integrals, theorems of Green and Stokes. Ma 1 b,c is divided into two tracks: Practical and Analytical. Students will be given information helping them to choose a track at the end of the fall term. Instructors: Simon, Lorden, Aschbacher, Wales, Ramakrishnan, Meiron.

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. Instructors: Wolff, Makarov.
As of 1997-98, Ma 2 abc will be replaced by:
Ma 2 ab. Linear Algebra, Statistics, and Differential Equations. *9 units (4-0-5); first, second terms. Prerequisite: Ma 1 abc.* Linear algebra, basic statistics, ordinary differential equations.

Ma 3. Number Theory for Beginners. *9 units (3-0-6); third term.* Some of the fundamental ideas, techniques, and open problems of basic number theory will be introduced. Examples will be stressed. Topics: Euclidean algorithm, primes, Diophantine equations including $a^n + b^n = c^n$ and $a^2 - db^2 = \pm 1$, constructible numbers, composition of binary quadratic forms, and congruences. Instructor: Ramakrishnan.

Ma 4. Introduction to Mathematical Chaos. *9 units (3-0-6); third term.* An introduction to the mathematics of "chaos." Period doubling universality, and related topics; interval maps, symbolic itineraries, stable/unstable manifold theorem, strange attractors, iteration of complex analytic maps, applications to multidimensional dynamics systems and real-world problems. Possibly some additional topics, such as Sarkovski's Theorem, absolutely continuous invariant measures, sensitivity to initial conditions, and the horseshoe map. Graded pass/fail. Instructor: Jakobson.

Ma 5 abc. Introduction to Abstract Algebra. *9 units (3-0-6); first, second, third terms.* Groups, rings, fields, and vector spaces are presented as axiomatic systems. The structure of these systems is studied, making use of the techniques of automorphisms, homomorphisms, linear transformations, subsystems, direct products, and representation theory. Many examples are treated in detail. Instructor: Raghunathan.

Ma/CS 6 abc. Introduction to Discrete Mathematics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 1 abc.* Elementary counting, recurrence relations, generating functions. Permutations, permutation groups. Graph theory, paths and trees, flows in networks, combinatorial optimization. Linear programming. Combinatorial algorithms, recursive techniques. Integer matrices and coding theory. Topics from elementary set theory and mathematical logic: Lattices, Boolean algebras. Cardinals and ordinals. Propositional and predicate calculus. Introduction to the Gödel Completeness and Incompleteness Theorems. Instructors: Wilson, Kechris.

Ma 9. Problem Solving in Calculus. *3 units (3-0-0); first term. Prerequisite: Simultaneous registration in Ma 1 a.* A three-hour per week hands-on class for those students in Ma 1 a needing extra practice in problem solving in calculus and probability. Instructor: Leonard.

Ma 10. Frontiers in Mathematics. *3 units (2-0-1); first term. Open for credit to anyone. Freshmen must have permission of instructor to enroll.* Ma 10 is a weekly seminar by a member of the mathematics faculty or visitor on a topic of current research. The material will be presented in as elementary a manner as possible. The purpose is to introduce math majors and others to the research interests of the faculty and to give students a sense of what research in mathematics is about. Instructor: Wales.

The courses labeled Ma 91 are one-shot courses reflecting the interests of faculty, visitors, and students.

Ma 91 a. Introduction to Dynamical Systems. *9 units (3-0-6); first term. Prerequisite: Ma 2.* Concept of phase space. Stability and instability in ODE. Hamiltonian systems. Basic formalism, integrable systems. Quasiperiodic motion. Chaotic behavior. Levels of chaos. Elements of perturbation theory. Diophantine condition. Introduction to KAM. Instructor: Jitomirskaya.

Ma 91 b. Geometrical Paradoxes. *9 units (3-0-6); second term. Prerequisite: Ma 5 (or equivalent) or consent of instructor.* This course will provide an introduction to the striking paradoxes that challenge our geometrical intuition. One of the most famous ones is the Banach-Tarski Paradox: A pea can be decomposed into finitely many pieces which can be rearranged in space to form a ball the size of the sun. Topics to be discussed include geometrical transformations, especially rigid motions; free groups; amenable groups; group actions, equidecomposability, and invariant measures; Tarski's Theorem; the role of the Axiom of Choice; old and new paradoxes, including the Banach-Tarski Paradox, the Laczkovich Paradox (solving the Tarski Circle-Squaring Problem), and the Dougherty-Foreman Paradox (the solution of the Marczewski Problem). Instructor: Kechris.

Ma 91 c. Introduction to Geometric Group Theory and Low-Dimensional Topology. *9 units (3-0-6); third term.* The course will focus on the interplay of algebra and geometry. The first half of the course will concentrate on how to obtain algebraic information about infinite groups using the geometrical properties of their Cayley graphs. The results will range from the classical Nielsen-Schreier theorem, stating that every subgroup of a free group is free, to open problems in negatively curved groups. The second half of the course will describe the fundamental groups of low-dimensional manifolds with applications to surfaces and knots. It will also introduce Turing machines and the concept of unsolvability of a mathematical problem. The material of this course is an important part of the mathematical language used in diverse areas of science. Even though this course has minimal prerequisites, students will be introduced to research areas of current interest. Instructor: Gitik.

Ma 91 d. Representations of *GL*(2). *9 units (3-0-6); first term.* Instructor: Ramakrishnan.

Other Ma 91 titles may be announced.

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 108 abc. Classical Analysis. *9 units (4-0-5); first, second, third terms. Prerequisite: Ma 2 a and 2 b or equivalent. May be taken concurrently with Ma 109.* Topology of metric spaces, compactness, connectedness, convergence, completeness, continuity. Contraction mapping theorem and applications: existence and uniqueness of solutions to ordinary differential equations and the implicit function theorem. The theory of the Lebesgue integral and introduction to L^p-spaces. Fourier analysis. Analytic functions of one complex variable, including classification of isolated singularities, analytic continuation, and methods of contour integration. Instructor: Luxemburg.

Ma 109 abc. Introduction to Geometry and Geometric Analysis. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 2 a and 2 b or equivalent. May be taken concurrently with Ma 108.* Differential manifolds, differential forms, and calculus on manifolds, including Stokes theorem. Fundamental groups and universal covering space. Degree of a map. Riemann metric, geodesics, curvature. The differential geometry of curves and surfaces. Introduction to modern ideas in topology and differential geometry. Instructor: Kahn.

Ma 110 abc. Real and Complex Analysis. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 108 or equivalent.* First term: Linear topology: topological and metric spaces, topological vector spaces, Hilbert and Banach spaces, duality, convexity. Measure theory: measure spaces, integral, L^p-spaces, extensions of measures, measures in topological spaces, measures as functionals. Second term: Real analysis: Lebesgue measure in $\mathbb{R}^d$, change of variables, covering theorems, maximal functions, differentiation of measures and functions, Hausdorff measures, arc length and surface measures, integral and convolution operators, L^p-estimates, interpolation theorems, singular intervals, generalized functions, Sobolev spaces. Harmonic analysis: Fourier analysis of periodic functions, harmonic functions in the unit disc and Fourier series, harmonic analysis in $\mathbb{R}^d$, Fourier integral, boundary behavior of harmonic functions, convergence of Fourier series and integrals, applications to analysis of convolution operators. Third term: Complex analysis: elementary theory of analytic functions, H^p-spaces, Hilbert transform, functions of several complex variables, entire and meromorphic functions, Fourier integral on the complex plane. Instructor: Magyar.

Ma 112 a. Statistics. *9 units (3-0-6); first term only.* 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: Bossaerts.

Ma 116 abc. Mathematical Logic and Axiomatic Set Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 5 (or equivalent) or consent of instructor.* Propositional logic, predicate logic, formal proofs, Gödel Completeness Theorem, the method of resolution, elements of model theory. Computability, undecidability, Gödel Incompleteness Theorems. Axiomatic set theory, ordinals, transfinite induction and recursion, iterations and fixed points, cardinals, Axiom of Choice. Not offered 1996–97.

Ma/CS 117 abc. Computability Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 5 abc (or equivalent), or consent of instructor.* 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. Not offered 1996–97.

Ma 118 abc. Topics in Mathematical Logic. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 116 or Ma 117 or equivalent.* Topics to be chosen from model theory and its applications, infinitary logic and admissible sets, ordinary and generalized recursion theory, consistency and independence results in set theory, large cardinals, descriptive set theory. Contents vary from year to year so that students may take the course in successive years. Instructor: Zapletal.

Ma 120 abc. Abstract Algebra. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 5 abc or equivalent.* Basic theory of groups, rings, modules, and fields, including free groups; Sylow's Theorem; solvable and nilpotent groups; factorization in commutative rings; integral extensions; Wedderburn Theorems; Jacobson radical; semisimple, projective, and injective modules; tensor products; chain conditions; Galois theory; cyclotomic extensions; separability; transcendental extensions. Instructors: Aschbacher, Xiang.

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: Xiang, Wilson.

Ma 122 a. Topics in Group Theory. *9 units (3-0-6); first term. Prerequisite: Ma 5 abc or consent of instructor.* Representation theory of finite groups with number theoretic applications. Not offered 1996–97.

EE/Ma 126 ab. 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) first and second terms; (1-4-4) third term.* For course description, see Computer Science.

Ma 130 abc. Algebraic Geometry. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 120 (or Ma 5 plus additional reading).*

Plane curves, rational functions, affine and projective varieties, products, local properties, birational maps, divisors, differentials, intersection numbers, schemes, sheaves, general varieties, vector bundles, coherent sheaves, curves and surfaces. Not offered 1996–97.

Ma 140 abc. Functional Analysis. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 110.* First term: Theory of operators. Second term: Symmetric and selfadjoint operators, spectral analysis of differential operators. Third term: Perturbative theory, functional models for non-selfadjoint operators—methods of complex analysis. Not offered 1996–97.

Ma 142 ab. Ordinary and Partial Differential Equations. *9 units (3-0-6); second, third terms. Prerequisite: Ma 108. Ma 109 is desirable.* The mathematical theory of ordinary and partial differential equations, including a discussion of elliptic regularity, maximal principles, solubility of equations. The method of characteristics. Instructor: Makarov.

Ma 144 ab. Probability. *9 units (3-0-6); second, third terms.* Basic theory, including characteristic functions and limit theorems, random walk, Markov chains, Poisson process, Brownian motion. Instructor: Hof.

Ma 145 ab. Introduction to Unitary Group Representations. *9 units (3-0-6); first, second terms.* The study of representations of a group by unitary operators on a Hilbert space, including finite and compact groups, and to the extent that time allows, other groups. General representation theory of finite groups. Frobenius' theory of representations of semidirect products. The Young tableaux and the representations of symmetric groups. The Peter-Weyl theorem. The classical compact groups and their representation theory. Weyl character formula. Not offered 1996–97.

Ma 147 abc. Dynamical Systems. *9 units (3-0-6); first, second, third terms. Prerequisite: Ma 108, Ma 109, or equivalent.* First term: One-dimensional dynamics, circle homeomorphisms, rotation numbers. Complex dynamics, Julia sets. Second term: Smooth dynamical systems, hyperbolic sets, stable manifolds, structural stability. Markov partitions, symbolic dynamics. Ergodic theory, entropy, Gibbs measures. Third term: Hamiltonian systems. Basic formalism, symplectic geometry, integrable systems, celestial mechanics. Hyperbolicity, ergodic theory of Hamiltonian systems. Periodic orbits, KAM technique. Infinite-dimensional systems. Not offered 1996–97.

Ma 148 ab. Topics in Mathematical Physics. *9 units (3-0-6); first, second terms.* The subject matter will vary from year to year. Among the topics that have been covered in the past are the statistical mechanics of lattice gases, the general theory of Schrödinger operators, constructive quantum field theory, and random and almost periodic Jacobi matrices. May be taken for credit in multiple years. Instructor: Simon.

Ma 151 abc. 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: Candel, Rivin.

Ma 157 a. Geometry and Topology of Manifolds. *9 units (3-0-6); first term. Prerequisite: Ma 151 or equivalent.* The relationship between the hyperbolic geometry of two- and three-dimensional manifolds and their underlying topology. Course content varies widely from year to year so that students may take the course in subsequent years. Not offered 1996–97.

Ma 160 ab. Number Theory. *9 units (3-0-6); second, third terms. Prerequisite: Ma 5.* In this course, the basic structures and results of algebraic number theory will be systematically introduced. Topics covered will include the theory of ideals/divisors in Dedekind domains, Dirichlet unit theorem and the class group, p-adic fields, ramification, abelian extensions of local and global fields. Not offered 1996–97.

The courses labeled Ma 191 are one-shot courses reflecting the interests of faculty, visitors, and students.

Ma 191 abc. Topics in Algebraic Geometry. *9 units (3-0-6); first, second, third terms.* Instructor: Flach.

Ma 191 d. Representations of *GL*(2). *9 units (3-0-6); first term.* Instructor: Ramakrishnan.

Ma 191 e. Reflection Groups and Coxeter Groups. *9 units (3-0-6); first term.* Instructor: Doran.

Ma 191 f. Arrangements of Hyperplanes. *9 units (3-0-6); second term.* Instructor: Doran.

Ma 191 g. Computational Geometry. *9 units (3-0-6); third term.* Instructor: Wolff.

Ma 191 h. Topics in Geometry. *9 units (3-0-6); third term.* Instructor: Rivin.

Ma 191 i. Set Theoretic Methods in Harmonic Analysis. *9 units (3-0-6); first term.* Instructor: Kechris.

Ma 191 j. Topics in Number Theory. *9 units (3-0-6); third term.* Instructor: Shahidi.

Ma 191 k. Topics in Set Theory. *9 units (3-0-6); third term.* Instructor: Magidor.

Ma 191 l. Topics in Complex Analysis. *9 units (3-0-6); third term.* Instructor: Volberg.

Other Ma 191 titles may be announced.

Ma 290. Reading. *Hours and units by arrangement.* Occasionally, advanced work is given through 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. *6 units. Three terms.* Instructor: Kechris.

Ma 324 abc. Seminar in Combinatorics. *6 units.* 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 348 abc. Seminar in Mathematical Physics. *6 units. Three terms.* Instructor: Simon.

Ma 351 abc. Seminar in Topology. *6 units. Three terms.* Instructor: Gabai.

Ma 360 abc. Seminar in Number Theory. *6 units. Three terms.* Instructors: Flach, Ramakrishnan.

Ma 390. Research. *Units by arrangement.*

Ma 392. Research Conference. *Three terms.*

See also the list of courses in Applied Mathematics.

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Additional advanced courses in the field of mechanical engineering may be found listed in other engineering options such as applied mechanics, applied physics, jet propulsion, and materials science.

ME 18 ab. Thermodynamics. *9 units (3-0-6); first, second terms.* An introduction to classical thermodynamics with engineering applications. The first quarter includes: first and second laws; closed and open systems; properties of a pure substance; availability and irreversibility; generalized thermodynamic relations. Second quarter emphasizes applications: gas and vapor power cycles; propulsion; mixtures; combustion and thermochemistry; chemical equilibrium. Instructor: Goodwin.

ME 19 abc. Fluid Mechanics and Gasdynamics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 2, 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. Additional topics may include those related to energy production and conversion, and heat transfer phenomena, at the instructor's discretion. Instructor: Raichlen.

ME 20. Heat Transfer. *9 units (3-0-6); third term. Prerequisites: ME 18 ab, ME 19 ab.* An introduction to heat transfer. Steady-state and transient conduction, including numerical solutions. Forced and natural convective-heat transfer. Heat exchangers. Radiative heat transfer and solar energy. Instructors: Staff.

ME 70. Introduction to the Kinematics of Mechanical Systems. *9 units (3-0-6); second term. Prerequisites: none.* Introduction to the study of planar, rotational, and spatial rigid body motions with applications to linkages and mechanisms. Topics include dimensional synthesis of planar linkages; theory of gears and cams; and screw theory and its application to mechanism analysis. Instructor: Staff.

ME 71. Introduction to Engineering Design. *9 units (3-5-1); third term. Prerequisites: Ph 1 abc, Ma 1 abc, Ph 2 ab, Ma 2 ab, AM 35 ab. Enrollment is limited and will be based on responses to a questionnaire available in the registrar's office during registration. Not offered on a pass/fail basis.* Introduction to mechanical engineering design, fabrication, and visual communication. Concepts are taught through a series of short design projects and design competitions emphasizing physical concepts. Many class projects will involve substantial use of the shop facilities, and construction of working prototypes. Instructor: Burdick.

ME 72. Engineering Design Laboratory. *12 units (3-8-1); first term. Prerequisites: AM 35 abc, ME 71, or equivalent and permission of instructor.*

Enrollment is limited and will be based on responses to a questionnaire available in the registrar's office during registration. Not offered on a pass/fail basis. 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 reviewed and 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. These laboratory units of ME 72 can be used to fulfill a portion of the laboratory requirement in the Engineering and Applied Science Division. Instructor: Antonsson.

ME 73. Machine Component Design. *9 units (3-4-2); second term. Prerequisites: AM 35 abc, ME 72, 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: Staff. Not offered 1996–97.

ME 90 abc. Senior Thesis, Experimental. *9 units; (0-0-9) first term; (0-9-0) second and third terms. Prerequisite: senior status; instructor's permission.* Experimental research supervised by an engineering faculty member. The topic selection is determined by the adviser and the student and is subject to approval by the Mechanical Engineering Undergraduate Committee. First and second terms: midterm progress report and oral presentation during finals week. Third term: completion of thesis and final presentation. The second and third terms may be used to fulfill laboratory credit for EAS. Not offered on a pass/fail basis. Instructor: Murray.

ME/CE 96. Mechanical Engineering Laboratory. *6 or 9 units as arranged with instructor; third term. Prerequisites: ME 18 ab, AM 35 ab.* A laboratory course in the experimental techniques for heat transfer, solid mechanics, and dynamics. Students usually select approximately three regular experiments, but they may propose special investigations of brief research projects on their own. Instructor: Hunt.

CE/ME 97. Fluid Mechanics Laboratory. *6–9 units as arranged with instructor.* For course description, see Civil Engineering.

ME 100. Advanced Work in Mechanical Engineering. The staff in mechanical engineering will arrange special courses on problems to meet the needs of qualified undergraduate students. Graded pass/fail for research and reading. A written report is required for each term.

CE/ME 101 abc. Fluid Mechanics. *9 units (3-0-6).* For course description, see Civil Engineering.

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. A written report is required for each term of work. Instructors: Staff.

ME 115 ab. Introduction to Kinematics and Robotics. *9 units (3-0-6); first and second terms. Prerequisites: Ma 2, AMa 95 ab recommended.* Introduction to the study of planar, rotational, and spatial motions with applications to robotics, computers, computer graphics, and mechanics. Topics in kinematic analysis will include screw theory, rotational representations, matrix groups, and Lie algebras. Applications include robot kinematics, mobility in mechanisms, and kinematics of open and closed chain mechanisms. Additional topics in robotics include path planning for robot manipulators, dynamics and control, and assembly. Course work will include laboratory demonstrations using simple robot manipulators. Instructors: Burdick, Murray.

ME 119 abc. Heat Transfer and Thermodynamics. *9 units (3-0-6); first, second, third terms. Prerequisites: ME 18, ME 19, ME 20, AMa 95 or equivalent, CE/ME 101 or Ae 101 (may be taken concurrently).* The first term covers the fundamentals of classical and statistical thermodynamics. Topics include: basic postulates, thermodynamic potentials, work and heat, chemical equilibrium, phase transitions, and the thermodynamic properties of solids, liquids, and gases. The second and third terms focus on heat, mass, and momentum transfer. Topics include: transport properties, conservation equations, conduction heat transfer in solids, convective heat, mass, and momentum transport in laminar and turbulent flows, phase change processes, thermal radiation, and selected engineering applications. Instructor: Sahu.

ME 125 abc. Concurrent Spacecraft Systems Engineering. *9 units (3-0-6); first term. 12 units (2-4-6); second and third terms. Prerequisites: Ph 1 abc, Ma 1 abc, Ph 2 ab, Ma 2 ab, AM 35 ab. Not offered on a pass/fail basis.* This course presents the fundamentals of modern concurrent systems engineering in the context of spacecraft and mission engineering. The basic theory and practical application of the following topics are addressed: concurrent systems engineering principles and methods; spacecraft systems analysis; attitude determination and control; rocket propulsion; space avionics; payload integration; spacecraft mechanical and thermal design; and elementary astrodynamics. ME 125 a: Spacecraft and mission design problems selected by the instructor. ME 125 b,c: Spacecraft and mission design studies in which students assume the roles of cognizant engineers. Instructor: Sercel.

ME 131. Advanced Robotics: Manipulation and Sensing. *9 units (3-6-0); third term. Prerequisite: ME 115 ab.* The course focuses on current topics in robotics research in the area of robotic manipulation and sensing. Past topics have included advanced manipulator kinematics, grasping and dextrous manipulation using multifingered hands, and advanced obstacle avoidance and motion planning algorithms. The lectures will be divided between a review of the appropriate analytical techniques and a survey of the current research literature. Course work will focus on an independent research project chosen by the student. Offered alternate years; not offered 1996–97. Instructors: Staff.

ME 132. Advanced Robotics: Navigation and Vision. *9 units (3-6-0); third term. Prerequisite: ME 115 ab.* The course focuses on current topics in robotics research in the area of autonomous navigation and vision. Topics will include mobile robots, multilegged walking machines, use of vision in navigation systems. The lectures will be divided between a review of the appropriate analytical techniques and a survey of the current research literature. Course work will focus on an independent research project chosen by the student. Offered alternate years; offered 1996–97. Instructors: Staff.

ME 171. Computer-Aided Engineering Design. *9 units (3-0-6); third term. Prerequisites: AMa 95 abc or AM 114 abc, AM 35 abc, ME 72, CS 1, or equivalent, working knowledge of the C computer programming language.* Design of engineering systems using computer techniques. Topics include the design process; interactive computer graphics; curves and surfaces (including cubic and B-splines); solid modeling (including constructive solid geometry and boundary models); kinematic and dynamic mechanism simulation; single and multivariable optimization; optimal design, and symbolic manipulation. Assessment of CAD as an aid to the design process. Students will design several parts and/or a complete device. Instructor: Antonsson.

ME 175. Fuzzy Sets in Engineering. *9 units (3-0-6); second term. Prerequisites: AMa 95 abc or AM 114 abc, working knowledge of the C computer programming language.* The relatively new mathematics of fuzzy sets has recently been used to represent and manipulate vague and imprecise information in engineering. This course will present the basics of fuzzy sets and fuzzy mathematics and explore applications in the areas of data representation; function representation; filters and triggers; engineering design and optimization, including (fuzzy) set-based concurrent engineering. Instructor: Antonsson.

ME 177. Introduction to Mechanical CAD. *4 units (1-0-3); third term. Prerequisites: none.* An introduction to the use of one or more mechanical computer-aided design (CAD) packages via a series of weekly instructional exercises. 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 graduate students. Graded pass/fail; a written report is required for each term of work.

ME 202 abc. Engineering Two-Phase Flows. *9 units (3-0-6). Prerequisites: AMa 95 abc, CE/ME 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. Not offered 1996–97. Instructor: Brennen.

ME 206 ab. Acoustic Waves in Fluids. *9 units (3-0-6); first, second terms. Prerequisites: AM 114 abc, AM 125 abc (may be taken concurrently), or equivalent. Recommended prerequisite: CE/ME 101 abc or Ae 101 abc or equivalent.* This course stresses the fundamentals of acoustic wave motion in gases, especially the interactions of acoustic waves with flows and solid boundaries, and the generation of acoustic waves by turbulence. Analogies with electromagnetics, water waves, geophysics, and other fields will be discussed. Emphasis will be given to various analytical and computational techniques for solving wave equations, but practical results relevant to engineering devices will also be discussed. *First term:* Review of the equations of motion, thermodynamic relations, constitutive relations; review of Fourier Analysis; the speed of sound; small amplitude disturbances and the equations of linear acoustics; compact source regions and multipole expansions; sound from radiating bodies; wave guides and lumped-parameter models of sound transmission; acoustic energy and intensity; dissipative effects; nonlinear effects in sound propagation, shock waves, and sonic booms. *Second term:* Low-frequency scattering from bodies and flow inhomogeneities; geometrical acoustics, diffraction, and caustics; sound generation by turbulence; acoustic analogy theories; subsonic and supersonic jet noise; vortex sound theory; computational methods in acoustics; nonreflecting boundary conditions. Instructor: Colonius.

ME 219. Advanced Topics in Thermal Sciences. *Prerequisite: ME 119 or consent of instructor.* Current topics in thermal sciences research. Course content will depend on interests of students and instructor. Not offered every year. Instructors: Staff.

ME 300. Research in Mechanical Engineering. *Hours and units by arrangement.* Research in the field of mechanical engineering. By arrangement with members of the staff, properly qualified graduate students are directed in research.

MUSIC

These courses are open only to students who have fulfilled the freshman humanities requirement.

Mu 101. Selected Topics in Music. *Offered by announcement. 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.

Mu 121. Understanding Music. *9 units (3-0-6); first term.* The Listening Experience I. How to listen to and what to listen for in classical and other musical expressions. Listening, analysis, and discussion of musical forms, genres, and styles. Course is intended for musicians as well as nonmusicians and is strongly recommended as an introduction to other music courses. Not offered 1996–97. Instructor: Neenan.

Mu 122. Form and Style in Music. *9 units (3-0-6); second term.* The Listening Experience II. One or more major genres (i.e., symphony, concerto, opera, etc.) will be traced through several periods of music history. Course will include guided listening and analysis intended to deepen the students' understanding of various composers' approaches to similar forms of musical expression. Not offered 1996–97. Instructor: Neenan.

Mu 123. Major Figures. *9 units (3-0-6); third term.* A major personality in the history of music (i.e., Bach, Mozart, Beethoven) will be studied in depth. Course to be coordinated with major off-campus concerts, commemorations, and other events. Specific course content to be announced prior to registration. Not offered 1996–97. Instructor: Neenan.

Mu 127. 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: Neenan.

Mu 128. Harmony I. *9 units (3-0-6); second term. Prerequisite: Mu 127 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: Neenan.

Mu 129. Harmony II. *9 units (3-0-6); third term. Prerequisite: Mu 128 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: Neenan.

Mu 131. Music of Courts and Cathedrals. *9 units (3-0-6); first term.* Explores the music of the Middle Ages and Renaissance, including that of the great medieval monasteries, cathedrals, and chapels. Will include study of the music and dances from courts, towns, and countryside by trouveres, troubadours, and other entertainers. Instructor: Neenan.

Mu 132. Monteverdi to Bach: Music of the Baroque. *9 units (3-0-6); second term.* Survey of musical forms and composers during the period 1600–1750. To include masterworks of Monteverdi, Purcell, Vivaldi, Handel, Bach, and others. Instructor: Neenan.

Mu 133. Music of the Age of Enlightenment. *9 units (3-0-6); third term.* Music of the so-called "pre-Classic" and "Classic" periods (ca. 1750–1825), with emphasis on C. P. E. Bach, Gluck, Haydn, Mozart, and the early works of Beethoven. Instructor: Neenan.

Mu 134. Music of the Early Romantics. *9 units (3-0-6); first term.* Romanticism in music during the early 19th century. Examines a wealth of music from late Beethoven to Schubert, Berlioz, Chopin, Mendelssohn, Schumann, and Liszt. Not offered 1996–97. Instructor: Neenan.

Mu 135. Music of the Late Romantics. *9 units (3-0-6); second term.* An exploration of the music of the late 19th century. Included will be nationalist composers: Dvorak, Mussorgsky, and Grieg; major symphonists: Brahms, Bruckner, and Mahler; and opera composers: Verdi, Wagner, and Puccini. Not offered 1996–97. Instructor: Neenan.

Mu 136. Music of Our Time. *9 units (3-0-6); third term.* The diversity of music in the 20th century will be explored. Included will be music of composers from Stravinsky, Schoenberg, and Bartok to John Adams and Phillip Glass. Course will include music for film, electronically generated music, and a field trip to an electronic music studio. Not offered 1996–97. Instructor: Neenan.

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. Instructors: Staff.

PA 30 abc. Women's Glee Club. *3 units (0-3-0); first, second, third terms.* Study and performance of the choral repertoire for women's voices encompassing all styles, all periods. Includes both group and individual instruction; campus and off-campus performances.

Instructor: Hubbard.

PA 31 abc. Chamber Music. *3 units (0-3-0); first, second, third terms.* Study and performance of music for ensembles of three to seven members. Literature ranges from the Baroque to contemporary eras. Open to students who play string, woodwind, or brass instruments, or piano. Instructor: D. Bing.

PA 32 abc. Symphony Orchestra. *3 units (0-3-0); first, second, third terms.* Study and performance of music written for full symphony orchestra and chamber orchestra. The orchestra performs both the standard symphonic repertoire and contemporary music. Two and a half hours of rehearsal per week. Instructor: Gross.

PA 33 abc. Concert Band. *3 units (0-3-0); first, second, third terms.* Study and performance of music written for the classical wind ensemble. Emphasis is placed on the traditional literature, but the study of contemporary music is an important part of the curriculum. Instructor: W. Bing.

PA 34 abc. Jazz Band. *3 units (0-3-0); first, second, third terms.* Study and performance of all styles of jazz music, from Duke Ellington to Pat Metheny. Jazz improvisation is also stressed. Instructor: W. Bing.

PA 35 abc. Guitar. *3 units (0-3-0); first, second, third terms.* Offered on three levels: beginning, intermediate, and advanced. Instruction in a strong classical technique, followed by exploration of various styles of guitar—classical, flamenco, folk, and popular. Instructor: Denning.

PA 36 abc. Men's Glee Club. *3 units (0-3-0); first, second, third terms.* Classical repertoire from Renaissance to the present day for both men's and mixed voices, often with orchestra. Includes both group and individual instruction. Three hours of rehearsal per week. No prerequisite. Instructor: Caldwell.

PA 37 abc. Chamber Singers.*3 units (0-3-0); first, second, third terms.* A sixteen-voice SATB auditioned student ensemble, the Chamber Singers provide costumed entertainments for the Athenaeum in December and perform annually on the All-Mozart Concerts in the spring. One and a half hours of rehearsal per week. Instructor: Caldwell.

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 61 abc. Silkscreen and Airbrush. *3 units (0-3-0); first, second, third terms.* Instruction in silkscreen and airbrush techniques, using a variety of media including T-shirts. Instructor: Barry.

PA 62 abc. Drawing and Painting. *3 units (0-3-0); first, second, third terms.* Instruction in techniques of drawing and painting, utilizing models, architecture, and still-life as subjects. Instructor: Barry.

PA 63 abc. Ceramics. *3 units (0-3-0); first, second, third terms.* Instruction in the techniques of creating ceramics, including slab roller and potter's wheel, and glazing methods. Instructor: Freed.

PHILOSOPHY

These courses are open only to students who have fulfilled the freshman humanities requirement.

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 toward 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. Not offered 1996–97. Instructors: Staff.

Pl 102. Selected Topics in Philosophy. *9 units (3-0-6). Offered by announcement. Advanced credit to be determined on a course-by-course basis by instructor.* Instructors: Staff and visiting lecturers.

SES/Pl 122. Philosophy of Science.* *9 units (3-0-6).* For course description, see Science, Ethics, and Society.

SES/Pl 125. Philosophy and Biology.* *9 units (3-0-6).* For course description, see Science, Ethics, and Society.

SES/Pl 126. Biomedical Ethics.* *9 units (3-0-6).* For course description, see Science, Ethics, and Society.

SES/Pl 127. Ethics in Research.* *4 units (2-0-2) or 9 units (2-0-7).* For course description, see Science, Ethics, and Society.

SES/Pl 131. Philosophy of Mind and Psychology.* *9 units (3-0-6).* For course description, see Science, Ethics, and Society.

Pl 150. History of Early Modern Philosophy.* *9 units (3-0-6).* A study of important figures and ideas in the empiricist and rationalist traditions in the period from Descartes through Kant. Material covered will vary depending on the decision of the instructor, but will include readings from some of the following: Descartes, Spinoza, Leibniz, Kant, Hobbes, Locke, Berkeley, and Hume. Not offered 1996–97. Instructor: Cowie.

SES/Pl 169. Selected Topics in Science, Ethics, and Society. *9 units (3-0-6).* For course description, see Science, Ethics, and Society.

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. Not offered 1996–97. Instructors: Staff.

SES/Pl 185. Moral Philosophy.* *9 units (3-0-6).* For course description, see Science, Ethics, and Society.

* *Advanced courses with credit toward the 36-unit humanities requirement. Other advanced courses receive credit toward the 36-unit H&SS requirement. See page 152.*

PHYSICAL COMPUTATION AND COMPLEX SYSTEMS

(See Physics)

PHYSICAL EDUCATION

PE 1. Student Designed Fitness. *3 units.* Independent fitness program as arranged with instructor, three times a week. Proposals must be submitted in writing during first week of each term. Instructor: Jackson.

PE 2. Skin Diving. *3 units. A prerequisite for PE 3 (Scuba).* Fundamentals of skin diving and oceanography. Instructor: Dodd.

PE 3. Scuba, Beginning. *3 units. Prerequisite: PE 2.* Open Water Scuba Diving will involve classroom instruction on diving physics, physiology, water safety, equipment, and oceanography. There will be confined water training (pool), and open water training consisting of two dives from a local beach and two dives from a boat. A third trip will be to conduct snorkeling. Students must pass a difficult swim test (see instructor for men's and women's qualifying standards) prior to enrollment. Instructor: Dodd.

PE 5. Jazz Dance, Beginning. *3 units.* All basic steps in Jazz Dance will be covered with an emphasis placed on proper warm-up techniques, increasing flexibility through stretching, working with rhythm, and memorizing simple routines. Instructor: Eckler.

PE 10. Aerobic Dance. *3 units.* Each class includes a thorough warm-up, a cardiovascular workout phase that also includes a variety of conditioning exercises designed to tone and strengthen various muscle groups, and a relaxation cool-down and stretch, all done to music. Instructor: Webster.

PE 14. Basketball Skills, Beginning and Beginning/Intermediate. *3 units.* Features fundamental instruction on shooting, dribbling, passing, defensive positioning, and running an offense. Class includes competitive play and free-throw shooting. Instructor: Victor.

PE 20. Fencing, Beginning and Intermediate/Advanced. *3 units.* Introduction to Fencing to include basic techniques of attack, defense, and counter-offense. Lecture topics include fencing history, strategy, scouting and analysis of opponents, and gamesmanship. Intermediate/Advanced covers foil theory and techniques, group drill-work, and video analysis. Instructor: Clovis.

PE 23. Track and Field, Beginning. *3 units.* Features instruction on ten different track events, allowing the student an opportunity to attempt a variety of skills to include: shot put, discus, javelin, sprints, hurdles, long jump, high jump, middle and long distance running, and the relays. Class emphasis placed on learning new skills safely with time devoted to warm-up and stretching, as well as weight training for specific events. Instructor: Bene.

PE 24. Yoga, Beginning. *3 units.* Hatha Yoga is a system of physical postures designed to stretch and strengthen the body, calm the nervous system, and center the mind. It is a non-competitive activity designed to reduce stress for improved health of body and mind while increasing flexibility, strength, and stamina, and reducing the chance of athletic injury. Instructor: Tartaglione.

PE 27. Ultimate Frisbee. *3 units.* Instruction will center on developing student's knowledge of techniques, rules, strategy, etiquette, and safety regulations of the game. Students will develop the ability to perform all skills necessary to play the game confidently on a recreational basis. Instructor: Staff.

PE 30. Golf; Beginning, Intermediate, and Advanced. *3 units.* Beginning class covers fundamentals of the game, including rules, terminology, etiquette, basic grip, set-up, swing, and club selection for each shot. The following shots will be covered: full swing (irons and woods), chip, pitch, sand, and putting. Intermediate class will focus on swing development of specialty shots and on course play management. Advanced instruction covers course management and mental aspects of performance. Instructor: Jackson.

PE 35. Diving, Beginning/Intermediate. *3 units.* Teaches the fundamentals of springboard diving to include basic approach, and five standard dives. Intermediate class includes instruction in the back somersault, forward somersault, forward somersault full twist, and reverse somersault. Instructor: Dodd.

PE 36. Swimming, Beginning/Intermediate and Advanced. *3 units.* Instruction in all basic swimming strokes, including freestyle, elementary backstroke, racing backstroke, breaststroke, sidestroke, and butterfly. Advanced class focuses on proper technique of the four competitive strokes using video and drills along with instruction on training methods and proper workout patterns. Instructor: Dodd.

PE 38. Water Polo. *3 units.* Basic recreational water polo with instruction of individual skills and team strategies. A swimming background is encouraged. Instructor: Dodd.

PE 44. Karate (Shotokan), Beginning and Intermediate/Advanced. *3 units.* Fundamental self-defense techniques including form practice and realistic sparring. Emphasis on improving muscle tone, stamina, balance, and coordination, with additional requirement of memorizing one or more simple kata (forms). Instructor: Bankes.

PE 46. Karate (Tang Soo Do), Beginning and Intermediate/Advanced. *3 units.* Korean martial art focusing on self-defense and enhancement of physical and mental health. Practical and traditional techniques such as kicks, blocks, hyungs (forms) are taught. Intermediate/Advanced level incorporates technique combinations, sparring skills, jumping and spinning kicks, and history and philosophy. Instructor: Pasqualino.

PE 50. Badminton, Beginning/Intermediate. *3 units.* Basic skills will be taught, including grips, services, overhead and underhand strokes, and footwork. Rules, terminology, and etiquette are covered. Intermediate skills such as drives, service returns, forehand and backhand smash returns, attacking clears, and sliced drop shots are taught. Singles and doubles play along with drill work throughout the term. Instructor: Staff.

PE 54. Racquetball, Beginning and Intermediate/Advanced. *3 units.* Fundamentals of the game will be emphasized, including rules, scoring, strategy, and winning shots. All types of serves will be covered, as well as a variety of shots to include kill, pinch-off, passing, ceiling, and off-the-backwall. Singles and doubles games will be played. Intermediate/Advanced course will review all fundamentals with a refinement of winning shots and serves and daily games. Instructors: D'Auria, Nelson, Torres.

PE 56. Squash; Beginning, Intermediate, Advanced. *3 units.* Learn by playing as the basic rules and strokes are taught. Fundamentals to include proper grip, stroke, stance, and positioning, along with serve and return of serve. Intermediate and Advanced classes will concentrate on skill development with the inclusion of forehand and backhand drives, lobs, volleys, and drops, with an emphasis on court movement, shot selection, and tactics. Instructors: Bresanello, Jackson.

PE 60. Tennis; Beginning, Beginning/Intermediate, Intermediate, and Advanced. *3 units.* Stroke fundamentals, singles and doubles play, plus rules, terminology, and etiquette are covered in all classes. Beginning class emphasizes groundstrokes, volleys, serve, and grips. Beginning/Intermediate class is for those players caught between levels and will concentrate on strategy, drills, and match play. Intermediate level focuses on improving technique, footwork, and court positioning, with instruction on approach shots, volleys, overheads, and lobs. Advanced course fine tunes each individual's skills while targeting weaknesses. Instructors: D'Auria, Nelson, Bower.

PE 70. Weight Training, Beginning/Intermediate. *3 units.* Active participation in a strength and conditioning program designed for individual skill level and desired effect. Course will enlighten students to various methods, terminology, and techniques in the areas of isokinetic strength and cardiovascular fitness training. Instructors: D'Auria, Victor, Bene.

PE 77. Volleyball; Beginning, Intermediate, and Advanced. *3 units.* Fundamental instruction on drills, strategies, and rules, with game-playing opportunity. Basics of serve, pass, set, spike, defense, and court position will be taught. Intermediate level focuses on skill development to a more competitive standard and features multiple offenses and understanding officiating. Advanced class emphasizes specialization of all skills, court position, and multiple offenses and defenses. Instructor: Burl.

PE 82. Rock Climbing, Beginning and Intermediate. *3 units.* Basic skills will be covered to utilize each student's strength and endurance while learning to climb safely. Use of climbing rope and other equipment for belaying, rappelling, and emergency ascent will be taught. Skills will be demonstrated and practiced on climbing wall and then later at off-campus climbing site. Intermediate level will include ascents on prussiks or jumars, with more off-campus climbing.

Instructors: Ramos, Cox.

PE 84. Table Tennis, Beginning, Intermediate, and Advanced. *3 units.* Introductory course to provide general knowledge of equipment, rules, and basic strokes, including topspin drive, backspin chop, and simple block in both forehand and backhand. Multi-ball exercise with robot machines and video utilized. Intermediate class covers regulations for international competition and fundamentals of winning table tennis, including footwork drills, smash, serve, and attack. Instructor: Wang.

Intercollegiate and Club Teams

PE 6. Club Hockey Team (Men). *3 units.* Coach: Staff.

PE 8. Club Water Polo Team (Women). *3 units.* Coach: Dodd.

PE 83. Intercollegiate Basketball Team (Women). *3 units.* Coach: TBD.

PE 85. Intercollegiate Track and Field Team. *3 units.* Coach: Bene.

PE 87. Intercollegiate Swimming Team (Men and Women). *3 units.* Coach: Dodd.

PE 89. Intercollegiate Fencing Team (Men and Women). *3 units.* Coach: Clovis.

PE 90. Intercollegiate Water Polo Team (Men). *3 units.* Coach: Dodd.

PE 91. Intercollegiate Basketball Team (Men). *3 units.* Coach: Victor.

PE 92. Intercollegiate Soccer Team (Men). *3 units.* Coach: Howells.

PE 93. Intercollegiate Baseball Team (Men). *3 units.* Coach: D'Auria.

PE 94. Intercollegiate Golf Team (Men). *3 units.* Coach: Jackson.

PE 95. Intercollegiate Tennis Team (Men). *3 units.* Coach: Bower.

PE 96. Intercollegiate Tennis Team (Women). *3 units.* Coach: Nelson.

PE 97. Intercollegiate Cross Country Team (Men and Women). *3 units.* Coach: Bene.

PE 99. Intercollegiate Volleyball Team (Women). *3 units.* Coach: Burl.

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 in Ph 1 a; electricity and magnetism, and special relativity, in Ph 1 b, c. Emphasis on physical insight and problem solving. Ph 1 b, c is divided into two tracks: the Practical Track emphasizing practical electricity with take-home lab kits, and the Analytic Track which has no lab component but teaches and uses methods of multivariable calculus. Students will be given information helping them to choose a track at the end of fall quarter. Lecturers: McKeown, Lange, Filippone, Martin. Section leaders: Bradford, Harrison, Hogg, Jones, Maron, Newman, Politzer, Weinberger.

Ph 2 ab. Statistical Physics, Waves, and Quantum Mechanics.* *9 units (4-0-5); first, second terms. Prerequisites: Ph 1 abc, Ma 1 abc, or their equivalents.* The second year of a five-term introductory course in classical and modern physics. Topics to be covered include statistical physics and classical waves first term, introductory quantum mechanics second term. Lecturers: Goodstein, Hughes.

** Students may transfer from Ph 12 b to Ph 2 b any time during the quarter, before the last day for dropping courses. The final grade will be based on the combined record in the two courses.*

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: Neugebauer, Skelton.

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: Neugebauer, Skelton.

Ph 5. Physics Laboratory. *9 units; first term. Prerequisites: Ph 1 abc, Ph 3, or their equivalents.* A laboratory course dealing with "operational" electronics with emphasis on analog electronics. The following topics are studied: RC circuits, electrical oscillations, operational amplifiers, diodes, and transistors. Combining diodes, transistors, and operational amplifiers; computer data acquisitions. The course culminates in a two-week project of the student's choosing. Instructors: Neugebauer, Skelton.

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: Neugebauer, Skelton.

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: Neugebauer, Skelton.

Ph 10 abc. Frontiers in Physics. *3 units (2-0-1); 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: Tombrello.

Ph 11 abc. Research Tutorial. *6 units (2-0-4); second and third terms of freshman year and first term of sophomore year.* A small number of students will be offered the opportunity to enroll in this tutorial, the purpose of which is to demonstrate how research ideas arise, and are evaluated and tested, and how those ideas that survive are developed. This is accomplished by doing individual, original projects. There will be weekly group meetings and individual tutorial meetings with the instructor. Support for summer research at Caltech between the freshman and sophomore years will be automatic for those students making satisfactory progress. Graded pass/fail. Instructor: Tombrello.

Ph 12 abc. Waves, Quantum Physics, and Statistical Mechanics.* *9 units (4-0-5); 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: classical waves; 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, Preskill.

* *Students may transfer from Ph 12 b to Ph 2 b any time during the quarter, before the last day for dropping courses. The final grade will be based on the combined record in the two courses.*

Ph 20, 21, 22. Freshman/Sophomore Computational Physics Laboratory. A series of courses on the application of computational techniques to simulate or solve simple physical systems, with the intent of aiding both physics understanding and programming ability. Instructor: Prince.

20. *6 units (0-6-0); first, second terms. Prerequisite: CS 1 or equivalent experience with computers.* Introduction to computing and its application to problems in classical mechanics. Use of spreadsheets in physical problems, numerical integration, and numerical simulation of differential equations of motion. Simulation of orbital mechanics.

21. *6 units (0-6-0); second, third terms. Prerequisite: Ph 20 or equivalent experience with computers and numerical techniques.* Introduction to the use of symbolic manipulation programs and expert systems for mathematics. Use of root-finding and Monte Carlo numerical techniques. Multi-variable minimization techniques, including neural networks. Discrete-element electromagnetism.

22. *6 units (0-6-0); second, third terms. Prerequisite: Ph 20 or Ph 21 or equivalent experience with computers.* Laboratory applications of computers. Interfacing computers to external sensors and control elements. One supervised project involving development of a computer hardware interface. Not offered 1996–97.

Ph 70. Oral Presentation. *3 units; second term.* A seminar on physics topics of contemporary interest, with emphasis on organization and communication. Intended to provide guidance and practice in the effective oral presentation of scientific material. Instructor: Hitlin.

Ph 76 a. Atomic/Laser Physics Laboratory. *9 units; first, second, third terms; limited enrollment. Prerequisites: Ph 5 or Ph 6 or APh 24, and Ph 7.* A one-term course in which students undertake a series of laboratory experiments in atomic and laser physics. Students will assemble a tunable frequency-stabilized 670-nm diode laser and perform several spectroscopic experiments with it. Topics include saturated absorption spectroscopy, optical pumping, nonlinear spectroscopy, laser cooling and trapping of atoms, and others. Instructor: Libbrecht.

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: Kavanagh.

Ph 78 abc. Senior Thesis Experimental. *9 units; first, second, third terms. Prerequisite: to register for this course the student must obtain approval of the chair of the Physics Undergraduate Committee (Gomez). Open only to senior physics majors.* This research must be supervised by a faculty member, your thesis adviser. Laboratory work is required for this course. Two fifteen-minute presentations to the Physics

Undergraduate Committee are required, one at the end of the first term and the second at the midterm week of the third term. The written thesis must be completed and distributed to the committee one week before the second presentation. Not offered on pass/fail basis. See note below.

Ph 79 abc. Senior Thesis Theoretical. *9 units; first, second, third terms. Prerequisite: to register for this course the student must obtain approval of the chair of the Physics Undergraduate Committee (Gomez). Open only to senior physics majors.* This research must be supervised by a faculty member, your thesis adviser. Two fifteen-minute presentations to the Physics Undergraduate Committee are required, one at the end of the first term and the second at the midterm week of the third term. The written thesis must be completed and distributed to the committee one week before the second presentation. Not offered on pass/fail basis. See note below.

Note: Students wishing assistance in finding an adviser and/or a topic for a senior thesis are invited to consult with the chair of the Physics Undergraduate Committee, or any other member of this committee. A grade will not be assigned in Ph 78 or Ph 79 until the end of the third term. 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 ab, Ma 2, 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-$^1/_2$ systems, and selected topics in atomic, solid-state, nuclear, and particle physics. Instructor: Weinstein.

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. In 1996–97, offered second and third terms.

Ph 103 b. Order-of-Magnitude Physics. *Second term.* Emphasis will be on using basic physics to understand complicated systems. Examples will be selected from properties of materials, geophysics, weather, planetary science, astrophysics, cosmology, biomechanics, etc. Instructors: Goldreich, Phinney.

Ph/Bi 103 c. Neuroscience for Physicists and Engineers. *Third term.* A reading and discussion course on topics ranging from the function of single neurons to methods for studying multineural activity in the intact brain. Possible topics are the nerve cell; ion channels; synapses; electrical recording; vision; positron and NMR tomography; and neural modeling. Enrollment limited to 30. Instructor: Pine.

Ph 105. Analog Electronics for Physicists. *9 units; first term. Prerequisites: Ph 1 abc, Ph 3, or their equivalents (the take-home lab of Ph 1* *bc may be substituted for Ph 3).* A laboratory course dealing with "operational" electronics with emphasis on analog electronics. The following topics are studied: RC circuits, electrical oscillations, operational amplifiers, diodes, and transistors. Combining diodes, transistors, and operational amplifiers; computer data acquisition. The course culminates in a two-week project of the student's choosing. Instructors: Neugebauer, Skelton.

Ph 106 abc. Topics in Classical Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 2 ab or Ph 12 abc, Ma 2.* An intermediate course in the 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: Weichman, Zmuidzinas, Phillips.

Ph 118 ab. Electronic Circuits and Their Application to Physical Research. *9 units (3-0-6); second, third terms. Prerequisite: Ph 105 or equivalent.* A lecture course on 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; not offered 1996–97.

Ph 125 abc. Quantum Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 2 ab. 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, and identical particles. Instructor: Weinstein.

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, and knowledge of basic thermodynamics (Ph 12 c or APh 17).* A self-contained course beginning with a thorough introduction to the formalism of modern statistical mechanics, then proceeding through a series of progressively more advanced topics including ideal and weakly nonideal classical and quantum fluids; phonons and crystal lattice vibrations; black body radiation; the Mayer cluster expansion and theories of dense fluids; Brownian motion, time-dependent correlations, and linear response; and the modern theory of phase transitions, including an introduction to the renormalization group. In 1996–97, offered second and third terms. Instructor: Mitra.

Ph 129 abc. Mathematical Methods of Physics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 106 abc or the equivalent. Recommended: AMa 95 abc or Ma 108 abc.* Practical methods of summing series, integrating, and solving differential equations, including numerical methods. The special functions (Bessel, Elliptic, Gamma, etc.) arising in physics, as well as partial differential equations, orthogonal functions, integral equations and transforms, tensors, linear spaces and operators, group theory, and probability and statistics. Instructors: Vogel, Gottschalk, Porter.

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 1996–97, elementary particle physics, nuclear physics, and condensed matter physics. Terms may be taken separately. Instructors: Porter, McKeown, Weichman.

** Physics graduate students cannot take Ph 135 or Ph 136 on a pass/fail basis.*

Ph 136 abc. Applications of Classical Physics.* *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 106 abc or equivalent.* Applications of classical physics to topics of interest in contemporary "macroscopic" physics. Continuum physics and classical field theory; elasticity and hydrodynamics; plasma physics; magnetohydrodynamics; thermodynamics and statistical mechanics; gravitation theory, including general relativity and cosmology; modern optics. Content will vary from year to year, depending on the instructor. An attempt will be made to organize the material so that the terms may be taken independently. Instructors: Cross, Thorne.

** Physics graduate students cannot take Ph 135 or Ph 136 on a pass/fail basis.*

Ph 138 ab. Topics in Classical Physics. *9 units (3-0-6); second, third terms. Prerequisite: Ph 106 abc or equivalent.* In 1996–97, this course will concentrate on various aspects of physical oceanography including internal waves, wind generation of surface waves, the statistics of surface wave fields in the ocean, transport of energy by surface waves, the interaction of internal and surface waves, etc. There will also be excursions into other aspects of fluid mechanics, for example, shock waves. Instructor: Zachariasen.

Ay/Ph 145. Signal Processing and Data Analysis. *9 units (3-0-6).* For course description, see Astronomy.

Ph 151 ab. Algorithms and Applications of Physical Computation and Complex Systems. *9 units (3-3-3); first, second terms.* Computational techniques and the relation between the physical structure of problems and computers, illustrated by applications in a variety of scientific fields. Cellular automata, parallel algorithms, and multiscale methods will be covered. The course will use parallel computers, including hypercube computers and the Connection Machine. Not offered 1996–97.

Ph 161 ab. Introduction to Complex Systems. *9 units (3-0-6); first, second terms. Prerequisites: Ph 136 or AMa 95 or Ph 129 provide a useful but not essential background.* An introduction to nonequilibrium physics, using systems from physics, fluid dynamics, chemistry, and biology as examples. The first term will study dissipative chaos. The emphasis of the second term will be the formation of spatial structures (sometimes called "dissipative structures" or "pattern formation"). Some familiarity with solutions to partial differential equations will be assumed, and computer assignments should be expected in the first term. Offered alternate years; not offered 1996–97.

Ph 171. Reading and Independent Study. *Units in accordance with work accomplished.* Occasionally, advanced work involving reading, special problems, or independent study is carried out under the supervision of an instructor. Approval of the instructor and of the student's departmental adviser or registration representative must be obtained before registering. Graded pass/fail.

Ph 172. Experimental Research in Physics. *Units in accordance with work accomplished.* Approval of the student's research supervisor and department adviser or registration representative must be obtained before registering. Graded pass/fail.

Ph 173. Research in Theoretical Physics and PCCS. *Units in accordance with work accomplished.* Approval of the student's research supervisor and departmental adviser or registration representative must be obtained before registering. Graded pass/fail.

CNS/Ph 175. Artificial Life. *9 units (3-0-6).* For course description, see Computation and Neural Systems.

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 1996–97.

CNS/Bi/Ph 185. Collective Computation. *9 units (3-1-5).* 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 will include electroweak and hadronic interactions in nuclear systems. Not offered 1996–97.

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: Frautschi.

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. Not offered 1996–97.

Ph 220 abc. Condensed Matter Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 98 or Ph 125 or equivalent; statistical physics at level of APh 105 or Ph 127 also useful but not required.* The first and second terms will provide an intensive focus upon fundamental concepts of condensed matter physics and their experimental underpinnings: simple models of the properties of solids; crystal lattices, symmetries, and binding; phonons, specific heat, and dispersion relations; electronic states in metals, semiconductors, and insulators; transport and scattering processes. Topics introduced may include disorder and localization; optical properties of solids; physics of surfaces, interfaces, and heterostructures; mesoscopic systems. In 1996–97, offered first and second terms only, but note Ph/APh 223 second and third terms. Instructor: Roukes.

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. Not offered 1996–97.

Ph/APh 223 abc. Advanced Topics in Condensed Matter Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 220 or equivalent, or permission of the instructor.* Content includes advanced topics in theoretical and experimental condensed matter physics, emphasizing the application of formal methods such as quantum field theory and group theory to diverse experimental phenomena in both the solid and liquid state. In 1996–97, only Ph 223 a and Ph 223 b will be offered in the second and third terms. Topics to be covered include second quantization and many-body techniques; group theory and its application to electronic band structures, phonon spectroscopy and optical properties of metals and semiconductors; microscopic and phenomenological theories of superconductivity; and magnetism. Instructor: Yeh.

Ph 224 abc. Space Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 98, Ph 106, or equivalent.* Instrumental and observational aspects of X-ray, cosmic-ray, and gamma-ray astrophysics, with emphasis on topics of current interest. Analysis of astronomical and technical aspects of current and future space physics and astronomy missions. Not offered 1996–97.

Ph 225 ab. Quantum Optics. *9 units (3-0-6). Prerequisite: Ph 98 or Ph 125 or equivalent; the quantum optics term of Ph 135 or permission of the instructor.* An introduction to experimental and theoretical quantum optics with emphasis on modern topics related to quantum measurement and to dissipative quantum dynamics. The course will include discussions of the classical and quantum theories of coherence, as well as of the interaction of the radiation field with simple atomic systems. Not offered 1996–97.

Ph 228 ab. Topics in Mathematical Physics. *9 units (3-0-6). Prerequisite: instructor's permission.* Content changes from year to year. Not offered 1996–97.

Ph 229 abc. Advanced Mathematical Methods of Physics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 129 abc or equivalent.* Content changes from year to year. In 1996–97, advanced topics in geometry and topology that are widely used in modern theoretical physics will be presented. The emphasis will be on understanding and applications more than on rigor and proofs. The first term will cover basic concepts in topology and manifold theory. The second term will include Riemannian geometry, fibre bundles, characteristic classes, and index theorems. The subjects of the third term will be anomalies in gauge field theories and the theory of Riemann surfaces with emphasis on applications 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, and the quark-gluon theory of strong interactions, including renormalization, confinement, chiral symmetry breaking, anomalies, perturbation theory for high energy, and lattice calculations. Offered alternate years; not offered 1996–97.

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. Offered alternate years; not offered 1996–97.

Ph 234 abc. Topics in Theoretical Physics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 205 or equivalent.* The course covers the standard model for strong, weak, and electromagnetic interactions based on the gauge group SU(3) x SU(2) x U(1). Techniques such as the renormalization group and chiral perturbation theory will be used to make comparisons with experiments. Problems and extensions such as grand unification, low-energy supersymmetry, and axions will be discussed. Offered alternate years; offered first and second terms only in 1996–97. Instructor: Wise.

Ph 235 abc. Introduction to String Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 230 and Ph 236 (both may be taken concurrently).* Classical and quantum theory of relativistic strings, both bosonic and supersymmetric, with emphasis on the problem of unification. Calculation of tree and one-loop amplitudes. Other topics include compactification of extra dimensions, conformal field theory, and heterotic string phenomenology. Not offered 1996–97, but note Ph 229.

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. Offered alternate years; not offered 1996–97.

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 1996–97.

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 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. Instructors: Barish, Vogt.

Ph 300. Thesis Research. *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

PS 12. Introduction to Political Science. *9 units (3-0-6); third term.* 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, Congress, congressional-bureaucratic relations, and coverage of political issues by the mass media.

Instructor: Ordeshook.

PS 101. Selected Topics in Political Science. *Units to be determined by arrangement with the instructor. Offered by announcement.* Instructors: Staff.

PS 120. American Electoral Behavior and Party Strategy. *9 units (3-0-6).* A consideration of existing literature on the voting behavior of the citizen, and an examination of theoretical and empirical views of the strategies followed by the parties. Not offered 1996–97. Instructor: Alvarez.

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. Instructor: Katz.

PS 122. Problems of Representation. *9 units (3-0-6). Prerequisite: PS 12.* Considers the theoretical foundations of democratic governments and modern problems of representation, including alternative approaches and solutions to representing minorities. Not offered 1996–97. Instructors: Staff.

PS 123. Fiscal Federalism. *9 units (3-0-6); third term.* In the United States, as in many other countries, taxes are collected and benefits are provided by federal, state, and local governments. Because politicians like to take credit for benefits but avoid blame for taxes, fiscal relations between levels of government are an ongoing source of controversy and confusion. Course covers the major budgetary problems that currently face state, local, and federal governments. Specific topics will include intergovernmental revenue flows, the municipal bond market, and policy mandates. Grades only. Instructor: Kiewiet.

PS/SS 125. Political Economy of Development. *9 units (3-0-6); third term. Prerequisite: PS 12 or SS 13.* The role of political institutions in economic development and the interplay between economic development and political change. The course applies tools drawn from economics and political science to examples from history and from current-day developing countries. Instructor: Hoffman.

PS 132. Formal Theories in Political Science. *9 units (3-0-6) second term. Prerequisite: PS 12 or equivalent.* Axiomatic structure and behavioral interpretations of game theoretic and social choice models and models of political processes based on them. Instructor: McKelvey.

PS/Ec 134. The Political Economy of Urban Areas. *9 units (3-0-6); second term. Prerequisite: PS 12 or equivalent.* Development of a theory of urban government, using analytic concepts from microeconomics and political science. Instructor: Kiewiet.

PS/SS 139. Comparative Politics. *9 units (3-0-6). Prerequisite: PS 12 or SS 13.* The politics of non-American political systems. Areas of study: the politics of nondemocratic 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 1996–97. Instructor: Ordeshook.

H/PS 148 ab. The Supreme Court in U.S. History.* *9 units (3-0-6).* For course description, see History.

Ec/PS 160 abc. Laboratory Experiments in the Social Sciences. *9 units (3-3-3).* For course description, see Economics.

PS/Ec 172. Noncooperative Games in Social Sciences. *9 units (3-0-6); third term. Prerequisites: PS 12 or equivalent.* Axiomatic structure and behavioral interpretations of game theory models in social science. Axiomatic utility theory and general noncooperative games. Instructors: Staff.

PS/Ec 173. Cooperation and Social Behavior. *9 units (3-0-6); second term. Prerequisite: PS/Ec 172 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. 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 152.*

PSYCHOLOGY

Psy 15. Social Psychology. *9 units (3-0-6); second term.* The study of how people think about other people and behave toward or around others. Topics include attribution, social cognition, motivation and incentives, social influence, liking, stereotyping, deception, fairness and altruism, and conformity. Instructors: Staff.

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. Offered by announcement.* Instructors: Staff.

Psy 115. Cognitive Psychology. *9 units (3-0-6); third term. Prerequisite: Ma 112 or consent of instructor.* The study of how people think and behave. An introduction to the methods psychologists use to understand cognition, and the knowledge these methods have created:

behaviorism (its rise and eclipse), memory, perception, learning, induction, categorization, intelligence, decision making and judgment, and evolutionary psychology. Instructor: Camerer.

Psy 125. Reading and Research in Psychology. Same as Psy 25, but for graduate credit. *Not available for credit toward humanities-social science requirement.*

RUSSIAN (See Languages)

SCIENCE, ETHICS, AND SOCIETY

SES 101 ab. Introduction to Science, Ethics, and Society.* *9 units (3-0-6); first, second terms.* A two-quarter introduction to issues past and present in science, ethics, and society. The first quarter emphasizes historical study, taking up subjects such as cosmology, theories and uses of force and matter, the understanding and control of life, molecular biology and biotechnology, big science; the second emphasizes philosophical study, exploring topics such as theories of scientific method, changes in scientific practices, method, and knowledge, how scientists come to replace one theory with another, the influence of social and political factors on the conduct of science, the moral and political problems raised by science and technology. Instructors: Barkan, Cowie.

SES 102 abc. Senior Seminar.* *9 units (2-0-7).* The first two quarters consist of directed tutorial study and research to develop further the student's area of concentration in the option and to prepare the student for the writing of a research paper. Work in the tutorial will comprise intensive reading in the relevant literature and the beginnings of work on the paper. In the third quarter, students will present and discuss the results of their research and successive drafts of their papers in a seminar for discussion and criticism. Open to students in the SES option and the SES graduate minor, and to others by special permission. Instructors: Staff.

SES 103. Public Lecture Series. *1 unit (1-0-0).* Lectures offered under the rubric Science, Ethics, and Public Policy, featuring speakers from outside and inside Caltech, that introduce students to a broad variety of SES-related topics past and present. The seminar is held roughly four times per quarter. Not available for credit toward humanities-social science requirement. Instructors: Guest lecturers.

SES/Hum 121. Freud.* *9 units (2-0-7); first term.* The development of psychoanalysis, especially Freud's theories of hysteria and dreams, from its origins until the early years of the 20th century. Topics include the interplay between Freud's developing theories and clinical evidence and his relations with the scientific and medical community of the day.

Not offered 1996–97. Instructor: Pigman.

SES/Pl 122. Philosophy of Science.* *9 units (3-0-6). Offered by announcement.* An introduction to fundamental philosophical problems concerning the nature of science. Topics may include the character of scientific explanation, criteria for the conformation and falsification of scientific theories, the relationship between theory and observation, philosophical accounts of the concept of "law of nature," causation, chance, realism about unobservable entities, the objectivity of science, and issues having to do with the ways in which scientific knowledge changes over time. Instructor: Hajek.

SES/Pl 125. Philosophy and Biology.* *9 units (3-0-6); second term.* Philosophical and conceptual issues relating to the biological sciences. Topics covered may include: the logical structure of evolutionary theory, units of selection, optimization theory, the nature of species, reductionism, teleological and functional reasoning, and ethical issues arising from contemporary biological research. Instructors: Staff.

SES/Pl 126. Biomedical Ethics.* *9 units (3-0-6); first term.* Ethical and public policy issues arising from the biological sciences, biotechnology, and medical practice. Topics covered may include ethical and conceptual issues arising in the following areas: clinical decision making and patient autonomy, right to die and euthanasia, human genetics and genetic engineering, reproductive technology and abortion, health insurance and the allocation of medical resources. Not offered 1996–97. Instructors: Staff.

SES/Pl 127. Ethics in Research.* *4 units (2-0-2) or 9 units (2-0-7); third term.* Course will address a number of ethical and philosophical issues arising in scientific research. Among the topics discussed will be the following: fraud and misconduct in science; various theories of the scientific method; the realities of science as practiced in laboratories and the pressures facing scientists in the real world; ethical issues raised by collaborative research; reward and credit in science; responsibilities of mentors, referees, and editors in the conduct of research; the role of government regulation and supervision in dealing with scientific misconduct; the role of the university; and changes in ethical standards due to advancing technology. Undergraduates wishing to take the course for advanced humanities credit should register for 9 units (a term paper will be required). Students who register for 4 units may do so on a pass/fail basis only. Instructors: Woodward, D. Goodstein.

SES/H/Lit 128. British Science Fiction.* *9 units (3-0-6); third term.* This course will examine fictional representations of nature, scientific knowledge, and scientific method in 19th- and 20th-century Britain. Topics will include representations of the laboratory, the scientist, forensic science and detection, as well as imaginative reflections on future societies and other cultures and of the impact of the development of scientific culture and technological innovation on modern society. Sources will be drawn from novels, short stories, and films.

They might include the work of H. G. Wells and Arthur C. Clarke, and specific sources like *The Island of Doctor Moreau, Brave New World, The Shape of Things to Come*, and *2001*. Instructor: Winter.

SES/Pl 131. Philosophy of Mind and Psychology.* *9 units (3-0-6); second term.* Philosophical issues regarding the nature of mind and the impact of recent developments in cognitive science on these issues. Topics may include: the nature of belief and other psychological attitudes, perception, mental imagery, and behavior, all with a focus on relevant empirical work. Instructor: Cowie.

SES/H 156. The History of Modern Science.* *9 units (3-0-6); third term.* Selected topics in the development of the physical and biological sciences since the 17th century. Not offered 1996–97. Instructors: Barkan, Kevles.

SES/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. Not offered 1996–97. Instructor: Kevles.

SES/H 158. The Scientific Revolution.* *9 units (3-0-6); second term.* The birth of modern Western science from 1400 to 1700. The course examines the intellectual revolution brought about by the contributions of Copernicus, Galileo, Descartes, Kepler, Newton, and Harvey, and their relation to major political, social, and economic developments. Instructor: Johns.

SES/H 159. Science and Society.* *9 units (3-0-6).* A historical examination from a socioeconomic, political, and ethical perspective of selected issues in science and technology — for example, biotechnology, human reproduction, nuclear power, and the environment. Not offered 1996–97. Instructor: Kevles.

SES/H 160 ab. History of the Modern Physical Sciences.* *9 units (3-0-6); first, second terms.* An exploration of the most significant scientific developments in the physical sciences from the late 19th century to the present. The first part of the course examines the emergence of new theories of radiation, the structure of matter, relativity, and quantum theory. The second part examines quantum mechanics, the developments in nuclear physics, atomic weapons, particle physics, and the organization of modern science. Scientific, historical, and philosophical texts will be used. (The two courses may be offered in alternate years.) Instructor: Barkan.

SES/H 162. Social Studies of Science.* *9 units (3-0-6); second term.* A comparative, multidisciplinary course that examines the practice of science in a variety of locales, using methods from the history, sociology, and anthropology of scientific knowledge. Topics covered include the high-energy particle laboratory as compared with a biological one; Western as compared to non-Western scientific reasoning; the use of visualization techniques in science from their inception to virtual reality; gender in science; and other topics. Not offered 1996–97. Instructor: Barkan.

SES/H 163. Gender in the History of Science, Technology, and Medicine.* *9 units (3-0-6); second term.* An examination of how notions of masculinity and femininity have influenced the history of science, technology, and medicine since 1600. Topics will include study of the rise of women in scientific and medical institutions and of the ongoing debates about whether men and women have (or have had) different ways of understanding the natural world. Not offered 1996–97. Instructor: Winter.

SES/H 164. Sciences of Mind from the French Revolution to the Great War.* *9 units (3-0-6).* The history of psychology, psychiatry, and related intellectual developments, beginning with the new definitions of madness and mental functioning in the era of the French Revolution and ending with the emergence of 20th-century psychiatry after World War I. Not offered 1996–97. Instructor: Winter.

SES/H 165. History of Technology in the United States.* *9 units (3-0-6).* An examination of technological innovation from 19th-century craft and mechanical technologies through the science-based varieties of the 20th century. Attention will also be given to the rise of the industrial research laboratory, technology in American life and culture, and the relationship of technological development to the activities of government, particularly the military. Not offered 1996–97. Instructors: Staff.

SES/H 166. The History of Environmentalism.* *9 units (3-0-6).* An examination of attitudes and ideas toward nature in American culture since the early 19th century and of the development of the environmental movement in the United States, including its recent globalization. Emphasis will be given to issues of preservation and conservation, pollution and public health, and conflicts of race, class, and economic interest in environmental policies and practices. Not offered 1996–97. Instructor: Kevles.

SES/H 168. The History of Modern Medicine.* *9 units (3-0-6); first term.* An examination of various themes in the history of medicine in western Europe and America since the Renaissance. Topics will include key developments of medical theory (such as the circulation of the blood and germ theory), relations between doctors and patients, rivalries between different kinds of healers and therapists, and the development of the hospital and of laboratory medicine. Instructor: Winter.

SES/H 169. Selected Topics in Science, Ethics, and Society. *9 units (3-0-6). Offered by announcement.* Advanced credit to be determined on a course-by-course basis by instructor. Instructors: Staff and visiting lecturers.

SES/Pl 169. Selected Topics in Science, Ethics, and Society. *9 units (3-0-6). Offered by announcement.* Advanced credit to be determined on a course-by-course basis by instructor. Instructors: Staff and visiting lecturers.

SES/Pl 185. Moral Philosophy.* *9 units (3-0-6).* A survey of topics in moral philosophy. The emphasis will be on meta-ethical issues, although some normative questions may be addressed. Meta-ethical topics that may be covered include the fact/value distinction; the nature of right and wrong (consequentialism, deontological theories, rights-based ethical theories, virtue ethics); the status of moral judgments (cognitivism vs. non-cognitivism, realism vs. irrealism); morality and psychology; moral relativism; moral skepticism; morality and self-interest; the nature of justice. The implications of these theories for various practical moral problems may also be considered. Not offered 1996–97. 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 152.*

SOCIAL 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. Instructor: Davis.

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). Offered by announcement.* Not available for social science credit unless specifically approved by social science faculty. Instructors: Staff, visiting lecturers.

PS/SS 125. Political Economy of Development. *9 units (3-0-6).* For course description, see Political Science.

Ec/SS 128. Economic and Financial Development in the 19th and 20th Centuries. *9 units (3-0-6).* For course description, see Economics.

Ec/SS 129. Economic History of the United States. *9 units (3-0-6).* For course description, see Economics.

Ec/SS 130. Economic History of Europe from the Middle Ages to the Industrial Revolution. *9 units (3-0-6).* For course description, see Economics.

PS/SS 139. Comparative Politics. *9 units (3-0-6).* For course description, see Political Science.

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. Offered by announcement.* Instructors: Staff and visiting lecturers.

SS 201 abc. Analytical Foundations of Social Science. *9 units (3-0-6).* This course covers the fundamentals of utility theory, game theory, and social choice theory. These basic theories are developed and illustrated with applications to electoral politics, market trading, bargaining, auctions, mechanism design and implementation, legislative and parliamentary voting and organization, public economics, industrial organization, and other topics in economics and political science. Instructors: Ghirardato, Palfrey, McKelvey.

SS 202 abc. Political Theory. *9 units (3-0-6).* Course will introduce the student to the central problems of political theory and analysis, beginning with the essential components of the democratic state and proceeding through a variety of empirical topics. These topics will include the analysis of electoral and legislative institutions, legislative agenda processes, voting behavior, comparative political economy, and cooperation and conflict in international politics. The student will be sensitized to the primary empirical problems of the discipline and trained in the most general applications of game theoretic reasoning to political science. Instructors: Ordeshook, Alvarez, Katz.

SS 203. American Electoral Processes. *9 units (3-0-6).* An in-depth analysis of American electoral processes, with emphasis on the application of new theory and quantitative techniques. Not offered 1996–97. Instructor: Kousser.

SS 205 abc. Foundations of Economics. *9 units (3-0-6). Prerequisite: Ec 121 ab or consent of instructor.* This is a graduate course in the fundamentals of economics. Topics include: comparative statics and maximization techniques, the neoclassical theory of consumption and production, general equilibrium theory and welfare economics, public goods and externalities, the economic consequences of asymmetric information and incomplete markets, and recursive methods with applications to labor economics and financial economics. Instructors: Border, Page, Wilkie.

SS 210 abc. Foundations of Political Economy. *9 units (3-0-6). Prerequisites: SS 202 c, SS 205 b.* Mathematical theories of individual and social choice applied to problems of welfare economics and political decision making as well as to the construction of political economic processes consistent with stipulated ethical postulates, political platform formulation, the theory of political coalitions, and decision making in political organizations. Instructor: Palfrey.

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: Ghirardato, Camerer, Page.

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: Ledyard, Wilkie.

SS 213 abc. Financial Economics. *9 units (3-0-6).* First term: introduction to theoretical financial economics at the graduate level. Course covers leading financial models such as the capital asset pricing model and arbitrage pricing theory in depth. Second term: theory of asset pricing in a dynamic context. Considers both the discrete and continuous time cases. Third term: theory and tests of asset pricing (including option pricing and term structure). Theory and tests of market microstructure. Theory of international finance. Instructors: Bossaerts, Strnad.

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. Not offered 1996–97. Instructors: Staff.

SS 216. Interdisciplinary Studies in Law and Social Policy. *9 units (3-0-6); second term.* A policy problem or problems involving the legal system will be studied, using concepts from at least one social science discipline. Each offering will be taught by a law professor, alone or in conjunction with a member of the social science faculty. The topic will differ from term to term, so the course may be taken more than once. Selected undergraduates may enroll in this course with the permission of the instructor. Instructor: Spitzer.

SS 222 abc. Econometrics. *9 units (3-0-6).* Introduction to the use of multivariate and nonlinear methods in the social sciences. Instructors: Sherman, Dubin, Grether.

SS 223 abc. Advanced Topics in Econometric Theory. *9 units (3-0-6). Prerequisite: SS 222 abc; may be repeated for credit.* A course in quantitative methods for second- and third-year social science graduate students. Instructors: Grether, Sherman.

SS 229 abc. Theoretical and Quantitative Dimensions of Historical Development. *9 units (3-0-6). 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. Second and third terms will be graded together. A pass/fail will be assigned in the second term and then changed to the appropriate grade at the end of the third term. Instructors: Davis, Fohlin, Hoffman.

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: Alvarez, Katz, Kiewiet.

SS 232 abc. Historical and Comparative Perspectives in Political Analysis. *9 units (3-0-6). Prerequisite: SS 203.* Provides a knowledge and understanding of developments in both the American past and in other parts of the world. Instructor: Ordeshook.

SS 240. Techniques of Policy Research. *9 units (3-0-6). Prerequisites: SS 205 ab.* The application of social science theory and methods to the formulation and evaluation of public policy. Instructor: Dubin.

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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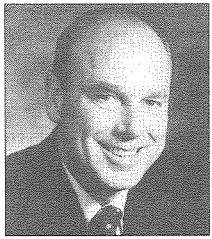

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