SEPTEMBER 1970

BULLETIN OF THE CALIFORNIA INSTITUTE OF TECHNOLOGY

INFORMATION FOR STUDENTS

1970/1971

BULLETIN OF THE
CALIFORNIA INSTITUTE OF TECHNOLOGY
1201 EAST CALIFORNIA BOULEVARD
PASADENA, CALIFORNIA 91109

Volume 79, Number 3, September 1970

The California Institute of Technology Bulletin is published quarterly.

Second-class postage paid at Pasadena, California

BULLETIN

OF THE CALIFORNIA INSTITUTE OF TECHNOLOGY

PASADENA, CALIFORNIA

Information for Students

1970-1971

CONTENTS

KEY TO ABBREVIATIONS

Aeronautics	Ae
Air Force-Aerospace Studies	AS
Anthropology	An
Applied Mathematics	AMa
Applied Mechanics	AM
Applied Physics	APh
Astronomy	Ay
Biology	Bi
Chemical Engineering	ChE
Chemistry	Ch
Civil Engineering	CE
Economics	Ec
Electrical Engineering	EE
Engineering	E
Engineering Graphics	Gr
Engineering Science	ES
English	En
Environmental Engineering Science	Env
Geology	Ge
History	H
Hydraulics	Hy
Information Science	IS
Jet Propulsion	JP
Languages	L
Materials Science	MS
Mathematics	Ma
Mechanical Engineering	ME
Music	Mu
Philosophy and Psychology	Pl
Physical Education	PE
Physics	Ph
Political Science	PS

ACADEMIC CALENDAR

1970-71

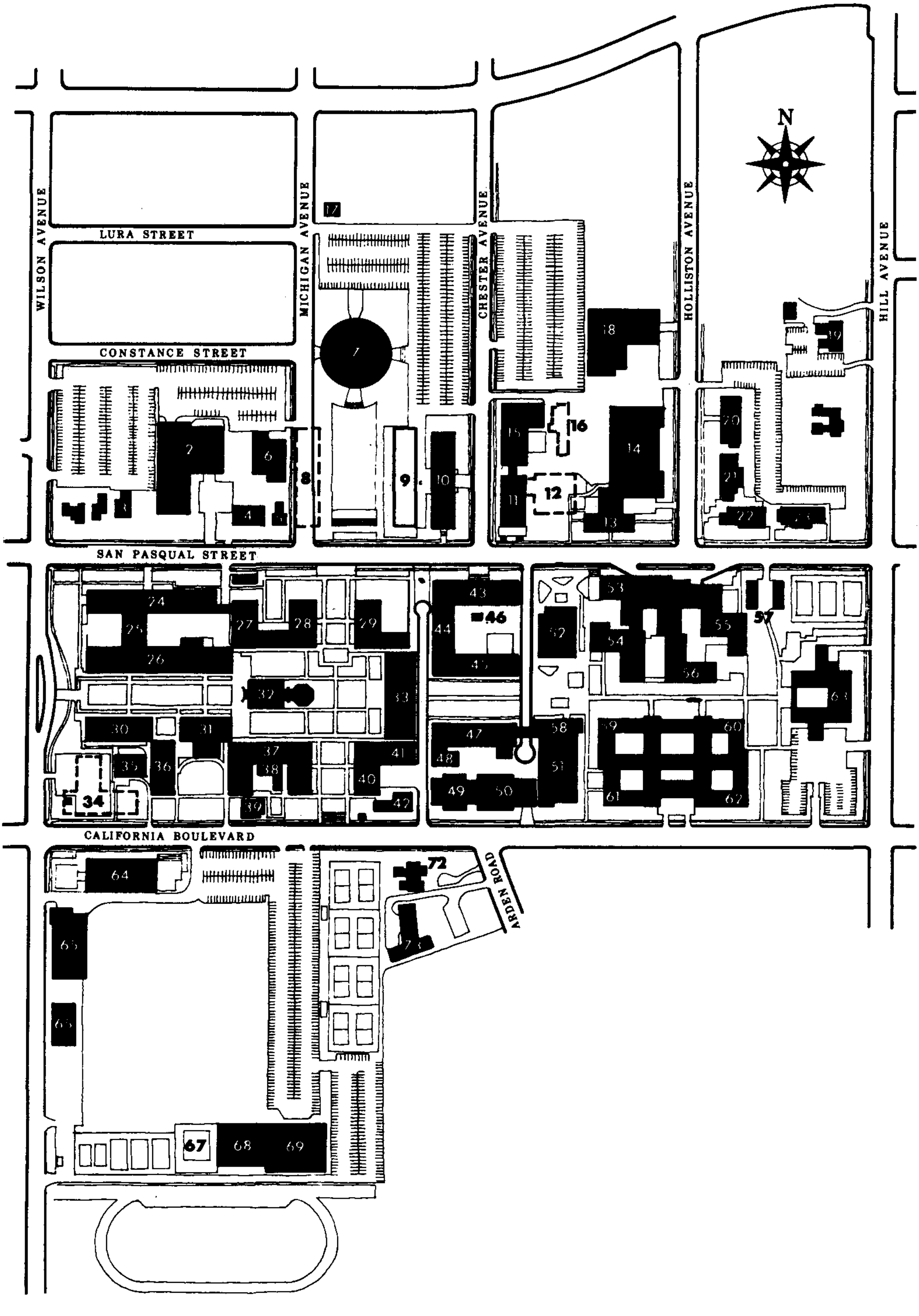
1970	FIRST TERM
September 24	Registration of entering freshmen—8:00 a.m. to 9:30 a.m.
September 24-26	New Student Orientation.
September 28	General Registration—8:30 a.m. to 3:30 p.m.
September 28	Undergraduate Academic Standards and Honors Committee 3:00 p.m.
September 29	Beginning of instruction—8:00 a.m.
October 16	Last day for adding courses and changing sections.
October 17	Examinations for the removal of conditions and incompletes.
October 24	Parents' Day.
November 2-6	Mid-Term Week.
November 6	Last day for admission to candidacy for Masters' and Engineers' degrees.
November 7	MID-TERM.
November 9	Mid-Term deficiency notices due—9:00 a.m.
November 13	Last day for dropping courses.
November 16-20	Pre-registration for second term, 1970-71.
November 26-29	Thanksgiving recess.
November 26, 27	Thanksgiving holiday for employees.
December 12-18	Final examinations—first term, 1970-71.
December 19	End of first term, 1970-71.
December 20-January 3	Christmas vacation.
December 21	Instructors' final grade reports due—9:00 a.m.
December 24, 25	Christmas holidays for employees.

1971	SECOND TERM
January 1	New Year's Day holiday for employees.
January 4	General Registration—8:30 a.m. to 3:30 p.m.
January 4	Undergraduate Academic Standards and Honors Committee 1:00 p.m.
January 5	Beginning of instruction—8:00 a.m.
January 22	Last day for adding courses and changing sections.
January 23	Examinations for the removal of conditions and incompletes.
February 1-5	Mid-Term Week.
February 6	MID-TERM.
February 8	Mid-Term deficiency notices due—9:00 a.m.
February 12	Last day for dropping courses.
February 22-26	Pre-registration for third term 1970-71.
March 13-19	Final examinations—second term, 1970-71.
March 19	Last day for obtaining admission to candidacy for the degree of Doctor of Philosophy.
March 20	End of second term, 1970-71.
March 21-28	Spring recess.
March 22	Instructors' final grade reports due—9:00 a.m.
March 26	Undergraduate Academic Standards and Honors Committee 9:00 a.m.

1971	THIRD TERM
March 29	General Registration—8:30 a.m. to 3:30 p.m.
March 30	Beginning of instruction—8:00 a.m.
April 16	Last day for adding courses and changing sections.
April 17	Examinations for the removal of conditions and incompletes.
April 26-30	Mid-Term Week.
May 1	MID-TERM.
May 3	Mid-Term deficiency notices due—9:00 a.m.
May 7	Last day for dropping courses.
May 7, 8	Examinations for admission to upper classes, September 1971.
May 17	Registration for summer research (graduate students).
May 17-21	Pre-registration for first term, 1971-72, and registration for undergraduate summer research.
May 28	Last day for final oral examinations and presenting of theses for the degree of Doctor of Philosophy.
May 28	Last day for presenting theses for Engineer's degree.
May 30	Memorial Day holiday (observed on Monday, May 31).
May 30	Memorial Day holiday for employees (observed on Monday, May 31).
May 29-June 4	Final examinations for senior and graduate students, third term, 1970-71.
June 5-11	Final examinations for undergraduate students, third term, 1970-71.
June 7	Instructors' final grade reports due for senior and graduate students—9:00 a.m.
June 9	Curriculum Committee—10:00 a.m.
June 9	Faculty Meeting—2:00 p.m.
June 10	Class Day.
June 11	Commencement.
June 12	End of third term, 1970-71.
June 14	Instructors' final grade reports due for undergraduate students—9:00 a.m.
June 18	Undergraduate Academic Standards and Honors Committee 9:00 a.m.
July 4	Independence Day holiday for employees (observed on Monday, July 5).
September 6	Labor Day.

FIRST TERM 1971-72

September 23	Registration of entering freshmen—8:00 a.m. to 9:30 a.m.
September 23-25	New Student Orientation.
September 27	General registration—8:30 a.m. to 3:30 p.m.
September 28	Beginning of instruction—8:00 a.m.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WILSON AVENUE
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CHESTER AVENUE
HOLLISTON AVENUE
HILL AVENUE
LURA STREET
CONSTANCE STREET
SAN PASQUAL STREET
CALIFORNIA BOULEVARD
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CAMPUS DIRECTORY

INFORMATION DESK

ROOM 4, THROOP HALL, BUILDING NO. 33

ɩir Force ROTC
\lles Laboratory (Molecular Biology)
ɩlumni Swimming Pool
\rden House (Residence of Master of
ɩtudent Houses)
\rms Laboratory (Geological Sciences)
\thenaeum (Faculty Club)
ɜaxter Hall (Humanities)
ɜeckman Auditorium
ɜehavioral Biology (Future)
ɜlacker House (Undergraduate Residence)
ɜookstore (Student Center)
ɜooth Computing Center
ɜooth Addition
ɜraun House (Graduate Residence)
ɜridge Laboratory (Physics)
ɜrown Gymnasium
ɜusiness Services (Administration)
ɔampbell Laboratory (Plant Research)
ɔentral Engineering Services
ɔentral Plant
ɔhandler Dining Hall
ɔhemical Engineering Laboratory
ɔhurch Laboratory (Chemical Biology)
ɔosmic Ray Laboratory
ɔrellin Laboratory (Chemistry)
ɔulbertson Hall (Auditorium)
ɔabney Hall (Humanities and Social Sciences)
ɔabney House (Undergraduate Residence)
ɔevelopment Offices
ɔolk Laboratory (Plant Physiology)
ɔowns Laboratory (Physics)
ɜarhart Laboratory (Art Program)
ʼirestone Laboratory (Flight Sciences)
ʼleming House (Undergraduate Residence)
ɜates Laboratory (Chemistry)
ɜeophysics Laboratory (Future)
ɜraphic Arts and Safety Office
ɜuggenheim Laboratory (Aeronautics)
ndustrial Relations Center
sotope Handling Laboratory
ɩarman Laboratory
ɩeck House (graduate residence)
ɩeck Laboratory
ɩellogg Radiation Laboratory
ɩerckhoff Laboratory (Biological Sciences)
ɩauritsen Laboratory (High Energy Physics)
ɩloyd House (Undergraduate Residence)
ɩocker Rooms
ʌarks House (Graduate Residence)
ʌillikan Library
ʌosher-Jorgensen House (Graduate Residence)

30. Mudd Laboratory (Geological Sciences)
2. Noyes Laboratory (Chemical Physics)
46. Nuclear Engineering
13. Office of the Campus Architect
54. Page House (Undergraduate Residence)
14. Physical Plant
57. Residence and Dining Halls office
60. Ricketts House (Undergraduate Residence)
36. Robinson Laboratory (Astrophysics)
55. Ruddock House (Undergraduate Residence)
40. Sloan Laboratory (Mathematics & Physics)
43. Spalding Laboratory (Chemical Engineering)
15. Steele Laboratory of Electrical Sciences
45. Thomas Laboratory (Civil & Mechanical Engineering)
33. Throop (Administration)
17. Ticket Agency
52. Winnett Student Center
52. Y.M.C.A.
73. Young Health Center

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Big Bear Solar Observatory
Fawnskin, California

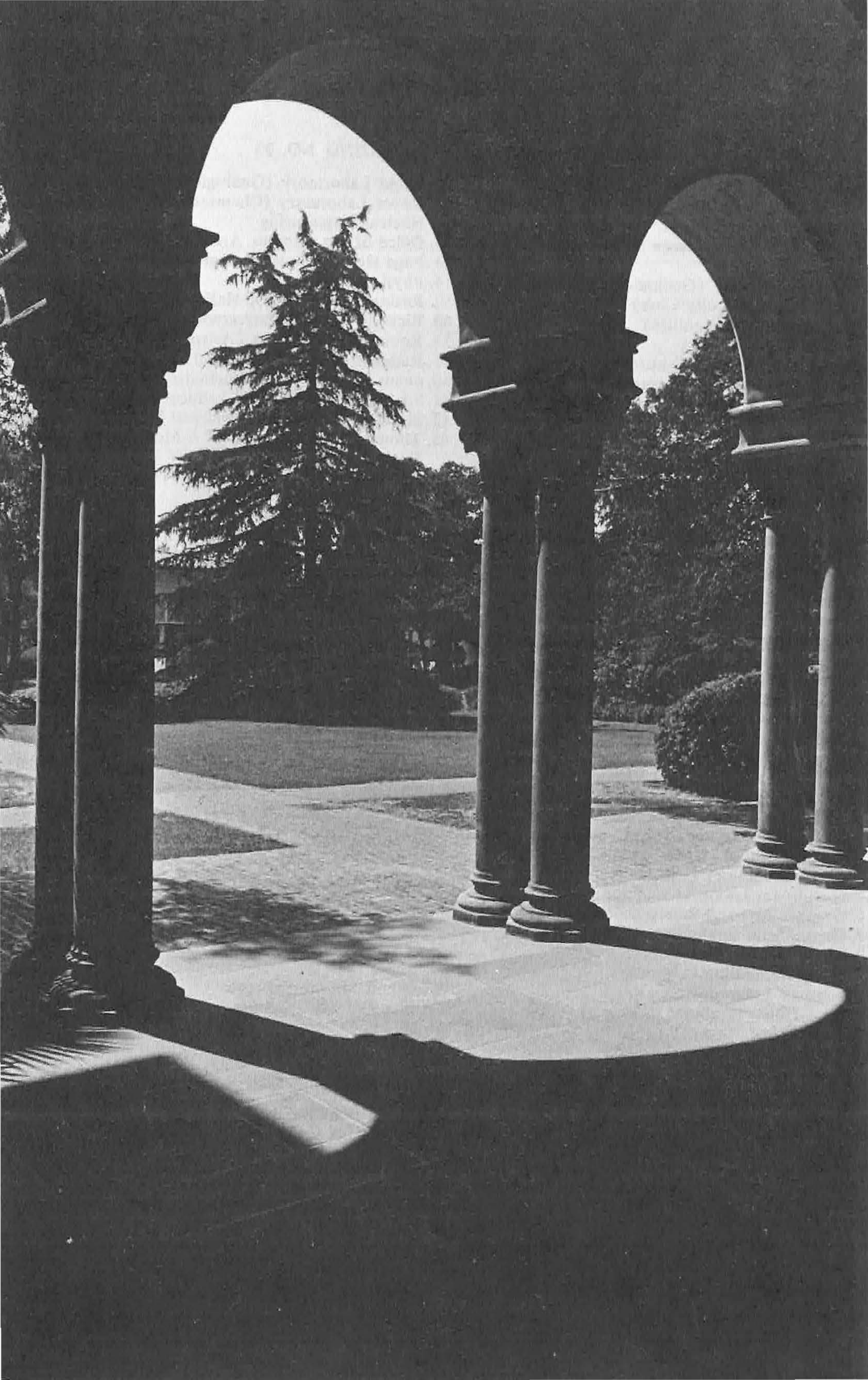
Jet Propulsion Laboratory
4800 Oak Grove Drive, Pasadena

Kerckhoff Marine Laboratory
Corona Del Mar, California

Palomar Observatory
Palomar Mountain
San Diego County, California

Radio Astronomy Observatory
Owens Valley, California

Seismological Research Laboratory
295 N. San Rafael Ave., Pasadena



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1970-71

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**Not on campus
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Richard L. Russell, Ph.D.	*Biology*
James H. Strauss, Jr., Ph.D.	*Biology*

VISITING ASSISTANT PROFESSOR

Eric H. Davidson, Ph.D.*	*Biology*

GOSNEY RESEARCH FELLOWS

Ronald J. Billing	*Biology*
Mogens Westergaard, Ph.D. *	*Biology*

RESEARCH FELLOWS

Ronald T. Acton,[2] Ph.D.
Yosef Aloni, Ph.D.
Stephen Arch,[1] Ph.D.
Kimiko Asano, Ph.D.
Irving H. Brown,[3] Ph.D.
Gisela Charlang, Ph.D.
Robert J. Cohen,[1] Ph.D.
Thomas A. DeVlieger,[4] Ph.D.*
Robert C. Dickson, Ph.D.
John F. Disterhoft, Ph.D.
Maurice Dupras,[3] Ph.D.
David B. Dusenbery,[1] Ph.D.
Robert Eason, Ph.D.
James M. England,[1] Ph.D.
Arnold Eskin,[1] Ph.D.
Linda Fagan, Ph.D.
Peter H. Fishman,[1] Ph.D.
Akio Fukuda, Ph.D.
Ellis E. Golub,[1] Ph.D.
Gerhard Gopel,[5] Ph.D.
Richard L. Hallberg,[1] Ph.D.
Thomas E. Hanson,[6] Ph.D.
Paul A. Hargrave,[1] Ph.D.
Stephen E. Harris,[1] Ph.D.
Yoshiki Hotta, Ph.D.
Muneyuki Ito, M.D.
John D. Johnson, Ph.D.
Paul H. Johnson, Ph.D.
Douglas R. Kankel,[1] Ph.D.
Harumi Kasamatsu,[7] Ph.D.
Donald L. Kimmel, Jr.,[8] Ph.D.
Herman Kühn,[5] Dr. rer. nat.
Santosh Kumar, Ph.D.
Marion T. Laico, Ph.D.
Muriel Lederman,[1] Ph.D.
Robert J. Lorenz, Ph.D.
Livia Mattoccia, Ph.D.*
John E. Mayfield,[1] Ph.D.
Leelavati Murthy,[9] Ph.D.*
Louis-Marie Nicole, Ph.D.

*In residence 1969-70

Allan R. Oseroff,[10] Ph.D.
David S. Papermaster,[11] M.D.
Margaret Petzuch,[1] Ph.D.*
John S. Pierce,[12] Ph.D.
Ramendra K. Poddar, Ph.D.
Peter Polgar, Ph.D.
Bruno B. F. Preilowski, Ph.D.
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Mark G. Rush, Ph.D.*
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Dennis G. Searcy, Ph.D.
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Yuriy M. Sivolap,[13] Ph.D.*
Ellen G. Strauss, Ph.D.
Henry T. Tai,[14] Ph.D.
Keh-Ping Ting, Ph.D.*
Janett Trubatch, Ph.D.
Nicole Truffaut, Ph.D.
Michael D. Waterfield, Ph.D.
David L. Wilson,[7] Ph.D.
Jung-Rung Wu,[1] Ph.D.
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Uri Yinon, Ph.D.
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Barbara York, Ph.D.

*In residence 1969-70
1National Institute of Health, Public Health Service Fellow
2Smith Kline & French Fellow
3National Cancer Institute of Canada Fellow
4Free University, Amsterdam
5North Atlantic Treaty Organization Fellow
6National Science Foundation Fellow
7Helen Hay Whitney Foundation Fellow
8Brown University
9International Atomic Energy Agency Fellow
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11American Cancer Society Fellow
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*In residence 1969-1970 academic year
[1]American Association of University Women
[2]National Science Faculty Fellowship

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Edwin A. Pecker, M.S. . . . . *Chemical Engineering*
Alan Rembaum, Ph.D. . . . . *Chemical Engineering*

INSTRUCTOR

David Holtz, Ph.D. . . . . *Chemistry*

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Gustav Albrecht, Ph.D.
Nancy Ann Beach,* Ph.D.
Phillipe Bey, Docteur es Sciences
Larry Blair,*[1] Ph.D.
Celia J. Bonaventura,*[2] Ph.D.
Joseph Bonaventura,[3] Ph.D.
Simon F. Campbell,*[1] Ph.D.
Claude Charrier,*[4] Ph.D.
Kin Fai Cheng, Ph.D.
Manfred Christl,[5] Ph.D.
Donald G. Clark,[6] Ph.D.
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Wilmer Otis Crain, Jr., Ph.D.
Vitas Dauksas,[14] Ph.D.
Ronald W. Davis,* Ph.D.
James W. Dawson, Ph.D.
Marcia Ann Dawson, Ph.D.
Don Dennis,*[6] Ph.D.
Riccardo Destro, Laurea in Chimica Industriale
Douglas Earl Dorman, Ph.D.
Bertram Frenz, Ph.D.
Gail Galasko, Ph.D.
Robert Jay Gordon, Ph.D.
Peter Göser, Dr. rer. nat.
Bruce L. Hawkins, Ph.D.
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Ming-Chu Hsu, Ph.D.
Richard W. Hyman, Ph.D.
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Michael J. Laing,[8] Ph.D.
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Minoru Tsuda,*[12] Ph.D.
Bi-Cheng Wang,* Ph.D.
Richard Weiss, Ph.D.
Stephen C. Welch,*[6] Ph.D.
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Madeline Chang-Sung Wu, Ph.D.
Sheldon York,[13] Ph.D.
Leo Fang-Hung Yuan,[6] Ph.D.

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[1]National Academy of Sciences Fellow
[2]National Institute of General Medical Sciences
[3]National Heart Institute Fellow
[4]NATO Fellow
[5]Max Kade Foundation
[6]National Institutes of Health Fellow
[7]National Science Foundation Fellow
[8]South African CSIR
[9]Fight for Sight Fellowship
[10]Paint Research Institute
[11]National Canadian Research Council Fellowship
[12]Japanese Government Fellowship
[13]American Cancer Society Fellowship
[14]International Research and Exchange Fellowship

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Frank E. Marble, Ph.D. . . . . *Jet Propulsion and Mechanical Engineering*
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Carver A. Mead, Ph.D. . . . . *Electrical Engineering*
Robert D. Middlebrook, Ph.D. . . . . *Electrical Engineering*
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Wheeler J. North, Ph.D. . . . . *Environmental Science*
Charles H. Papas, Ph.D. . . . . *Electrical Engineering*
William H. Pickering,* Ph.D. . . . . *Electrical Engineering*
Milton S. Plesset,** Ph.D. . . . . *Engineering Science*
W. Duncan Rannie,** Ph.D. . . . . *Robert H. Goddard Professor of Jet Propulsion*

*On leave of absence
**On leave of absence 1st term

Anatol Roshko, Ph.D. . . . . *Aeronautics*
Rolf H. Sabersky, Ph.D. . . . . *Mechanical Engineering*
Philip G. Saffman,*** Ph.D. . . . . *Applied Mathematics*
Ronald F. Scott, Sc.D. . . . . *Civil Engineering*
Ernest E. Sechler, Ph.D. . . . . *Aeronautics*
Eli Sternberg,** Ph.D., D.Sc. . . . . *Mechanics*
Homer J. Stewart, Ph.D. . . . . *Aeronautics*
Frederick B. Thompson, Ph.D. . . . . *Applied Science and Philosophy*
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J. Harold Wayland, Ph.D. . . . . *Engineering Science*
Gerald B. Whitham, Ph.D. . . . . *Applied Mathematics*
Charles H. Wilts, Ph.D. . . . . *Electrical Engineering*
David S. Wood, Ph.D. . . . . *Materials Science*
Theodore Y. Wu, Ph.D. . . . . *Engineering Science*
Amnon Yariv, Ph.D. . . . . *Electrical Engineering*
Edward E. Zukoski, Ph.D. . . . . *Jet Propulsion*

VISITING PROFESSORS

Mahlon F. Easterling,* M.S.E.E. . . . . *Applied Science*
Reimar H. Lüst, Dr. rer. nat. . . . . *Astrophysics and Aeronautics*
Leo Stoolman, Ph.D. . . . . *Aeronautics*

RESEARCH ASSOCIATES

Richard F. Baker, Ph.D. . . . . *Engineering Science*
Richard J. Bing, M.D. . . . . *Engineering Science*
George S. Campbell,* Ph.D. . . . . *Aeronautics*
E. Richard Cohen, Ph.D. . . . . *Engineering Science*
Ken-Ichi Naka, D.Sc. . . . . *Biology and Applied Science*
Simon Ramo, Ph.D. . . . . *Electrical Engineering*
Dean E. Wooldridge, Ph.D. . . . . *Engineering*

ASSOCIATE

Henry Dreyfuss . . . . *Industrial Design*

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Arthur N. L. Chiu,* Ph.D. . . . . *Civil Engineering*
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Akio Hiraki, D.Sc. . . . . *Electrical Engineering*
Tung-Ming Lee, Ph.D. . . . . *Aeronautics*
George O. Schumann, Ph.D. . . . . *Environmental Health Engineering*
Sengadu R. Seshadri, Ph.D. . . . . *Electrical Engineering*

*In residence 1969-70.
**On leave of absence 1st term
***On leave of absence

ASSOCIATE PROFESSORS

Charles D. Babcock, Jr., Ph.D. . . . . . *Aeronautics*
Francis S. Buffington, Sc.D. . . . . . *Materials Science*
Fred E. C. Culick, Sc.D. . . . . . *Jet Propulsion*
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Paul C. Jennings, Ph.D. . . . . . *Applied Mechanics*
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David F. Welch, I.D. . . . . . *Engineering Design*

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Viktor Evtuhov, Ph.D. . . . . . *Electrical Engineering*
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Robert S. Harp, Ph.D. . . . . . *Electrical Engineering*
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Hugh P. Taylor, Jr., Ph.D. .... *Geology*
Gerald J. Wasserburg, Ph.D. .... *Geology and Geophysics*

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Cinna Lomnitz, Ph.D. .... *Geophysics*
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Bradford A. Smith, B.S. .... *Planetary Science*
Grenville Turner, Ph.D. .... *Nuclear Geophysics*

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David G. Harkrider, Ph.D. .... *Geophysics*
Duane O. Muhleman, Ph.D. .... *Planetary Science*

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Taro Takahashi, Ph.D. . . . . *Geophysics*

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Fouad Tera, Ph.D. . . . . *Geochemistry*
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Leverett Davis, Jr., Ph.D. . . . . *Theoretical Physics*
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Gerry Neugebauer, Ph.D. . . . . *Physics*

*On leave of absence 1970-71
**On leave of absence second and third terms, 1970-71.

J. Beverley Oke, Ph.D. .... *Astronomy*
Jerome Pine, Ph.D. .... *Physics*
Herbert J. Ryser, Ph.D. .... *Mathematics*
Maarten Schmidt, Ph.D. .... *Astronomy*
Kip S. Thorne, Ph.D. .... *Theoretical Physics*
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Fredrik Zachariasen,* Ph.D. .... *Theoretical Physics*
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Reimar Lüst, Ph.D. .... *Astrophysics and Aeronautics*
Rudolf L. Mössbauer, Dr. rer. nat., Sc.D., Nobel Laureate .... *Physics*
Jacobus H. van Lint,[1] Ph.D. .... *Mathematics*

[1]Morgan Ward Visiting Professor, 1970-71

RESEARCH ASSOCIATES

Gordon J. Stanley, Dipl. .... *Radio Astronomy*
Olga T. Todd, Ph.D. .... *Mathematics*

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Curtis G. Callan, Jr., Ph.D. .... *Theoretical Physics*
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Yorikiyo Nagashima, Ph.D.	*Physics*
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David L. Goodstein, Ph.D.	*Physics*
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Jeffrey E. Mandula, Ph.D.	*Theoretical Physics*
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Neil H. Fenichel,[2] Ph.D.	*Mathematics*
Hershy H. Kisilevsky, Ph.D.	*Mathematics*
Gary Sampson,[3] Ph.D.	*Mathematics*

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[1]Richard Chace Tolman Senior Research Fellow, 1970-71
[2]Harry Bateman Research Instructor, 1970-71
[3]Ford Foundation Research Instructor, 1970-71

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[4]Robert Andrews Millikan Research Fellow, 1970-71

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Hudson L. Scott, M.S.

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Daniel C. Siegel, M.D. .... *Consulting Psychiatrist*
Gregory Ketabgian .... *Attending Physician*
Judson S. James, M.D. .... *Attending Physician*
Ian Hunter, Ph.D. .... *Institute Psychologist*
Nancy Beakel, Ph.D. .... *Institute Psychologist*
Alice A. Shea, R.N. .... *Nursing Director*

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A.B., Columbia College, 1945; A.M., Columbia University, 1946; Ph.D., 1949. California Institute, 1969-. (Throop)

Allan James Acosta, Ph.D., *Professor of Mechanical Engineering*

B.S., California Institute, 1945; M.S., 1949; Ph.D., 1952. Assistant Professor, 1954-58; Associate Professor, 1958-66; Professor, 1966-. (Thomas)

Ronald T. Acton, Ph.D., *Research Fellow in Biology*

B.A., Birmingham Southern College, 1965; Ph.D., University of Alabama, 1970. California Institute, 1970-71.

John Tilman Adams, Ph.D., *Research Fellow in Chemistry*

B.S., Arkansas State University, 1964; Ph.D., University of Arkansas, 1970. California Institute, 1970-71. (Noyes)

Thomas J. Ahrens, Ph.D., *Associate Professor of Geophysics*

B.S., Massachusetts Institute of Technology, 1957; M.S., California Institute, 1958; Ph.D., Rensselaer Polytechnic Institute, 1962. California Institute, 1967-. (Seismo Lab.)

Arden Leroy Albee, Ph.D., *Professor of Geology*

A.B., Harvard College, 1950; A.M., Harvard University, 1951; Ph.D., 1957. Visiting Assistant Professor, California Institute, 1959-60; Associate Professor, 1960-66; Professor, 1966-. (Arms)

Gustav Albrecht,** Ph.D., *Research Fellow in Chemistry*

B.A., University of California (Los Angeles), 1935; M.S., California Institute, 1939; Ph.D., University of California (Los Angeles), 1941. California Institute, 1963-64; 1964-.

Clarence Roderic Allen, Ph.D., *Professor of Geology and Geophysics*

B.A., Reed College, 1949; M.S., California Institute, 1951; Ph.D., 1954. Assistant Professor, 1955-59; Associate Professor, 1959-64; Professor, 1964-. Interim Director of Seismological Laboratory, 1965-67; Acting Division Chairman, 1967-68. (Seismo Lab.)

David Anthony Allen, Ph.D., *Research Fellow in Astronomy*

B.A., University of Cambridge, 1967; Ph.D., 1970. California Institute, 1970-.

Suzanne Menzel Allswang,** M.A., *Lecturer in German*

B.A., University of Wisconsin, 1959; M.A., University of Tennessee, 1964. California Institute, 1969-. (Dabney)

Yosef Aloni, Ph.D., *Research Fellow in Biology*

M.Sc., Tel-Aviv University, 1963; Ph.D., Weizmann Institute, 1968. California Institute, 1968-. (Church)

Carl David Anderson, Ph.D., ScD., LL.D., Nobel Laureate, *Professor of Physics, Emeritus*

B.S., California Institute, 1927; Ph.D., 1930. Research Fellow, 1930-33; Assistant Professor, 1933-37; Associate Professor, 1937-39; Professor, 1939-; Chairman, Division of Physics, Mathematics and Astronomy, 1962-70; Professor Emeritus, 1970-. (E. Bridge)

Don Lynn Anderson, Ph.D., *Professor of Geophysics; Director, Seismological Laboratory*

B.S., Rensselaer Polytechnic Institute, 1955; M.S., California Institute, 1958; Ph.D., 1962. Research Fellow, 1962-63; Assistant Professor, 1963-64; Associate Professor, 1964-68; Professor, 1968-; Director, 1967-. (Seismo Lab.)

Ernest Gustaf Anderson, Ph.D., *Professor of Genetics, Emeritus*

B.S., University of Nebraska, 1915; Ph.D., Cornell University, 1920. Associate Professor, California Institute, 1928-47; Professor, 1947-61; Professor Emeritus, 1961-.

Thomas Howard Anderson, Ph.D., *Research Fellow in Geology*

B.A., Franklin and Marshall College, 1964; M.S., University of Texas, 1967; Ph.D., 1968. California Institute, 1968-. (Arms)

Fred Colvig Anson, Ph.D., *Professor of Analytical Chemistry*

B.S., California Institute, 1954; Ph.D., Harvard University, 1957. Instructor, California Institute, 1957-58; Assistant Professor, 1958-62; Associate Professor, 1962-68; Professor, 1968-. (Gates)

**Part-time

Tom M. Apostol, Ph.D., *Professor of Mathematics*
B.S., University of Washington, 1944; M.S., 1946; Ph.D., University of California, 1948. Assistant Professor, California Institute, 1950-56; Associate Professor, 1956-62; Professor, 1962-. (Sloan)

Johann Arbocz,** Ph.D., *Research Fellow in Aeronautics*
B.S., Northrop Institute of Technology, 1963; M.S., California Institute, 1964; Ph.D., 1968. Staff Member, Northrop Institute of Technology, 1968-. Research Fellow, California Institute, 1968-. (Firestone)

Stephen William Arch, Ph.D., *Research Fellow in Biology*
A.B., Stanford University, 1964; Ph.D., University of Chicago, 1969. California Institute, 1970-71. (Kerckhoff)

Charles Bruce Archambeau, Ph.D., *Associate Professor of Geophysics*
B.S., University of Minnesota, 1955; M.S., 1959; Ph.D., California Institute, 1965. Associate Professor, 1966-. (Seismo Lab.)

Harbans Lall Arora, Ph.D., *Visiting Associate in Biology*
B.S., Punjab University, 1944; M.S., 1945; Ph.D., Stanford University, 1949. Research Fellow, California Institute, 1957-65; Visiting Associate, 1969-. (Church)

Halton Christian Arp, Ph.D., *Staff Member, Hale Observatories*
A.B., Harvard College, 1949; Ph.D., California Institute, 1953. Hale Observatories, 1957-. (Hale Office)

Kimiko Asano, Ph.D., *Research Fellow in Biology*
M.S., Nagoya University, 1957; Ph.D., 1961. California Institute, 1963-64; 1970. (Kerckhoff)

Michael Aschbacher, Ph.D., *Bateman Research Instructor in Mathematics*
B.S., California Institute, 1966; Ph.D., University of Wisconsin, 1969. California Institute, 1970-71.

Giuseppe Attardi, M.D., *Professor of Biology*
M.D., University of Padua, 1947. Research Fellow, California Institute, 1959-60; Assistant Professor, 1963; Associate Professor, 1963-67; Professor, 1967-. (Church)

Charles Dwight Babcock, Jr., Ph.D., *Associate Professor of Aeronautics*
B.S., Purdue University, 1957; M.S., California Institute, 1958; Ph.D., 1962. Research Fellow, 1962-63; Assistant Professor, 1963-68; Associate Professor, 1968-. (Firestone)

Horace Welcome Babcock, Ph.D., Sc.D., *Director, Hale Observatories*
B.S., California Institute, 1934; Ph.D., University of California, 1938; Sc.D., University of Newcastle-upon-Tyne, 1965. Staff Member, Hale Observatories, 1946-. Assistant Director, 1956-63; Associate Director, 1963-64; Director, 1964-. (Hale Office)

Robert Fox Bacher, Ph.D., Sc.D., *Professor of Physics*
B.S., University of Michigan, 1926; Ph.D., 1930; Sc.D., 1948. Professor of Physics, California Institute, 1949-; Chairman, Division of Physics, Mathematics and Astronomy; Director, Norman Bridge Laboratory of Physics, 1949-62; Provost, 1962-70; Vice President, 1969-70. (Downs)

Richard McLean Badger, Ph.D., *Professor of Chemistry, Emeritus*
B.S., California Institute, 1921; Ph.D., 1924. Research Fellow, 1924-28; International Research Fellow, 1928-29; Assistant Professor, 1929-38; Associate Professor, 1938-45; Professor, 1945-66; Professor Emeritus, 1966-. (Crellin)

John Norris Bahcall, Ph.D., *Associate Professor of Theoretical Physics; Staff Associate, Hale Observatories*
A.B., University of California, 1956; M.A., University of Chicago, 1957; Ph.D., Harvard University, 1960. Research Fellow in Physics, California Institute, 1962-63; Senior Research Fellow, 1963-65; Assistant Professor of Theoretical Physics, 1965-67; Associate Professor, 1967-. (Kellogg)

Neta A. Bahcall,** Ph.D., *Research Fellow in Physics*
B.S., The Hebrew University of Jerusalem, 1963; M.S., Weizmann Institute of Science, 1965; Ph.D., Tel-Aviv University, 1969. California Institute, 1970-71. (Kellogg)

Richard Freligh Baker,** Ph.D., *Research Associate in Engineering Science*
B.S., The Pennsylvania State University, 1932; M.S., 1933; Ph.D., University of Rochester, 1938. Professor of Microbiology, University of Southern California School of Medicine, 1958-. Senior Research Fellow in Chemistry, California Institute, 1953-57; Research Associate in Engineering Science, 1968-. (Thomas)

**Part-time

Barry Clark Barish, Ph.D., *Associate Professor of Physics*

B.A., University of California, 1957; Ph.D., 1962. Research Fellow, California Institute, 1963-66; Assistant Professor, 1966-69; Associate Professor, 1969-. (Lauritsen)

Zalman Barkat, Ph.D., *Research Fellow in Physics*

B.S., The Hebrew University of Jerusalem, 1955; M.S., 1961; Ph.D., 1969. California Institute, 1969-. (Kellogg)

Charles Andrew Barnes, Ph.D., *Professor of Physics*

B.A., McMaster University, 1943; M.A., University of Toronto, 1944; Ph.D., Cambridge University, 1950. Research Fellow, California Institute, 1953-54; Senior Research Fellow, 1954-55; 1956-58; Associate Professor, 1958-62; Professor, 1962-. (Kellogg)

Robert H. Bates, Ph.D., *Assistant Professor of Political Science*

B.A., Haverford College, 1964; Ph.D., Massachusetts Institute of Technology, 1969. California Institute, 1969-. (Spalding)

Nancy Ann Beach, Ph.D., *Research Fellow in Chemistry*

A.B., Bryn Mawr College, 1961; M.A., Columbia University, 1962; Ph.D., 1967. California Institute, 1969-70.

Jesse Lee Beauchamp, Ph.D., *Assistant Professor of Chemistry*

B.S., California Institute, 1964; Ph.D., Harvard University, 1967. Noyes Research Instructor, California Institute, 1967-69; Assistant Professor, 1969-. (Crellin)

Arthur J. Becker, Ph.D., *Research Fellow in Physics*

B.S., De Paul University, 1962; M.S., Purdue University, 1965; Ph.D., 1968. California Institute, 1969-. (W. Bridge)

Wilhelm Behrens, Ph.D., *Assistant Professor of Aeronautics*

Dipl.Ing., Technical University of Munich, 1960; Ph.D., California Institute, 1966. Research Fellow, 1966-67; Assistant Professor, 1967-. (Firestone)

Major Eugene W. Bendel, M.B.A., *Lecturer in Aerospace Studies*

B.A., University of Omaha, 1958; M.B.A., University of Southern California, 1967. California Institute, 1970-. (1107 San Pasqual)

John Frederick Benton, Ph.D., *Professor of History*

B.A., Haverford College, 1953; M.A., Princeton University, 1955; Ph.D., 1959. Assistant Professor, California Institute, 1965-66; Associate Professor, 1966-70; Professor, 1970-. (Dabney)

Seymour Benzer, Ph.D., D.Sc., *Professor of Biology*

B.A., Brooklyn College, 1942; M.S., Purdue University, 1943; Ph.D., 1947; D.Sc., 1968. Research Fellow, California Institute, 1949-50; Visiting Associate, 1965-67; Professor, 1967-. (Church)

Glenn Leroy Berge, Ph.D., *Senior Research Fellow in Radio Astronomy; Staff Member, Owens Valley Radio Observatory*

B.A., Luther College, 1960; M.S., California Institute, 1962; Ph.D., 1965. Research Fellow, 1965-70; Senior Research Fellow, 1970-. (Robinson)

Robert George Bergman, Ph.D., *Assistant Professor of Chemistry*

B.A., Carleton College, 1963; Ph.D., University of Wisconsin, 1966. Noyes Research Instructor, California Institute, 1967-69; Assistant Professor, 1969-. (Crellin)

Philippe Bey, D.Sc., *Research Fellow in Chemistry*

Lic.Sc., Lebanese University, 1963; D.Sc., 1967. California Institute, 1969-. (Crellin)

Richard John Bing, M.D., *Research Associate in Engineering Science*

M.D., University of Munich, 1934; M.D., University of Bern, 1935. Professor of Medicine, University of California; Director, Cardiology and Intramural Medicine, Huntington Memorial Hospital, 1969-. California Institute, 1970-. (Thomas)

Robert J. Bishop, Ph.D., *Research Fellow in Biology*

B.S., Marietta College, 1961; M.S., Rutgers University, 1965; Ph.D., Princeton University, 1970. California Institute, 1970-71.

Richard Allen Blade, Ph.D., *Visiting Associate in Physics*

B.S., University of Colorado, 1960; Ph.D., 1964. Associate Professor; Associate Chairman, University of Colorado, 1967-. California Institute, 1969-70.

Larry Keene Blair, Ph.D., *Research Fellow in Chemistry*

B.A. Berea College, 1966; Ph.D., Stanford University, 1970. California Institute, 1970.

Felix Hans Boehm, Ph.D., *Professor of Physics*

Dipl. Phys., Federal Institute of Technology, Zurich, 1948; Ph.D., 1951. Research Fellow, California Institute, 1953-55; Senior Research Fellow, 1955-58; Assistant Professor, 1958-59; Associate Professor, 1959-61; Professor, 1961-. (W. Bridge)

Henri Frederic Bohnenblust, Ph.D., *Professor of Mathematics; Dean of Graduate Studies*

A.B., Federal Institute of Technology, Zurich, 1928; Ph.D., Princeton University, 1931. Professor, California Institute, 1946-; Dean of Graduate Studies, 1956-. (Sloan, Throop)

James Bonner, Ph.D., *Professor of Biology*

A.B., University of Utah, 1931; Ph.D., California Institute, 1934. Research Assistant, 1935-36; Instructor, 1936-38; Assistant Professor, 1938-42; Associate Professor, 1942-46; Professor, 1946-. (Kerckhoff)

Lyman Gaylord Bonner, Ph.D., *Director of Student Relations; Associate in Chemistry*

B.A., University of Utah, 1932; Ph.D., California Institute, 1935. Director of Foundation Relations, 1965-67; Associate, 1966-; Assistant to the President, 1967-69; Director, 1969-. (Throop)

Henry Borsook, Ph.D., M.D., *Professor of Biochemistry, Emeritus*

Ph.D., University of Toronto, 1924; M.B., 1927; M.D., 1940. Assistant Professor, California Institute, 1929-35; Professor, 1935-68; Professor Emeritus, 1968-.

Ira Sprague Bowen, Ph.D., Sc.D., *Distinguished Service Member, Carnegie Institution: Hale Observatories*

A.B., Oberlin College, 1919; Ph.D., California Institute, 1926. Instructor, 1921-26; Assistant Professor, 1926-28; Associate Professor, 1928-31; Professor, 1931-45; Director, Hale Observatories, 1946-64; Distinguished Service Member, 1964-. (Hale Office)

Paul Bowerman, A.M., *Professor of Modern Languages, Emeritus*

A.B., Dartmouth College, 1920; A.M., University of Michigan, 1936. Instructor, California Institute, 1942-45; Assistant Professor, 1945-47; Associate Professor, 1947-69; Professor Emeritus, 1969-. (Dabney)

David William Boyd, Ph.D., *Associate Professor of Mathematics*

B.Sc., Carleton College, 1963; M.A., University of Toronto, 1964; Ph.D., 1966. Assistant Professor, California Institute, 1967-70; Associate Professor, 1970-. (Sloan)

Arthur Gerald Brady, Ph.D., *Research Fellow in Applied Mechanics*

B.E., University of Auckland, 1959; M.E., 1960; B.Sc., 1961; Ph.D., California Institute, 1966. Research Fellow, 1968- (Thomas)

David Reed Branch, Ph.D., *Research Fellow in Astrophysics*

B.S., Rensselaer Polytechnic Institute, 1964; Ph.D., University of Maryland, 1969. California Institute, 1969-. (Robinson)

Louis Breger, Ph.D., *Visiting Associate Professor of Psychology*

B.A., University of California (Los Angeles), 1957; M.A., The Ohio State University, 1959; Ph.D., 1961. California Institute, 1970-71.

Christopher Brennen, Ph.D., *Research Fellow in Engineering Science*

B.A., Oxford University, 1963; M.A., Ph.D., 1966. California Institute, 1969-. (Karman)

James Eugene Broadwell,** Ph.D., *Senior Research Fellow in Aeronautics*

B.S., Georgia Institute of Technology, 1942; M.S., California Institute, 1944; Ph.D., University of Michigan, 1952. Senior Staff Engineer, TRW Systems, 1964-. California Institute, 1967-. (Karman)

Charles Jacob Brokaw,* Ph.D., *Professor of Biology*

B.S., California Institute, 1955; Ph.D., University of Cambridge, 1958. Visiting Assistant Professor, California Institute, 1960; Assistant Professor, 1961-63; Associate Professor, 1963-68; Professor, 1968-.

Norman Herrick Brooks, Ph.D., *Professor of Environmental Science and Civil Engineering*

A.B., Harvard College, 1949; M.S., Harvard University, 1950; Ph.D., California Institute, 1954. Instructor, 1953-54; Assistant Professor, 1954-58; Associate Professor, 1958-62. Professor, 1962-. (Keck)

Garry Leslie Brown, Ph.D., *Research Fellow in Aeronautics*

B.E., University of Adelaide, 1964; Ph.D., Oxford University, 1967. California Institute, 1967-. (Karman)

Harold Brown, Ph.D., D.Eng., LL.D.

(See page 38.)

*Leave of absence, 1970-71
**Part-time

Harrison Scott Brown, Ph.D., LL.D., Sc.D., D.Sc., *Professor of Geochemistry and of Science and Government*

B.S., University of California, 1938; Ph.D., Johns Hopkins University, 1941; LL.D., University of Alberta, 1960; Sc.D., Rutgers University, 1964; D.Sc., Amherst College, 1966. Professor of Geochemistry, California Institute, 1951-67; Professor of Geochemistry and of Science and Government, 1967-. (Mudd)

Irving Herbert Brown, Ph.D., *Research Fellow in Biology*

B.Sc., University of Toronto, 1964; M.Sc., 1966; Ph.D., 1968. California Institute, 1968-. (Church)

James Neil Brune, Ph.D., *Visiting Associate in Geophysics*

B.A., University of Nevada, 1956; Ph.D., Columbia University, 1961. Professor of Geophysics, University of California (San Diego), 1969-. Associate Professor, California Institute, 1965-69; Visiting Associate, 1970-71. (Seismo Lab.)

Jean Robert Buchler, Ph.D., *Research Fellow in Physics*

Lic.Sc., University of Liege, 1965; M.S., University of California (San Diego), 1967; Ph.D., 1969. California Institute, 1969-. (Kellogg)

Francis Stephan Buffington, Sc.D., *Associate Professor of Materials Science*

S.B., Massachusetts Institute of Technology, 1938; Sc.D., 1951. Assistant Professor of Mechanical Engineering, California Institute, 1951-56; Associate Professor, 1956-63; Associate Professor of Materials Science, 1963-. (Keck)

Charles Edwin Bures, Ph.D., *Professor of Philosophy*

B.A., Grinnell College, 1933; M.A., University of Iowa, 1936; Ph.D., 1938. Assistant Professor, California Institute, 1949-53; Associate Professor, 1953-69; Professor, 1969-. (Dabney)

David T. Burhans, Jr.,** M.A., *Instructor in Speech*

B.A., Pepperdine College, 1967; M.A., University of Southern California, 1969. California Institute, 1969-. (Dabney)

William Lionel Burke, Ph.D., *Research Fellow in Physics*

B.S., California Institute, 1963; Ph.D., 1969. Research Fellow, 1969.

Donald Stacy Burnett, Ph.D., *Associate Professor of Nuclear Geochemistry*

B.S., University of Chicago, 1959; Ph.D., University of California, 1963. Research Fellow in Physics, California Institute, 1963-65; Assistant Professor of Nuclear Geochemistry, 1965-68; Associate Professor, 1968-. (Mudd)

Eliot Andrew Butler, Ph.D., *Visiting Associate in Chemistry*

B.S., California Institute, 1952; Ph.D., 1956. Professor and Executive Officer, Brigham Young University, 1962-. Noyes Research Fellow, California Institute, 1955-56; Visiting Associate, 1970.

Curtis G. Callan, Jr., Ph.D., *Visiting Associate in Theoretical Physics*

B.A., Haverford College, 1961; Ph.D., Princeton University, 1964. Member, The Institute for Advanced Study, 1969-. California Institute, 1970.

Dan Hampton Campbell, Ph.D., Sc.D., *Professor of Immunochemistry*

A.B., Wabash College, 1930; M.S., Washington University, 1932; Ph.D., University of Chicago, 1936; Sc.D., Wabash College, 1960. Assistant Professor, California Institute, 1942-45; Associate Professor, 1945-50; Professor, 1950-. (Church)

George Stuart Campbell, Ph.D., *Research Associate in Aeronautics*

B.S., Rensselaer Polytechnic Institute, 1947; Ae.E., 1949; M.S., California Institute, 1951; Ph.D., 1956. Professor; Head, Department of Aerospace Engineering, University of Connecticut, 1963-. California Institute, 1969-70.

Ian Campbell, Ph.D., *Professor of Geology, Emeritus*

A.B., University of Oregon, 1922; A.M., 1924; Ph.D., Harvard University, 1931. Assistant Professor, California Institute, 1931-35; Associate Professor, 1935-46; Professor, 1946-60; Research Associate, 1960-70; Professor Emeritus, 1970-.

Simon Fraser Campbell, Ph.D., *Research Fellow in Chemistry*

B.Sc., University of Birmingham (England), 1962; Ph.D., 1965. California Institute, 1969-70.

Wayne Harry Cannon, Ph.D., *Research Fellow in Radio Astronomy and Geophysics*

B.S., University of British Columbia, 1963; M.S., 1967; Ph.D., 1970. California Institute, 1970-71.

Richard Guy Casten, Ph.D., *Research Fellow in Applied Mathematics*

B.A., Temple University, 1965; Ph.D., California Institute, 1970. Research Fellow, 1970.

**Part-time

Thomas Kirk Caughey, Ph.D., *Professor of Applied Mechanics*

B.Sc., Glasgow University, 1948; M.M.E., Cornell University, 1952; Ph.D., California Institute, 1954. Instructor, 1953-54; Assistant Professor, 1955-58; Associate Professor, 1958-62; Professor, 1962-. (Thomas)

Klas Ivan Wilhelm Cederwall, D.Tech., *Research Fellow in Hydraulics*

C.E., Chalmers Institute of Technology (Sweden), 1960; Tekn.Lic., 1963; D.Tech., 1968. Assistant Professor, 1965-. California Institute, 1969-71. (Keck)

Sunney Ignatius Chan, Ph.D., *Professor of Chemical Physics*

B.S., University of California, 1957; Ph.D., 1960. Assistant Professor, California Institute, 1963-64; Associate Professor, 1964-68; Professor, 1968-. (Noyes)

Gisela Wohlrab Charlang, Ph.D., *Research Fellow in Biology*

B.A., University of Chicago, 1961; M.S., 1962; Ph.D., 1964. California Institute, 1969-. (Kerckhoff)

Claude Jean Charrier, D.d'Etat, *Research Fellow in Chemistry*

Lic.Sc., University of Paris, 1962; D.d'Etat, 1968. California Institute, 1969-70.

Yu-ssu Chen, Ph.D., *Research Fellow in Physics*

B.S., National Taiwan University, 1963; M.A., Rice University, 1966; Ph.D., California Institute, 1970. Research Fellow, 1969-70.

Kin-fai Cheng, Ph.D., *Research Fellow in Chemistry*

B.Sc., University of Hong Kong, 1965; Ph.D., University of British Columbia, 1969. California Institute, 1969-. (Crellin)

Arthur Nang Lick Chiu, Ph.D., *Visiting Associate in Civil Engineering*

B.A., Oregon State University, 1952; B.S., 1952; S.M., Massachusetts Institute of Technology, 1953; Ph.D., University of Florida, 1961. Professor, University of Hawaii, 1965-. California Institute, 1970.

Charles Bin Chiu, Ph.D., *Richard Chace Tolman Senior Research Fellow in Theoretical Physics*

B.S., Seattle Pacific College, 1961; Ph.D., University of California, 1966. Research Fellow, California Institute, 1969-70; Tolman Senior Research Fellow, 1970-. (Lauritsen)

Manfred Christl, Ph.D., *Research Fellow in Chemistry*

Dipl., University of Munich, 1965; Ph.D., 1969. California Institute, 1970-71. (Crellin)

Robert Frederick Christy, Ph.D., *Professor of Theoretical Physics; Vice President and Provost*

B.A., University of British Columbia, 1935; Ph.D., University of California, 1941. Associate Professor of Physics, California Institute, 1946-50; Professor of Theoretical Physics, 1950-; Executive Officer for Physics, 1968-70; Vice President and Provost, 1970-. (Throop)

Billie Mae Chu, Ph.D., *Research Fellow in Engineering Science*

A.B., Agnes Scott College, 1948; M.A., Emory University, 1949; Ph.D., California Institute, 1970. Research Fellow, 1970-. (Thomas)

Donald Gregory Clark, Ph.D., *Research Fellow in Chemistry*

B.S., University of New Mexico, 1965; Ph.D., Indiana University, 1970. California Institute, 1970. (Church)

Donald Sherman Clark, Ph.D., *Professor of Physical Metallurgy; Director of Placements*

B.S., California Institute, 1929; M.S., 1930; Ph.D., 1934. Instructor in Mechanical Engineering, 1934-37; Director, 1935-; Assistant Professor, 1937-45; Associate Professor, 1945-51; Professor, 1951-63; Professor of Physical Metallurgy, 1963-. (Throop)

J. Kent Clark, Ph.D., *Professor of English*

A.B., Brigham Young University, 1939; Ph.D., Stanford University, 1950; Instructor, California Institute, 1947-50; Assistant Professor, 1950-54; Associate Professor, 1954-60; Professor, 1960-. (Dabney)

Francis Hettinger Clauser, Ph.D., *Clark Blanchard Millikan Professor of Aeronautics; Chairman, Division of Engineering and Applied Science*

B.S., California Institute, 1934; M.S., 1935; Ph.D., 1937. Millikan Professor, Division Chairman, 1969-. (Thomas)

David Alvin Clayton, Ph.D., *Research Fellow in Biology*

B.S., Northern Illinois University, 1965; Ph.D., California Institute, 1970. Research Fellow, 1969-70.

Donald S. Cohen, Ph.D., *Associate Professor of Applied Mathematics*

Sc.B., Brown University, 1956; M.S., Cornell University, 1959; Ph.D., New York University (Courant Institute), 1962. Assistant Professor of Mathematics, California Institute, 1965-67; Associate Professor of Applied Mathematics, 1967-. (Firestone)

Emanuel Richard Cohen,** Ph.D., *Research Associate in Engineering Science*

A.B., University of Pennsylvania, 1943; M.S., California Institute, 1946; Ph.D., 1949. Associate Director, North American Rockwell Science Center, 1964-. Senior Lecturer, California Institute, 1962-63; Research Associate, 1964-. (Thomas)

Marshall Harris Cohen, Ph.D., *Professor of Radio Astronomy; Staff Member, Owens Valley Radio Observatory*

B.E.E., The Ohio State University, 1948; M.S., 1949; Ph.D., 1952. Visiting Associate Professor, California Institute, 1965; Professor, 1968-. (Robinson)

Robert J. Cohen, Ph.D., *Research Fellow in Biology*

B.S., University of Wisconsin, 1964; M.S., Yale University, 1966; Ph.D., 1969. California Institute, 1969-. (Church)

Donald Earl Coles, Ph.D., *Professor of Aeronautics*

B.S., University of Minnesota, 1947; M.S., California Institute, 1948; Ph.D., 1953. Research Fellow, 1953-55; Senior Research Fellow, 1955-56; Assistant Professor, 1956-59; Associate Professor, 1959-64; Professor, 1964-. (Karman)

Anthony Francis Collings, Ph.D., *Senior Research Fellow in Chemical Engineering*

B.Sc., University of New South Wales, 1962; Ph.D., Imperial College of Science and Technology (London), 1965. Research Fellow, California Institute, 1966-67; Senior Research Fellow, 1970-71. (Spalding)

Donald James Collins, Ph.D., *Research Fellow in Aeronautics*

B.S., University of Arizona, 1962; M.S., 1963; Ph.D., California Institute, 1969. Research Fellow, 1969-70. (Firestone)

Theodore Carlos Combs, B.S., *Secretary*

B.S., California Institute, 1927. Director of Alumni Relations, 1966-68; Secretary, 1968- (Throop)

Paul Brainard Condit, Ph.D., *Research Fellow in Chemistry*

B.A., University of California (Riverside), 1965; Ph.D., University of Michigan, 1970. California Institute, 1970. (Crellin)

Frederick James Converse, B.S., *Professor of Soil Mechanics, Emeritus*

B.S., University of Rochester, 1914. Instructor, California Institute, 1921-33; Assistant Professor, 1933-39; Associate Professor, 1939-47; Professor, 1947-62; Professor Emeritus, 1962-. (Thomas)

Robert Sanderson Cooke, Ph.D., *Research Fellow in Chemistry*

A.B., Wesleyan University, 1966; Ph.D., California Institute, 1970. Research Fellow, 1969-70.

William Harrison Corcoran, Ph.D., *Professor of Chemical Engineering; Vice President for Institute Relations*

B.S., California Institute, 1941; M.S., 1942; Ph.D., 1948. Associate Professor, 1952-57; Professor, 1957-; Executive Officer for Chemical Engineering, 1967-69; Vice President, 1969-. (Throop)

Robert Brainard Corey, Ph.D., D.Sc., *Professor of Structural Chemistry, Emeritus*

B.Chem., University of Pittsburgh, 1919; Ph.D., Cornell University, 1924; D.Sc., University of Pittsburgh, 1964. Senior Research Fellow, California Institute, 1937-46; Research Associate, 1946-49; Professor, 1949-68; Professor Emeritus, 1968-. (Church)

Noel Robert David Corngold, Ph.D., *Professor of Applied Science*

A.B., Columbia University, 1949; A.M., Harvard University, 1950; Ph.D., 1954. California Institute, 1966-. (Thomas)

Richard Gerald Couch, Ph.D., *Research Fellow in Physics*

B.S., Illinois Institute of Technology, 1965; M.S., Northwestern University, 1967; Ph.D., 1970. California Institute, 1969-. (Kellogg)

Eugene Woodville Cowan, Ph.D., *Professor of Physics*

B.S., University of Missouri, 1941; S.M., Massachusetts Institute of Technology, 1943; Ph.D., California Institute, 1948. Research Fellow, 1948-50; Assistant Professor, 1950-54; Associate Professor, 1954-61; Professor, 1961-. (West Bridge)

**Part-time

William Reed Cozart, Ph.D., *Assistant Professor of English*
A.B., University of Texas, 1958; M.A., Harvard University, 1960; Ph.D., 1963. California Institute, 1965-. (Gates)

Wilmer Otis Crain, Jr., Ph.D., *Research Fellow in Chemistry*
B.S., Northwestern State College, 1965; Ph.D., Indiana University, 1969. California Institute, 1969-70.

Peter Linton Crawley, Ph.D., *Professor of Mathematics*
B.S., California Institute, 1957; Ph.D., 1961. Assistant Professor, 1963-65; Associate Professor, 1965-68; Professor, 1968-. (Sloan)

Fred E. C. Culick, Sc.D., *Associate Professor of Jet Propulsion*
S.B., S.M., Massachusetts Institute of Technology, 1957; Sc.D., 1961. Research Fellow, California Institute, 1961-63; Assistant Professor, 1963-66; Associate Professor, 1966-. (Karman)

Nachum Dafny, Ph.D., *Research Fellow in Biology*
M.Sc., Hebrew University of Jerusalem, 1965; Ph.D., 1968. California Institute, 1969-70.

Dikran Damlamayan,** Ph.D., *Research Fellow in Electrical Engineering*
B.S., California Institute, 1963; M.S., 1964; Ph.D., 1970. Research Fellow, 1969-70.

Robert Long Daugherty, M.E., *Professor of Mechanical and Hydraulic Engineering, Emeritus*
A.B., Stanford University, 1909; M.E., 1914. California Institute, 1919-56; Professor Emeritus, 1956-. (Thomas)

Vitas Kasimeras Dauksas, Ph.D., *Research Fellow in Chemistry*
B.S., University of Moscow, 1957; Ph.D., 1961. Professor of Organic Chemistry, State University of Vilnius, 1969-. California Institute, 1969-70.

Eric Harris Davidson, Ph.D., *Visiting Assistant Professor of Biology*
B.A., University of Pennsylvania, 1958; Ph.D., Rockefeller University, 1963. Assistant Professor, 1966-. California Institute, 1970.

Norman Ralph Davidson, Ph.D., *Professor of Chemistry; Executive Officer for Chemistry*
B.S., University of Chicago, 1937; B.Sc., Oxford University, 1938; Ph.D., University of Chicago, 1941. Instructor, California Institute, 1946-49; Assistant Professor, 1949-52; Associate Professor, 1952-57; Professor, 1957-; Executive Officer, 1967-. (Crellin)

Merton Edward Davies,** B.A., *Visiting Associate in Planetary Science*
B.A., Stanford University, 1938. Senior Staff Member, The RAND Corporation, 1948-. California Institute, 1969-. (Mudd)

Richard William Davies,** B.S., *Lecturer in Physics*
B.S., California Institute, 1946. Staff Scientist, Jet Propulsion Laboratory, 1961-. California Institute, 1969-70.

Lance Edwin Davis, Ph.D., *Professor of Economics*
B.A., University of Washington, 1950; Ph.D., The Johns Hopkins University, 1956. California Institute, 1968-. (Dabney)

Leverett Davis, Jr., Ph.D., *Professor of Theoretical Physics*
B.S., Oregon State College, 1936; M.S., California Institute, 1938; Ph.D., 1941. Instructor, 1941-46; Assistant Professor, 1946-50; Associate Professor, 1950-56; Professor, 1956-. (Downs)

Ronald Wayne Davis, Ph.D., *Research Fellow in Chemistry*
B.S., Eastern Illinois University, 1964; Ph.D., California Institute, 1970. Research Fellow, 1970.

James William Dawson, Ph.D., *Research Fellow in Chemistry*
B.A., Magdalen College, Oxford University, 1966; B.Sc., 1968; Ph.D., State University of New York (Albany), 1970. California Institute, 1970-71.

Marcia Ilton Dawson, Ph.D., *Research Fellow in Chemistry*
B.S., University of Michigan, 1964; Ph.D., Stanford University, 1968. California Institute, 1967-68; 1970-71. (Crellin)

Richard Albert Dean, Ph.D., *Professor of Mathematics*
B.S., California Institute, 1945; A.B., Denison University, 1947; M.S., Ohio State University, 1948; Ph.D., 1953. Harry Bateman Research Fellow, California Institute, 1954-55; Assistant Professor, 1955-59, Associate Professor, 1959-66; Professor, 1966-. (Sloan)

*Leave of absence, 1970-71.
**Part-time

Richard John Defouw, Ph.D., *Research Fellow in Astrophyscis*
A.B., Harvard College, 1966; Ph.D., California Institute, 1970. Research Fellow, 1970.

Max Delbrück, Ph.D., Sc.D., Nobel Laureate, *Albert Billings Ruddock Professor of Biology*
Ph.D., University of Gottingen, 1931; Sc.D., University of Chicago, 1967. Research Fellow California Institute, 1937-39; Professor, 1947-. (Alles)

Don Dennis, Ph.D., *Research Fellow in Chemistry*
B.S., University of Maryland, 1952; Ph.D., Brandeis University, 1959. Assistant Professor of Chemistry, University of Delaware, 1961-. California Institute, 1969-70.

Edwin Walter Dennison, Ph.D., *Staff Member, Hale Observatories*
B.A., Swarthmore College, 1949; M.A., University of Michigan, 1952; Ph.D., 1954. California Institute, 1963-. (Robinson)

John R. De Palma, M.D., *Visiting Assistant Professor of Chemical Engineering*
A.B., Syracuse University, 1956; M.D., State University of New York, College of Medicine, 1959. Director, Hemodialysis Programs, Cedars-Sinai Medical Center, 1969-. California Institute, 1970-71.

Charles Raymond De Prima, Ph.D., *Professor of Mathematics*
B.A., New York University, 1940; Ph.D., 1943. Assistant Professor of Applied Mechanics, California Institute, 1946-51; Associate Professor, 1951-56; Professor, 1956-64; Professor of Mathematics, 1964-. (Sloan)

Riccardo Destro, Laurea, *Research Fellow in Chemistry*
Laurea, University of Milan, 1964. Lecturer, Experimental Physical Chemistry, 1966-. California Institute, 1968-69; 1970.

Thomas Adriaan de Vlieger, Ph.D., *Research Fellow in Biology*
Ph.D., Free University (Amsterdam), 1968. California Institute, 1970.

Matthijs de Vries, D.Eng., *Visiting Associate in Civil Engineering*
D.Eng., Delft Technological University, 1966. California Institute, 1970.

Daniel T. Dick, Ph.D., *Visiting Assistant Professor of Economics*
B.A., Fresno State College, 1966; M.A., Claremont Graduate School, 1968; Ph.D., 1970. California Institute, 1970-71.

George John Dick, Ph.D., *Research Fellow in Physics*
A.B., Bethel College, 1961; Ph.D., University of California, 1969. California Institute, 1969-. (Sloan)

Richard Earl Dickerson, Ph.D., *Professor of Physical Chemistry*
B.S., Carnegie-Mellon University, 1953; Ph.D., University of Minnesota, 1957. Associate Professor, California Institute, 1963-68; Professor, 1968-. (Church)

Robert C. Dickson, Ph.D., *Research Fellow in Biology*
B.C., University of Redlands, 1965; Ph.D., University of California (Los Angeles), 1970. California Institute, 1970-71

Robert Palmer Dilworth, Ph.D., *Professor of Mathematics*
B.S., California Institute, 1936; Ph.D., 1939. Assistant Professor, California Institute, 1943-45; Associate Professor, 1945-51; Professor, 1951-. (Sloan)

John F. Disterhoft, Ph.D., *Research Fellow in Biology*
B.A., Loras College, 1966; M.A., Fordham University, 1968; Ph.D., 1971. California Institute, 1970-71.

Charles Hewitt Dix, Ph.D., *Professor of Geophysics*
B.S., California Institute, 1927; A.M., Rice Institute, 1928; Ph.D., 1931. Associate Professor, California Institute, 1948-54; Professor, 1954-. (Mudd)

David M. Doddrell, Ph.D., *Research Fellow in Chemistry*
B.Sc., University of Queensland, 1966; Ph.D., Indiana University, 1969. California Institute, 1969-70.

Richard Dolen, Ph.D., *Research Fellow in Theoretical Physics*
B.E., Cornell University, 1957; Ph.D., California Institute, 1966. Research Fellow, 1966-67; 1970.

Douglas Earl Dorman, Ph.D., *Research Fellow in Chemistry*
B.S., University of California (Los Angeles), 1963; M.A., Brandeis University, 1965; Ph.D., 1967. California Institute, 1968-. (Crellin)

Bozena Henisz Dostert, Ph.D., *Senior Research Fellow in Linguistics*
M.A., University of Warsaw, 1956; M.S., Georgetown University, 1961; Ph.D., 1965. Lecturer in English, California Institute, 1969; Senior Research Fellow, 1969-. (Dabney)

William Jakob Dreyer, Ph.D., *Professor of Biology*
B.A., Reed College, 1952; Ph.D., University of Washington, 1956. California Institute, 1963-. (Church)

Henry Dreyfuss, *Associate in Industrial Design*
California Institute, 1947-.

Lee Alvin DuBridge, Ph.D., Sc.D., LL.D., *President Emeritus*
A.B., Cornell College (Iowa), 1922; A.M., University of Wisconsin, 1924; Ph.D., 1926. President, California Institute, 1946-69; President Emeritus, 1969-.

Jesse William Monroe DuMond, Ph.D., D.H.C., *Professor of Physics, Emeritus*
B.S., California Institute, 1916; M.E., Union College, 1918; Ph.D., California Institute, 1929; D.H.C., Upsala University, 1966. Research Associate, California Institute, 1931-38; Associate Professor, 1938-46; Professor, 1946-63; Professor Emeritus, 1963-. (W.Bridge)

Thomas Harold Dunning, Jr., Ph.D., *Research Fellow in Chemistry*
B.S., University of Missouri, 1965; Ph.D., California Institute, 1970. Research Fellow, 1969.

Maurice Dupras, Ph.D., *Research Fellow in Biology*
B.Sc., University of Montreal, 1966; M.Sc., 1967; Ph.D., 1970. California Institute, 1970-71.

Eugene Peter Durbin,** Ph.D., *Lecturer in Business Economics*
B.S, United States Naval Academy, 1957; Ph.D., Stanford University, 1965. Staff Member, The RAND Corporation, 1969-. California Institute, 1970.

David Brock Dusenbery, Ph.D., *Research Fellow in Biology*
B.A., Reed College, 1964; Ph.D., University of Chicago, 1970. California Institute, 1970-71. (Kerckhoff)

Pol Edgard Duwez, D.Sc., *Professor of Materials Science*
Metallurgical Engineer, School of Mines, Mons, Belgium, 1932; D.Sc., University of Brussels, 1933. Research Engineer, California Institute, 1942-47; Associate Professor of Mechanical Engineering, 1947-52; Professor, 1952-63; Professor of Materials Science, 1963-. (Keck)

Mirmira Ramarao Dwarakanath, Ph.D., *Research Fellow in Physics*
B.S., The Central College, University of Mysore, 1958; M.S., California Institute, 1961; Ph.D., 1969. Scientific Officer, Bhabha Atomic Research Centre (India), 1968-. Research Fellow, 1970-71.

Alexander Ronald Dzierba, Ph.D., *Research Fellow in Physics*
B.S., Canisius College (Buffalo), 1964; Ph.D., University of Notre Dame, 1969. California Institute, 1969-. (Lauritsen)

Thomas Oren Early, Ph.D., *Research Fellow in Geochemistry*
B.S., Washington University (St. Louis), 1964; Ph.D., 1970. California Institute, 1970-71.

Robert Eason, Ph.D., *Research Fellow in Biology*
B.Sc., Glasgow University, 1961; Ph.D., 1964. Lecturer in Biochemistry, Glasgow University, 1963-. California Institute, 1969-70.

Mahlon Francis Easterling, M.S.E.E., *Visiting Professor of Applied Science*
B.S.E.E., Columbia University, 1949; M.S.E.E., 1951. Staff Engineer, Jet Propulsion Laboratory, 1958-. California Institute, 1969-70.

Paul Conant Eaton, A.M., *Associate Professor of English*
S.B., Massachusetts Institute of Technology, 1927; A.M., Harvard University, 1930. Visiting Lecturer in English, California Institute, 1946; Associate Professor, 1947-; Dean of Students, 1952-69. (Dabney)

Hendrik Erdmann Eckert, Ph.D., *Research Fellow in Applied Science*
Ph.D., Max-Planck-Institute, 1970. California Institute, 1970-71.

Peter Philip Eggleton, Ph.D., *Research Fellow in Physics*
M.A., Edinburgh University, 1961; B.S., 1962; Ph.D., University of Cambridge, 1966. Staff Member, 1967-. California Institute, 1970-71.

**Part-time.

John Joseph Eisch, Ph.D., *Visiting Associate in Chemistry*

B.S., Marquette University, 1952; Ph.D., Iowa State University, 1956. Professor; Chairman of Chemistry, Catholic University of America, 1966-. California Institute, 1969.

Heinz E. Ellersieck, Ph.D., *Associate Professor of History*

A.B., University of California (Los Angeles), 1942; M.A., 1948; Ph.D., 1955. Instructor, California Institute, 1950-55; Assistant Professor, 1955-60; Associate Professor, 1960-. (Dabney)

David Clephan Elliot, Ph.D., *Professor of History; Executive Officer for Humanities and Social Sciences*

M.A., St. Andrew's University, 1939; A.M., Harvard University, 1948; Ph.D., 1951. Assistant Professor, California Institute, 1950-53; Associate Professor, 1953-60; Professor, 1960-; Executive Officer, 1967-. (Dabney)

Sterling Emerson, Ph.D., *Professor of Genetics*

B.Sc., Cornell University, 1922; M.A., University of Michigan, 1924; Ph.D., 1928. Assistant Professor of Genetics, California Institute, 1928-37; Associate Professor, 1937-46; Professor, 1946-. (Kerckhoff)

Warren G. Emery, M.S., *Director of Physical Education and Athletics*

B.S., University of Nebraska, 1948; M.S., University of California (Los Angeles), 1959. Coach, California Institute, 1955; Assistant Director, 1963-64; Director, 1964-. (Gymnasium)

Stuart Alan Ende, Ph.D., *Assistant Professor of English*

A.B., Cornell University, 1965; M.A., New York University, 1966; Ph.D., Cornell University, 1970. California Institute, 1970-.

James Morris England, Ph.D., *Research Fellow in Biology*

A.B., Lafayette College, 1964; Ph.D., Washington University (St. Louis), 1970. California Institute, 1970-71. (Alles)

Samuel Epstein, Ph.D., *Professor of Geochemistry*

B.Sc., University of Manitoba, 1941; M.Sc., 1942; Ph.D., McGill University, 1944. Research Fellow, California Institute, 1952-53; Senior Research Fellow, 1953-54; Associate Professor, 1954-59; Professor, 1959-. (Mudd)

Arnold Eskin, Ph.D., *Research Fellow in Biology*

B.A., Vanderbilt University, 1961; Ph.D., University of Texas, 1968. California Institute, 1969-. (Kerckhoff)

Viktor Evtuhov,** Ph.D., *Senior Research Fellow in Electrical Engineering*

B.S., University of California (Los Angeles), 1956; M.S., California Institute, 1957; Ph.D., 1961. Senior Staff Physicist, Hughes Research Laboratories, 1965-. Research Fellow, California Institute, 1960-61; Senior Research Fellow, 1969-. (Steele)

Linda Fagan, Ph.D., *Research Fellow in Biology*

B.A., University of Pennsylvania, 1963; M.A., Bryn Mawr College, 1965; Ph.D., 1968. California Institute, 1967-. (Alles)

Fabian Tien-hwa Fang, Ph.D., *Visiting Associate in Chemistry*

B.S., National Central University (China), 1949; M.S. University of Illinois, 1952; Ph.D., 1954. Associate Professor and Chairman, California State College (Bakersfield), 1970-. California Institute, 1970.

John Lyman Fanselow, Ph.D., *Research Fellow in Physics*

B.A., College of Wooster, 1960; Ph.D., University of Chicago, 1967. California Institute, 1968-. (Downs)

Peter Ward Fay, Ph.D., *Professor of History*

A.B., Harvard College, 1947; B.A., Oxford University, 1949; Ph.D., Harvard University, 1954. Assistant Professor, California Institute, 1955-60; Associate Professor, 1960-70; Professor, 1970-. (Dabney)

Uri Feldman, Ph.D., *Visiting Associate in Astrophysics*

M.Sc., The Hebrew University of Jerusalem, 1963; Ph.D., 1965. Director, Stellar Observatory, Tel-Aviv University, 1969-. California Institute, 1970.

Derek Henry Fender, Ph.D., *Professor of Biology and Applied Science*

B.Sc., Reading University, England, 1939; B.Sc., (Sp), 1946; Ph.D., 1956. Senior Research Fellow in Engineering, California Institute, 1961-62; Associate Professor of Biology and Electrical Engineering, 1962-66; Professor of Biology and Applied Science, 1966-. (Booth)

Neil H. Fenichel, Ph.D., *Bateman Research Instructor in Mathematics*

B.S., Columbia University, 1966; Ph.D., New York University, 1970. California Institute, 1970-71.

**Part-time.

Richard Phillips Feynman, Ph.D., Nobel Laureate, *Richard Chace Tolman Professor of Theoretical Physics*

B.S., Massachusetts Institute of Technology, 1939; Ph.D., Princeton University, 1942. Visiting Professor, California Institute, 1950; Professor, 1950-59; Tolman Professor, 1959-. (Lauritsen)

Eva Fifkova, M.D., Ph.D., *Senior Research Fellow in Biology*

M.D., Charles University (Prague), 1957; Ph.D., Czechoslovakian Academy of Sciences, 1963. Research Fellow, California Institute, 1968-70; Senior Research Fellow, 1970-. (Kerckhoff)

Raymond Kurt Fisher, Ph.D., *Research Fellow in Physics*

S.B., Massachusetts Institute of Technology, 1965; Ph.D., California Institute, 1970. Research Fellow, 1970.

Peter H. Fishman, Ph.D., *Research Fellow in Biology*

S.B., Massachusetts Institute of Technology, 1961; M.S., George Washington University, 1967; Ph.D., 1970. California Institute, 1970-71.

William Tibbets Ford, Ph.D., *Research Fellow in Physics*

B.A., Carleton College, 1963; Ph.D., Princton University, 1967. California Institute, 1969-. (Lauritsen)

Arleen B. Forsheit, Ph.D., *Research Fellow in Chemistry*

B.S., Brooklyn College, The City University of New York, 1965; M.A., Columbia University, 1967; Ph.D., University of California (Los Angeles), 1970. California Institute, 1970-71.

Peter Vojta Foukal, Ph.D., *Research Fellow in Astrophysics*

B.Sc., McGill University, 1966; M.Sc., University of Manchester, 1967; Ph.D., 1969. California Institute, 1969-. (Robinson)

William Alfred Fowler, Ph.D., *Institute Professor of Physics*

B.Eng., Ohio State University, 1933; Ph.D., California Institute, 1936, Research Fellow, 1936-39; Assistant Professor, 1939-42; Associate Professor, 1942-46; Professor, 1946-. (Kellogg)

Geoffrey Fox, Ph.D., *Robert Andrews Millikan Research Fellow in Theoretical Physics*

B.A., University of Cambridge, 1965; Ph.D., 1967. Staff Member, Cavendish Laboratory, University of Cambridge, 1969-. California Institute, 1970-.

Joel N. Franklin, Ph.D., *Professor of Applied Mathematics*

B.S., Stanford University, 1950; Ph.D., 1953. Associate Professor of Applied Mechanics, California, Institute, 1957-65; Professor of Applied Science, 1965-69; Professor of Applied Mathematics, 1969-. (Booth)

Wallace Goodman Frasher, Jr.,** M.D., *Senior Research Fellow in Engineering Science*

A.B., University of Southern California, 1941; M.D., 1951. Associate Research Professor of Medicine, Loma Linda University, 1963-. Research Fellow, California Institute, 1961-63; Senior Research Fellow, 1963-. (Thomas)

Steven Clark Frautschi, Ph.D., *Professor of Theoretical Physics*

B.S., Harvard College, 1955; Ph.D., Stanford University, 1958. Assistant Professor, California Institute, 1962-64; Associate Professor, 1964-66; Professor, 1966-. (Lauritsen)

Gerald Alvin Frazier, Ph.D., *Research Fellow in Civil Engineering*

B.S., Montana State University, 1964; M.S., 1966., Ph.D., 1969. California Institute, 1969-. (Thomas)

Kenneth D. Frederick, Ph.D., *Assistant Professor of Economics*

B.A., Amherst College, 1961; Ph.D., Massachusetts Institute of Technology, 1965. California Institute, 1967-. (Spalding)

Bertram Anton Frenz, Ph.D., *Research Fellow in Chemistry*

B.S., University of Wisconsin, 1967; Ph.D., Northwestern University, 1970. California Institute, 1970-71.

Peter G. O. Freund, Ph.D., *Visiting Associate in Theoretical Physics*

E.E., Polytechnical Institute of Timisoara (Rumania), 1958; Ph.D., University of Vienna, 1960. Associate Professor, University of Chicago, 1969-. California Institute, 1970.

Erich Thomas Albert Frey,** Ph.D., *Lecturer in German*

B.A., Nebraska Wesleyan University, 1955; M.A., University of Nebraska, 1957; Ph.D., University of Southern California, 1963. California Institute, 1970-. (Dabney)

**Part-time

Sheldon Kay Friedlander, Ph.D., *Professor of Chemical and Environmental Health Engineering*

B.S., Columbia University, 1949; M.S., Massachusetts Institute of Technology, 1951; Ph.D., University of Illinois, 1954. California Institute, 1964-. (Keck)

Akio Fukuda, Ph.D., *Research Fellow in Biology*

B.S., Tokyo University of Agriculture and Technology, 1963; Ph.D., Princeton University, 1969. California Institute, 1969-. (Church)

Francis Brock Fuller, Ph.D., *Professor of Mathematics*

A.B., Princeton University, 1949; M.A., 1950; Ph.D., 1952. Research Fellow, California Institute, 1952-55; Assistant Professor, 1955-59; Associate Professor, 1959-66; Professor, 1966-. (Sloan)

Dieter Gaier, Dr.rer.nat., *Visiting Professor of Mathematics*

Ph.D., University of Rochester, 1951; Dr.rer.nat., Technical University of Stuttgart, 1952. Director, Institute of Mathematics, Giessen. Senior Research Fellow, California Institute, 1960-61; Visiting Professor, 1964-65; 1970-71.

Gail Galasko, Ph.D., *Research Fellow in Chemistry*

B.Sc., University of Witwatersrand, 1964; M.Sc., 1966; Ph.D., Queen Mary College, London University, 1969. California Institute, 1970.

Uri Ganiel, Ph.D., *Research Fellow in Electrical Engineering*

M.Sc., The Hebrew University of Jerusalem, 1963; Ph.D., Weizmann Institute of Science (Rehovot), 1968. California Institute, 1969-. (Steele)

Roger F. Gans, Ph.D., *Research Fellow in Geophysics and Planetary Science*

S.B., Massachusetts Institute of Technology, 1963; M.S., University of California (Los Angeles), 1968; Ph.D., 1969. California Institute, 1969-. (Mudd)

Zvi Garfunkel, Ph.D., *Research Fellow in Geology and Geophysics*

M.Sc., The Hebrew University of Jerusalem, 1965; Ph.D., 1970. California Institute, 1970.

Elsa Meints Garmire,** Ph.D., *Research Fellow in Applied Science*

A.B., Radcliffe College, 1961; Ph.D., Massachusetts Institute of Technology, 1965. California Institute, 1966-. (Steele)

Gordon Paul Garmire, Ph.D., *Associate Professor of Physics*

A.B., Harvard College, 1959; Ph.D., Massachusetts Institute of Technology, 1962. Senior Research Fellow, California Institute, 1966-68; Associate Professor, 1968-. (Downs)

Justine Spring Garvey, Ph.D., *Senior Research Fellow in Chemistry*

B.S., Ohio State University, 1944; M.S., 1948; Ph.D., 1950. Research Fellow, California Institute, 1951-57; Senior Research Fellow, 1957-. (Church)

Carole R. Gatz, Ph.D., *Visiting Associate in Chemistry*

B.S., State College of Iowa, 1954; Ph.D., University of Illinois, 1960. Assistant Professor, Portland State College, 1964-. California Institute, 1970-71.

George Rousetos Gavalas, Ph.D., *Associate Professor of Chemical Engineering*

B.S., Technical University of Athens, 1958; M.S., University of Minnesota, 1962; Ph.D., 1964. Assistant Professor, California Institute, 1964-67; Associate Professor, 1967-. (Spalding)

Murray Gell-Mann, Ph.D., Sc.D., D.Sc., Nobel Laureate, *Robert Andrews Millikan Professor of Theoretical Physics*

B.S., Yale University, 1948; Ph.D., Massachusetts Institute of Technology, 1950; Sc.D., Yale University, 1959; D.Sc., University of Chicago, 1967. Associate Professor, California Institute, 1955-56; Professor, 1956-67; Millikan Professor, 1967-. (Lauritsen)

Michael James George, Ph.D., *Research Fellow in Physics*

B.S., University of North Carolina, 1963; Ph.D., California Institute, 1969. Research Fellow, 1969-70.

Nicholas George, Ph.D., *Associate Professor of Electrical Engineering*

B.S., University of California, 1949; M.S., University of Maryland, 1956; Ph.D., California Institute, 1959. Visiting Associate Professor, 1959-60; Associate Professor, 1960- (Steele)

Victor Ghetie, Ph.D., *Visiting Associate in Chemistry*

Ph.D., University of Bucharest, 1959. Head, Laboratory of Immunochemistry, Rumanian Academy of Science. California Institute, 1970.

**Part-time.

Horace Nathaniel Gilbert, M.B.A., *Professor of Business Economics, Emeritus*
A.B., University of Washington, 1923; M.B.A., Harvard University, 1926. Assistant Professor, California Institute, 1929-30; Associate Professor, 1930-47; Professor, 1947-69; Professor Emeritus, 1969-. (Dabney)

Victor Gilinsky,** Ph.D., *Research Fellow in Engineering Science*
B.Eng., Cornell University, 1956; Ph.D., California Institute, 1961. Staff Member, The RAND Corporation, 1961-. California Institute, 1969-70.

Robert Blythe Gilmore, B.S., C.P.A., *Vice President for Business and Finance*
B.S., University of California (Los Angeles), 1937; C.P.A., State of California; State of Iowa, 1946. Manager of Accounting, California Institute, 1948-52; Assistant Controller, 1952-58; Controller, 1958-62; Vice President, 1962-. (Throop)

Moses Glasner, Ph.D., *Assistant Professor of Mathematics*
B.A., University of California (Los Angeles), 1963; Ph.D., 1966. California Institute, 1967-. (Sloan)

Ian Stewart Glass, Ph.D., *Research Fellow in Physics*
B.A., Trinity College (Dublin), 1961; S.M., Massachusetts Institute of Technology, 1964; Ph.D., 1968. California Institute, 1970-71. (Downs)

William Andrew Goddard III, Ph.D., *Assistant Professor of Theoretical Chemistry*
B.S., University of California (Los Angeles), 1960; Ph.D., California Institute, 1965. Noyes Research Fellow in Chemistry, 1964-66; Noyes Research Instructor, 1966-67; Assistant Professor of Theoretical Chemistry, 1967-. (Noyes)

Peter Martin Goldreich, Ph.D., *Professor of Planetary Science and Astronomy*
B.S., Cornell University, 1960; Ph.D., 1963. Associate Professor, California Institute, 1966-69; Professor, 1969-. (Mudd)

Richard Morris Goldstein,** Ph.D., *Visiting Associate Professor of Planetary Science*
B.S., Purdue University, 1947; M.S., California Institute, 1959; Ph.D., 1962. Manager, Telecommunications Research Section, Jet Propulsion Laboratory, 1958-. California Institute 1967-. (Mudd)

Ellis Eckstein Golub, Ph.D., *Research Fellow in Biology*
B.A., Brandeis University, 1963; Ph.D., Tufts University, 1969. California Institute, 1969-. (Kerckhoff)

Ricardo Gomez, Ph.D., *Senior Research Fellow in Physics*
S.B., Massachusetts Institute of Technology, 1953; Ph.D., 1956. Research Fellow, California Institute, 1956-59; Senior Research Fellow, 1959-. (Lauritsen)

David Louis Goodstein, Ph.D., *Assistant Professor of Physics*
B.S., Brooklyn College, 1960; Ph.D., University of Washington, 1965. Research Fellow, California Institute, 1966-67; Assistant Professor, 1967-. (Sloan)

Gerhard Göpel, Ph.D., *Research Fellow in Biology*
Ph.D., University of Cologne, 1967. California Institute, 1970. (Kerckhoff)

Joseph G. Gordon, Ph.D., *Assistant Professor of Chemistry*
A.B., Harvard College, 1966; Ph.D., Massachusetts Institute of Technology, 1970. California Institute, 1970-.

Robert Jay Gordon, Ph.D., *Research Fellow in Chemistry*
A.B., Harvard College, 1965; A.M., Harvard University, 1966; Ph.D., 1970. California Institute, 1970-71.

Stanislaw Gorgolewski, Ph.D., *Research Fellow in Radio Astronomy*
M.A., Trinity College, University of Cambridge, 1959; Ph.D., Nicholas Copernicus University, 1960. Staff Member, 1958-. California Institute, 1970.

Peter Göser, Ph.D., *Research Fellow in Chemistry*
Dipl., Technical University of Munich, 1967; Ph.D., 1969. California Institute, 1969-. (Church)

Roy Walter Gould,* Ph.D., *Professor of Electrical Engineering and Physics*
B.S., California Institute, 1949; M.S., Stanford University, 1950; Ph.D., California Institute, 1956. Assistant Professor of Electrical Engineering, 1955-58; Associate Professor, 1958-60; Associate Professor of Electrical Engineering and Physics, 1960-62; Professor, 1962-.

*Leave of absence, 1970-71.
**Part-time

Earl K. Graham, Jr., Ph.D., *Research Fellow in Geophysics*
A.B., Occidental College, 1962; M.S., Stanford University, 1964; Ph.D., Pennsylvania State University, 1968. California Institute, 1969-. (Seismo Lab.)

Bernhard Gramsch, Dr.rer.nat., *Visiting Associate Professor of Mathematics*
Dipl., University of the Saar, 1961; Dr.rer.nat., University of Mainz, 1964. California Institute, 1970.

Harry Barkus Gray, Ph.D., *Professor of Chemistry*
B.S., Western Kentucky College, 1957; Ph.D., Northwestern University, 1960. Visiting Professor of Inorganic Chemistry, California Institute, 1965; Professor of Chemistry, 1966-. (Noyes)

Robert Davis Gray, B.S., *Professor of Economics and Industrial Relations; Director of Industrial Relations Center*
B.S., Wharton School of Finance and Commerce, University of Pennsylvania, 1930. Associate Professor, California Institute, 1940-42; Professor, 1942-. (Industrial Relations Center)

James Wallace Greenlee,* Ph.D., *Assistant Professor of French*
B.A., University of Illinois, 1956; M.A., 1962; Ph.D., 1967. Instructor, California Institute, 1966; Assistant Professor, 1967-.

Jesse Leonard Greenstein, Ph.D., *Lee A. DuBridge Professor of Astrophysics; Staff Member, Hale Observatories, Owens Valley Radio Observatory; Executive Officer for Astronomy*
A.B., Harvard College, 1929; A.M., Harvard University, 1930; Ph.D., 1937. Associate Professor, California Institute, 1948-49; Professor, 1949-; Executive Officer, 1964-. (Robinson)

Peter Wheeler Greenwood,** Ph.D., *Lecturer in Business Economics*
B.S., United States Naval Academy, 1961; M.S., Stanford University, 1963; Ph.D., 1967. Staff Member, The RAND Corporation, 1967-. California Institute, 1970.

David M. Grether, Ph.D., *Associate Professor of Economics*
B.S., University of California, 1960; Ph.D., Stanford University, 1969. California Institute, 1970-.

Michael Gronau, Ph.D., *Research Fellow in Theoretical Physics*
M.S., The Hebrew University of Jerusalem, 1964; Ph.D., Tel-Aviv University, 1970. California Institute, 1970-71.

Gavril Grueff, Laurea, *Research Fellow in Radio Astronomy*
Laurea, University of Bologna, 1965. Staff Member, National Laboratory of Radio Astronomy (Bologna), 1965-. California Institute, 1970-71. (Robinson)

James Edward Gunn, Ph.D., *Assistant Professor of Astronomy*
B.A., Rice University, 1961; Ph.D., California Institute, 1966. Assistant Professor, 1970-. (Robinson)

Thomas Gutman, M.S., *Coach*
B.S., University of California (Los Angeles), 1962; M.S., 1963. California Institute, 1966-. (Gymnasium)

Jozsef Gyulai, Ph.D., *Research Fellow in Electrical Engineering*
Ph.D., University of Szeged (Hungary), 1960. Staff Member, Hungarian Academy of Sciences, 1956-. California Institute, 1969-70.

Arie Jan Haagen-Smit, Ph.D., *Professor of Bio-organic Chemistry*
A.B., University of Utrecht, 1922; A.M., 1926; Ph.D., 1929. Associate Professor, California Institute, 1937-40; Professor, 1940-. (Kerckhoff)

George Elisha Hall, Ph.D., *Visiting Associate in Chemistry*
B.S., Yale University, 1938; Ph.D., 1942. Professor; Chairman, Department of Chemistry, Mount Holyoke College. Visiting Professor, California Institute, 1953-54; Visiting Associate, 1969-70.

Marshall Hall, Jr.,*** Ph.D., *Professor of Mathematics*
B.A., Yale University, 1932; Ph.D., 1936. Professor, California Institute, 1959-; Executive Officer, 1966-69. (Sloan)

*Leave of absence, 1970-71
**Part-time
***Leave of absence, second and third terms, 1970-71

George Simms Hammond, Ph.D., *Arthur Amos Noyes Professor of Chemistry; Chairman of the Division of Chemistry and Chemical Engineering*

B.S., Bates College, 1943; M.S., Ph.D., Harvard University, 1947. Research Associate in Chemistry, California Institute, 1956-57; Professor of Organic Chemistry, 1958-64; Noyes Professor of Chemistry, 1964-; Division Chairman, 1968-. (Crellin)

Thomas E. Hanson, Ph.D., *Research Fellow in Biology*

B.S., Southern Illinois University, 1964; Ph.D., Michigan State University, 1969. California Institute, 1969-. (Alles)

Ellen Gundermann Hardebeck, Ph.D., *Research Fellow in Radio Astronomy*

B.S., University of Chicago, 1961; Ph.D., Harvard University, 1965. California Institute, 1969-. (Robinson)

Paul A. Hargrave, Ph.D., *Research Fellow in Biology*

A.B., Colgate University, 1960; M.S., University of Illinois, 1966; Ph.D., University of Minnesota, 1970. California Institute, 1970-71.

David Garrison Harkrider, Ph.D., *Associate Professor of Geophysics*

B.S., Rice University, 1953; M.A., 1957; Ph.D., California Institute, 1963. Associate Professor, 1970-.

Robert S. Harp, Ph.D., *Assistant Professor of Electrical Engineering*

S.B., Massachusetts Institute of Technology, 1959; M.S., Stanford University, 1961; Ph.D., 1964. California Institute, 1967-. (Steele)

Gordon Leonard Harris, D.Sc., *Assistant Professor of Aeronautics*

B.S., McGill University, 1960; M.S., Mississippi State University, 1963; D.Sc., University of Brussels, 1965. Research Fellow, California Institute, 1965-67; Senior Research Fellow, 1967-69; Assistant Professor, 1969-. (Guggenheim)

Stephen Eubonk Harris, Ph.D., *Research Fellow in Biology*

B.A., University of Texas, 1965; M.A., 1966; Ph.D., 1969. California Institute, 1970-71. (Kerckhoff)

William Douglas Harrison, Ph.D., *Research Fellow in Geology*

B.Sc., Mt. Allison University, New Brunswick, Canada, 1958; B.S., University of London, 1960; Ph.D., California Institute, 1966. Research Fellow, 1968-. (Mudd)

Ryusuke Hasegawa, Ph.D., *Research Fellow in Materials Science*

B.E., Nagoya University, 1962; M.E., 1964; M.S., California Institute, 1968; Ph.D., 1969. Research Fellow, 1969-. (Keck)

Geoffrey Ernest Hawkes, Ph.D., *Research Fellow in Chemistry*

B.Sc., Queen Mary College, University of London, 1967; Ph.D., 1970. California Institute, 1970-71.

Bruce Lowell Hawkins, Ph.D., *Research Fellow in Chemistry*

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Oscar Mandel, Ph.D., *Professor of English*
B.A., New York University, 1947; M.A., Columbia University, 1948; Ph.D., The Ohio State University, 1951. Visiting Associate Professor, California Institute, 1961-62; Associate Professor, 1962-68; Professor, 1968-. (Dabney)

Jeffrey Ellis Mandula, Ph.D., *Assistant Professor of Theoretical Physics*
A.B., Columbia University, 1962; A.M., Harvard University, 1964; Ph.D., 1966. Research Fellow, California Institute, 1967-69; Assistant Professor, 1970-.

Frank Earl Marble, Ph.D., *Professor of Jet Propulsion and Mechanical Engineering*
B.S., Case Institute of Technology, 1940; M.S., 1942; A.E., California Institute, 1947; Ph.D., 1948. Instructor, 1948-49; Assistant Professor, 1949-53; Associate Professor, 1953-57; Professor, 1957-. (Guggenheim)

Richard Edward Marsh, Ph.D., *Senior Research Fellow in Chemistry*
B.S., California Institute, 1943; Ph.D., University of California (Los Angeles), 1950. Research Fellow, California Institute, 1950-55; Senior Research Fellow, 1955-. (Noyes)

Hardy Cross Martel, Ph.D., *Associate Professor of Electrical Engineering; Executive Assistant to the President*
B.S., California Institute, 1949; M.S., Massachusetts Institute of Technology, 1950; Ph.D., California Institute, 1956. Instructor, 1953-55; Assistant Professor, 1955-58; Associate Professor, 1958-; Executive Assistant to the President, 1969-. (Steele, Throop)

Elizabeth Marvick,**Ph.D., *Lecturer in Political Science*
Ph.B., University of Chicago, 1944; M.A., 1956; Ph.D., Columbia University, 1968. California Institute, 1970-71.

Jon Mathews, Ph.D., *Professor of Theoretical Physics; Executive Officer for Physics*
B.A., Pomona College, 1952; Ph.D., California Institute, 1957. Instructor, 1957-59; Assistant Professor, 1959-62; Associate Professor, 1962-66; Professor, 1966-; Executive Officer, 1970-. (Downs)

Nobuyoshi Matsumoto, D.Sc., *Research Fellow in Applied Science*
B.S., Kyoto University, 1963; M.S., 1965; D.Sc., 1969. California Institute, 1969-. (Booth)

James Walter Mayer, Ph.D., *Associate Professor of Electrical Engineering*
B.S., Purdue University, 1952; Ph.D., 1959. California Institute, 1967-. (Steele)

John E. Mayfield, Ph.D., *Research Fellow in Biology*
B.A., College of Wooster, 1963; M.S., University of Pittsburgh, 1965; Ph.D., 1968. California Institute, 1968-. (Kerckhoff)

George P. Mayhew, Ph.D., *Professor of English*
A.B., Harvard College, 1941; M.A., Harvard University, 1947; Ph.D., 1953. Assistant Professor, California Institute, 1954-60; Associate Professor, 1960-68; Professor, 1968-. (Dabney)

James Oeland McCaldin, Ph.D., *Associate Professor of Applied Science*
B.A., University of Texas, 1944; Ph.D., California Institute, 1954. Associate Professor, California Institute, 1968-. (Keck)

Myron Thomas McCall, Ph.D., *Research Fellow in Chemistry*
B.S., University of Florida, 1964; Ph.D., University of North Carolina, 1969. California Institute, 1969-70.

Gilbert Donald McCann, Ph.D., *Professor of Applied Science; Director, Willis H. Booth Computing Center*
B.S., California Institute, 1934; M.S., 1935; Ph.D., 1939. Associate Professor of Electrical Engineering, 1946-47; Professor, 1947-66; Professor of Applied Science; Director, 1966-. (Booth)

Thomas Bard McCord, Ph.D., *Visiting Associate in Planetary Science*
B.S., Pennsylvania State University, 1964; M.S., California Institute, 1966; Ph.D., 1968. Assistant Professor, Massachusetts Institute of Technology, 1968-. Research Fellow, California Institute, 1968; Visiting Associate, 1969-70.

**Part-time

John McKay, Ph.D., *Visiting Assistant Professor of Mathematics*

B.Sc., Manchester University, 1961; Ph.D., Edinburgh University, 1969. California Institute, 1969-. (Sloan)

Christopher F. McKee, Ph.D., *Research Fellow in Astrophysics*

A.B., Harvard College, 1963; Ph.D., University of California, 1970. California Institute, 1970-71.

Jack Edward McKee, Sc.D., *Professor of Environmental Engineering*

B.S., Carnegie Institute of Technology, 1936; M.S., Harvard University, 1939; Sc.D., 1941. Associate Professor of Sanitary Engineering, California Institute, 1949-56; Professor, 1956-60; Professor of Environmental Health Engineering, 1960-. (Keck)

Basil Vincent McKoy, Ph.D., *Associate Professor of Theoretical Chemistry*

B.S., Nova Scotia Technical College, 1960; Ph.D., Yale University, 1964. Noyes Research Instructor in Chemistry, California Institute, 1964-66; Assistant Professor of Theoretical Chemistry, 1967-69; Associate Professor, 1969-. (Noyes)

Daniel McMahon, Ph.D., *Assistant Professor of Biology*

A.B., Case Western Reserve University, 1961; M.S., University of Chicago, 1962; Ph.D., 1966. California Institute, 1968-. (Kerckhoff)

Minnie McMillan, Ph.D., *Research Fellow in Chemistry*

B.A., Somerville College, Oxford University, 1964; B.Sc., 1965; Ph.D., University of York, 1967. California Institute, 1969-. (Church)

Carver Andress Mead, Ph.D., *Professor of Electrical Engineering*

B.S., California Institute, 1956; M.S., 1957; Ph.D., 1960. Instructor, 1958-59; Assistant Professor, 1959-62; Associate Professor, 1962-67; Professor, 1967-. (Steele)

Herbert Joel Meiselman, Sc.D., *Research Fellow in Engineering Science*

B.S., Michigan Technological University, 1962; Sc.D., Massachusetts Institute of Technology, 1965. California Institute, 1965-. (Thomas)

James Edgar Mercereau, Ph.D., D.Sc., *Professor of Physics*

B.A., Pomona College, 1953; M.S., University of Illinois, 1954; Ph.D., California Institute, 1959; D.Sc., Pomona College, 1968. Assistant Professor, California Institute, 1959-62; Visiting Associate, 1964-65; Research Associate, 1965-69; Professor, 1969-. (Sloan)

Otto August Meyer, Dr.Ing., *Research Fellow in Electrical Engineering*

Dipl., University of Frankfurt, 1962; Dr.Ing., Technical University of Karlsruhe, 1969. California Institute, 1969-70.

William Whipple Michael, B.S., *Professor of Civil Engineering, Emeritus*

B.S., Tufts College, 1909. Associate Professor, California Institute, 1918-56. Professor Emeritus, 1956-. (Thomas)

Robert David Middlebrook, Ph.D., *Professor of Electrical Engineering*

B.A., University of Cambridge, 1952; M.S., Stanford University, 1953; Ph.D., 1955. Assistant Professor, California Institute, 1955-58; Associate Professor, 1958-65; Professor, 1965-. (Steele)

Julius Miklowitz, Ph.D., *Professor of Applied Mechanics*

B.S., University of Michigan, 1943; Ph.D., 1949. Associate Professor, California Institute, 1956-62; Professor, 1962-. (Thomas)

Peter MacNaughton Miller, Ph.D., *Director of Admissions and of Undergraduate Scholarships; Lecturer in English*

A.B., Princeton University, 1934; Ph.D., 1939. Assistant Director of Admissions and of Undergraduate Scholarships, California Institute, 1956-63; Lecturer, 1957-; Associate Director, 1963-68; Director, 1968-. (Throop)

Francis Millett, Ph.D., *Research Fellow in Chemistry*

B.S., University of Wisconsin, 1965; Ph.D., Columbia University, 1970. California Institute, 1970-71.

Herschel Kenworthy Mitchell, Ph.D., *Professor of Biology*

B.S., Pomona College, 1936; M.S., Oregon State College, 1938; Ph.D., University of Texas, 1941. Senior Research Fellow, California Institute, 1946-49; Associate Professor, 1949-53; Professor, 1953-. (Alles)

Ian Vaughan Mitchell, Ph.D., *Research Fellow in Electrical Engineering*

B.Sc., University of Adelaide, 1959; Ph.D., The Australian National University, 1964. Staff Scientist, Chalk River Nuclear Laboratories, 1968. California Institute, 1970.

Tse-Chin Mo, Ph.D., *Research Fellow in Electrical Engineering*

B.S., National Taiwan University, 1964; M.S., California Institute, 1966; Ph.D., 1969. Research Fellow, 1969-. (Steele)

Alan Theodore Moffet, Ph.D., *Associate Professor of Radio Astronomy; Staff Member, Owens Valley Radio Observatory*

B.A., Wesleyan University, 1957; Ph.D., California Institute, 1961. Research Fellow, 1962-66; Assistant Professor, 1966-68; Staff Member, 1966-; Associate Professor, 1968-. (Robinson)

Derek William Moore, Ph.D., *Senior Research Fellow in Applied Mathematics*

B.A., University of Cambridge, 1954; M.A., Ph.D., 1958. California Institute, 1966; 1969; 1970.

Dino Antonio Morelli, Ph.D., *Professor of Engineering Design*

B.E., Queensland University, 1937; M.E., 1942; M.S., California Institute, 1945; Ph.D., 1946. Lecturer in Mechanical Engineering, 1948-49; 1958-59; Assistant Professor, 1949-56; Associate Professor, 1959-61; Professor of Engineering Design, 1961-. (Thomas)

James John Morgan, Ph.D., *Professor of Environmental Engineering Science*

B.C.E., Manhattan College, 1954; M.S.E., University of Michigan, 1956; M.A., Harvard University; 1962; Ph.D., 1964. Associate Professor, California Institute, 1965-69; Professor, 1969-. (Keck)

Thomas A. Morgan, Ph.D., *Research Fellow in Physics*

S.B., Massachusetts Institute of Technology, 1958; Ph.D., Syracuse University, 1964. California Institute, 1969-. (Bridge)

Edward Randolph Moser, M.S., *Associate Director of Libraries*

A.B., Wheaton College, 1943; M.S., Cornell University, 1944. Associate Director, California Institute, 1967-. (Millikan Library)

Rudolf Ludwig Mössbauer,** Dr.rer.nat., Sc.D., Nobel Laureate, *Visiting Professor of Physics*

B.S., Institute for Technical Physics, Munich, 1949; Dr.rer.nat., 1958; Sc.D., Gustavus Adolphus College, 1963. Professor of Physics, Institute for Technical Physics, Munich, 1964-. Research Fellow, California Institute, 1960; Senior Research Fellow, 1961; Professor, 1961-64; Visiting Professor, 1965-.

Duane O. Muhleman, Ph.D., *Associate Professor of Planetary Science; Staff Member, Owens Valley Radio Observatory*

B.S., University of Toledo, 1953; Ph.D., Harvard University, 1963. California Institute, 1967-. (Mudd)

Rokuro Muki, Ph.D., *Senior Research Fellow in Applied Mechanics*

B.E., Keio University, 1951; Ph.D., 1956. Associate Professor of Mechanics, University of California (Los Angeles), 1967-. Visiting Associate Professor, California Institute, 1965-66; Senior Research Fellow, 1966-67; 1968; 1969; 1970.

Guido Münch, Ph.D., *Professor of Astronomy; Staff Member, Hale Observatories*

B.S., Universidad Nacional Autonoma de Mexico, 1938; M.S., 1944; Ph.D., University of Chicago, 1947. Assistant Professor, California Institute, 1951-54; Associate Professor, 1954-59; Professor, 1959-. (Robinson)

Edwin Stanton Munger, Ph.D., *Professor of Geography*

M.S., University of Chicago, 1948; Ph.D., 1951. Visiting Lecturer, American Universities Field Staff, California Institute, 1954; 1957; 1960; Professor, 1961-. (Keck)

Bruce Churchill Murray, Ph.D., *Professor of Planetary Science*

S.B., Massachusetts Institute of Technology, 1953; S.M., 1954; Ph.D., 1955. Research Fellow in Space Science, California Institute, 1960-63; Associate Professor of Planetary Science, 1963-68; Professor, 1968-. (Mudd)

Leelavati Murthy, Ph.D., *Research Fellow in Biology*

B.Sc., University of Bombay, 1962; M.Sc., 1964; Ph.D., 1969. California Institute, 1969-70.

Harold Z. Musselman, A.B., *Director of Physical Education and Athletics, Emeritus*

A.B., Cornell College, 1920. Instructor, California Institute, 1921-24; Manager of Athletics, 1924-35; Assistant Director of Physical Education and Manager of Athletics, 1935-42; Acting Director of Physical Education, 1942-43; Director of Physical Education and Manager of Athletics, 1943-47; Director of Athletics and Physical Education, 1947-64; Administrative Adviser, 1964-66; Director, Emeritus, 1966-.

Yorikiyo Nagashima, Ph.D., *Senior Research Fellow in Physics*

B.S., University of Tokyo, 1960; M.S., 1962; Ph.D., 1965. California Institute, 1969-. (Lauritsen)

**Part-time

Norio Nagata, Dr.Eng., *Research Fellow in Materials Science*

B.Eng., Kyushu Institute of Technology, 1956; Dr.Eng., Tokyo Institute of Technology, 1969. Japanese Government Technical Official, 1957-. California Institute, 1969-. (Keck)

Ken-Ichi Naka, D.Sc., *Research Associate in Biology and Applied Science*

B.S., Kyushu University, 1955; M.S., 1957; D.Sc., 1960. California Institute, 1967-. (Booth)

Henry Victor Neher, Ph.D., Sc.D., *Professor of Physics, Emeritus*

A.B., Pomona College, 1926; Ph.D., California Institute, 1931; Sc.D., Pomona College, 1968. Research Fellow, California Institute, 1931-33; Instructor, 1933-37; Assistant Professor, 1937-40; Associate Professor, 1940-44; Professor, 1944-70; Professor Emeritus, 1970-. (E. Bridge)

Anthony Vincent Nero, Jr., Ph.D., *Research Fellow in Physics*

B.S., Fordham University, 1964; Ph.D., Stanford University, 1970. California Institute, 1970-71.

James H. Nerrie, B.S., *Coach*

Diploma, Savage School for Physical Education, 1933; B.S., Rutgers University, 1941. California Institute, 1946-. (Gymnasium)

Gerry Neugebauer, Ph.D., *Professor of Physics; Staff Associate, Hale Observatories*

A.B., Cornell University, 1954; Ph.D., California Institute, 1960. Assistant Professor, 1962-65; Associate Professor, 1965-70; Professor, 1970-. (Downs)

Eduardo Almeida Neves, Ph.D., *Visiting Associate in Chemistry*

B.S., University of Sao Paulo, 1957; Ph.D., 1966. Assistant Professor of Chemistry. California Institute, 1970-71.

Lawrence Ronald Newkirk, Ph.D., *Research Fellow in Materials Science*

B.S., California Institute, 1966; M.S., 1967; Ph.D., 1970. Research Fellow, 1970-71. (Keck)

Charles Newton, Ph.B., *Lecturer in English*

Ph.B., University of Chicago, 1933. Assistant to the President, California Institute, 1948-68; Director of Development, 1961-66; Lecturer, 1955; 1960-62; 1966-. (Dabney)

Marc-Aurele Nicolet, Ph.D., *Associate Professor of Electrical Engineering*

Ph.D., University of Basel, Switzerland, 1958. Assistant Professor, California Institute, 1959-65; Associate Professor, 1965-. (Steele)

Roger Gordon Noll,* Ph.D., *Associate Professor of Economics*

B.S., California Institute, 1962; M.A., Harvard University, 1965; Ph.D., 1967. Instructor, California Institute, 1965-67; Assistant Professor, 1967-69; Associate Professor, 1969-. (Dabney)

Wheeler James North, Ph.D., *Professor of Environmental Science*

B.S., California Institute, 1944; 1950; M.S., Ph.D., University of California, 1953. Visiting Assistant Professor of Biology, California Institute, 1962; Associate Professor of Environmental Health Engineering, 1963-68; Professor, 1968-. (Keck)

Harris Anthony Notarys, Ph.D., *Senior Research Fellow in Physics*

S.B., Massachusetts Institute of Technology, 1954; Ph.D., California Institute, 1964. Research Fellow, 1969; Senior Research Fellow, 1970-. (Sloan)

Roman Novins,** M.A., *Lecturer in Russian*

M.A., Sequoia University, 1952. Staff Member, Department of Slavic Studies, University of Southern California, 1960-. California Institute, 1962-. (Dabney)

Patrick William Nye, Ph.D., *Senior Research Fellow in Applied Science*

B.Sc., Reading University (England), 1958; Ph.D., 1962. Staff Physicist, California Institute, 1965-66; Research Fellow, 1966-69; Senior Research Fellow, 1969-. (Booth)

Orpha Caroline Ochse,** Ph.D., *Lecturer in Music*

B.M., Central College, Fayette, Missouri, 1947; M.M., Eastman School of Music, University of Rochester, 1949; Ph.D., 1953. California Institute, 1960-. (Dabney)

Richard John O'Connell, Ph.D., *Research Fellow in Geophysics*

B.S., California Institute, 1963; M.S., 1966; Ph.D., 1969. Research Fellow, 1969-. (Seismo Lab.)

Piermaria Jorge Oddone, Ph.D., *Research Fellow in Physics*

S.B., Massachusetts Institute of Technology, 1965; Ph.D., Princeton University, 1969. California Institute, 1969-. (Lauritsen)

*Leave of absence, 1970-71
**Part-time

John Beverly Oke, Ph.D., *Professor of Astronomy; Associate Director, Hale Observatories*

B.A., University of Toronto, 1949; M.A., 1950; Ph.D., Princeton University, 1953. Assistant Professor, California Institute, 1958-61; Staff Member, 1958-69; Associate Professor, 1961-64; Professor, 1964-; Associate Director, 1970-. (Robinson)

James Olds, Ph.D., *Bing Professor of Behavioral Biology*

B.A., Amherst College, 1947; M.D., Harvard University, 1951; Ph.D., 1952. California Institute, 1969-. (Kerckhoff)

Marianne Nicole Olds, Ph.D., *Senior Research Fellow in Biology*

B.A., Smith College, 1947; M.A., Radcliffe College, 1950; Ph.D., 1952. California Institute, 1969-. (Kerckhoff)

Robert Warner Oliver,* Ph.D., *Associate Professor of Economics*

A.B., University of Southern California, 1943; A.M., 1948; A.M., Princeton University, 1950; Ph.D., 1957. Assistant Professor, California Institute, 1959-61; Associate Professor, 1961-.

Allan R. Oseroff, Ph.D., *Research Fellow in Biology*

A.B., Princeton University, 1964; A.M. Harvard University, 1965; Ph.D., 1969. California Institute, 1971.

Jeremiah Paul Ostriker, Ph.D., *Visiting Associate in Astrophysics*

A.B., Harvard College, 1959; Ph.D., University of Chicago, 1964. Associate Professor, Princeton University, 1968-. California Institute, 1970.

Harald Ostvold, M.A., *Director of Libraries*

B.A., Hamline University, 1936; B.S., University of Minnesota, 1939; M.A., 1940. California Institute, 1963-. (Millikan Library)

David Keith Ottesen, Ph.D., *Research Fellow in Geochemistry*

B.S., New Mexico State University, 1966; Ph.D., California Institute, 1970. Research Fellow, 1970-71. (Noyes)

Ray David Owen, Ph.D., Sc.D., *Professor of Biology*

B.S., Carroll College, 1937; Ph.M., University of Wisconsin, 1938; Ph.D., 1941; Sc.D., Carroll College, 1962. Gosney Fellow, California Institute, 1946-47; Associate Professor, 1947-53; Professor, 1953-; Division Chairman, 1961-68. (Kerckhoff)

Yash Pal, Ph.D., *Visiting Associate in Physics*

B.S., M.S., Panjab University, 1949; Ph.D. Massachusetts Institute of Technology, 1958. Professor, Tata Institute of Fundamental Research (Bombay), 1967-. California Institute, 1970-71.

Dimitri A. Papanastassiou, Ph.D., *Research Fellow in Physics*

B.S., California Institute, 1965; Ph.D., 1970. Research Fellow, 1970. (Arms)

Charles Herach Papas, Ph.D., *Professor of Electrical Engineering*

B.S., Massachusetts Institute of Technology, 1941; M.S., Harvard University, 1946; Ph.D., 1948. Lecturer, California Institute, 1952-54; Associate Professor, 1954-59; Professor, 1959-. (Steele)

David S. Papermaster, M.D., *Research Fellow in Biology*

A.B. Harvard College, 1959; M.D., Harvard Medical School, 1963. California Institute, 1969-. (Church)

Jay Myron Pasachoff, Ph.D., *Research Fellow in Astrophysics*

A.B., Harvard College, 1963; A.M., Harvard University, 1965; Ph.D., 1969. California Institute, 1970-71.

Claire Cameron Patterson, Ph.D., *Senior Research Fellow in Geochemistry*

A.B., Grinnell College, 1943; M.S., University of Iowa, 1944; Ph.D., University of Chicago, 1951. Research Fellow, California Institute, 1952-53; Senior Research Fellow, 1953-. (Mudd)

Rodman Wilson Paul, Ph.D., *Professor of History*

A.B., Harvard College, 1936; M.A., 1937; Ph.D., 1943. Associate Professor, California Institute, 1947-51; Professor, 1951-. (Dabney)

Linus Pauling, Ph.D., Sc.D., L.H.D., U.J.D., D.H.C., D.F.A., LL.D., Nobel Laureate, *Research Associate in Chemistry*

B.S., Oregon State College, 1922; Ph.D., California Institute, 1925. Research Associate, 1926-27; Assistant Professor, 1927-29; Associate Professor, 1929-31; Professor, 1931-64; Chairman of the Division of Chemistry and Chemical Engineering, 1936-58; Research Associate, 1964-.

*Leave of absence, 1970-71

John Stuart Pearse, Ph.D., *Research Fellow in Environmental Health Engineering*

B.Sc., University of Chicago, 1958; Ph.D., Stanford University, 1965. Research Fellow in Biology, California Institute, 1967; Research Fellow in Environmental Health Engineering, 1968-. (Kerckhoff Marine Lab)

Charles William Peck, Ph.D., *Associate Professor of Physics*

B.S., New Mexico College of Agricultural and Mechanical Arts, 1956; Ph.D., California Institute, 1964. Research Fellow, 1964-65; Assistant Professor, 1965-69; Associate Professor, 1969-. (Synchrotron)

Edwin A. Pecker,** M.S., *Lecturer in Chemical Engineering*

B.S., University of California, 1949; M.S., University of California (Los Angeles), 1959. President, Bio/Systems, Incorporated, 1965-. Consultant, Veterans Administration, University of California (Los Angeles) Medical Center, 1965-. California Institute, 1968-.

Benjamin Franklin Peery, Jr., Ph.D., *Visiting Associate in Astrophysics*

B.S., University of Minnesota, 1949; M.S., Fisk University, 1955; Ph.D., University of Michigan, 1962. Associate Professor of Astronomy, Indiana University, 1968-. California Institute 1969-70.

Albert Eugene Pekary, Ph.D., *Research Fellow in Chemistry*

B.S., Stanford University, 1965; Ph.D., University of California, 1970. California Institute, 1970-71.

Thomas Lorne Penner, Ph.D., *Research Fellow in Chemistry*

B.Sc., University of Manitoba, 1965; M.Sc. 1966; Ph.D., California Institute, 1970. Research Fellow, 1969-70.

Michael Vistor Penston, Ph.D., *Research Fellow in Astronomy*

B.A., University of Cambridge, 1964; Ph.D., University of Sussex, 1969. California Institute, 1969-. (Hale Office)

Börje Ingvar Persson, Fil.dr., *Assistant Professor of Physics*

Fil.kand., University of Lund, 1954; Fil.mag., 1955; Fil.lic., 1959; Fil.dr., 1965. Research Fellow, California Institute, 1965-68; Assistant Professor, 1968-. (W. Bridge)

Anthony George Phillips, Ph.D., *Research Fellow in Biology*

B.A., University of Western Ontario, 1966; M.A., 1967; Ph.D., 1969. California Institute, 1969-70.

William Hayward Pickering, Ph.D., *Professor of Electrical Engineering; Director of Jet Propulsion Laboratory*

B.S., California Institute, 1932; M.S., 1933; Ph.D., 1936. Instructor, 1936-40; Assistant Professor, 1940-45; Associate Professor, 1945-47; Professor, 1947-; Director, Jet Propulsion Laboratory, 1954-. (Jet Propulsion Lab.)

John Sturtevant Pierce, Ph.D., *Research Fellow in Biology*

A.B., Clark University, 1959; M.S., University of Massachusetts, 1962; Ph.D., Yale University, 1970. California Institute, 1970-71.

Lajos Piko,** D.V.M., *Senior Research Fellow in Biology*

Dipl., University of Agricultural Science, Budapest-Godollo, 1956; D.V.M., Veterinary School of Alfort, France, 1957. Chief, Developmental Biology Laboratory Veterans Administration Hospital (Los Angeles), 1966-. Research Fellow, California Institute, 1959-65; Senior Research Fellow, 1965-.

Jerome Pine, Ph.D., *Professor of Physics*

B.A., Princeton University, 1949; Ph.D., Cornell University, 1956. Associate Professor, California Institute, 1963-67; Professor, 1967-. (Lauritsen)

Cornelius John Pings, Ph.D., *Professor of Chemical Engineering and Chemical Physics; Executive Officer for Chemical Engineering*

B.S., California Institute, 1951; M.S. 1952; Ph.D., 1955. Associate Professor of Chemical Engineering, 1959-64; Professor, 1964-70; Professor of Chemical Engineering and Chemical Physics, 1970-. (Spalding)

Itshak Plesser, Ph.D., *Research Fellow in Physics*

B.Sc., The Hebrew University of Jerusalem, 1963; M.Sc., Weizmann Institute of Science, 1965; Ph.D., 1969. California Institute, 1969-70.

Milton S. Plesset,*** Ph.D., *Professor of Engineering Science*

B.S., University of Pittsburgh, 1929; Ph.D., Yale University, 1932. Associate Professor of Applied Mechanics, California Institute, 1948-51; Professor, 1951-63; Professor of Engineering Science, 1963-. (Thomas)

**Part-time
***Leave of absence, first term, 1970-71

Ramendra Kumar Poddar, Ph.D., *Research Fellow in Biology*
B.S., University of Calcutta, 1950; M.S., 1952; Ph.D., 1958. Associate Professor of Biophysics, Saha Institute, 1967-. California Institute, 1970.

Frank Anthony Podosek, Ph.D., *Research Fellow in Physics*
A.B., Harvard College 1964; Ph.D., University of California, 1969. California Institute, 1969-. (Arms)

Peter Polgar, Ph.D., *Research Fellow in Biology*
A.B., University of California (Los Angeles), 1961; M.S., Tufts University, 1965; Ph.D., Boston University School of Medicine, 1967. California Institute, 1970-71.

Edward Charles Posner,** Ph.D., *Lecturer in Electrical Engineering*
B.A., University of Chicago 1952; M.S., 1953; Ph.D., 1957. Staff Member, Telecommunications Division, Jet Propulsion Laboratory, 1968-. California Institute, 1970.

James W. Prahl, M.D., Ph.D., *Senior Research Fellow in Biology*
B.A., Princeton University, 1953; M.D., University of Pennsylvania School of Medicine, 1957; Ph.D., University of Washington, 1964. Fellow of the Arthritis Foundation, La Jolla, 1967-. California Institute, 1970-71.

Stephen William Prata, Ph.D., *Research Fellow in Astrophysics*
B.S., California Institute, 1963; Ph.D., University of California, 1968. California Institute, 1969-. (Robinson)

Bruno B. F. Preilowski, Ph.D., *Research Fellow in Biology*
M.Sc., Tulane University, 1968; Ph.D. 1970. California Institute, 1970-71.

Edward T. Preisler, B.A., *Coach*
B.A., San Diego State College, 1941; California Institute, 1947-. (Gymnasium)

George Worrall Preston III, Ph.D., *Staff Member, Hale Observatories*
B.S., Yale University, 1952; Ph.D., University of California, 1959. Research Fellow in Astronomy, California Institute, 1959-60; Staff Member, 1968-. (Hale Office)

Richard Henry Price, Ph.D., *Research Fellow in Physics*
B.Eng., Cornell University, 1965; Ph.D. California Institute, 1970. Research Fellow, 1970-71.

William J. Quirk, Ph.D., *Research Fellow in Astrophysics*
B.S., Columbia University, 1967; Ph.D., 1970. California Institute, 1970-71.

Michael Augustine Raftery, Ph.D., *Associate Professor of Chemical Biology*
B.Sc., National University of Ireland, 1956; Ph.D., 1960. Noyes Research Instructor in Chemistry, California Institute, 1964-66; Assistant Professor of Chemical Biology, 1967-69; Associate Professor, 1969-. (Church)

Fredric Raichlen, Sc.D., *Associate Professor of Civil Engineering*
B.E., Johns Hopkins University, 1953; S.M., Massachusetts Institute of Technology, 1955; Sc.D., 1962. Assistant Professor, California Institute, 1962-67; Associate Professor, 1967-. (Keck)

Simon Ramo, Ph.D., *Research Associate in Electrical Engineering*
B.S., University of Utah, 1933; Ph.D., California Institute, 1936. California Institute, 1946-. (Booth)

W. Duncan Rannie,*** Ph.D., *Robert H. Goddard Professor of Jet Propulsion*
B.A., University of Toronto, 1936; M.A., 1937; Ph.D., California Institute, 1951. Assistant Professor of Mechanical Engineering, 1947-51; Associate Professor, 1951-55; Professor, 1955-. (Guggenheim)

Charles vanBlekkingh Ray,** M.S., *Lecturer in Applied Science*
B.E.E., Cornell University, 1952; M.S., California Institute, 1956. Senior Engineer, Computing Center, 1964-; Lecturer, 1965-. (Booth)

Donald George Rea, Ph.D., *Research Associate in Planetary Science*
B.Sc., University of Manitoba, 1950; M.Sc. 1951; Ph.D., Massachusetts Institute of Technology, 1954. Staff Member, Jet Propulsion Laboratory, 1970-. California Institute, 1970-. (Arms)

Richard Bradley Read, Ph.D., *Senior Research Fellow in Radio Astronomy; Staff Member, Owens Valley Radio Observatory*
B.S., California Institute, 1955; Ph.D., 1962. Research Fellow, 1962-66; Senior Research Fellow; Staff Member, 1966-. (Robinson)

**Part-time
***Leave of absence, first term, 1970-71

H. Hollis Reamer, M.S., *Senior Research Fellow in Chemical Engineering*

A.B., University of Redlands, 1937; M.S., California Institute, 1938; Research Assistant, 1938-52; Research Fellow, 1952-58; Senior Research Fellow, 1958-. (Spalding)

Lawlor Maxwell Reck, M.A., *Coach*

A.B., Cornell University, 1960; M.A., California State College (San Jose), 1967. California Institute, 1967-. (Gymnasium)

Alan Rembaum,** Ph.D., *Lecturer in Chemical Engineering*

Lic., University of Lyon, 1941; Ph.D., Syracuse University, 1955. Technical Staff Member, Jet Propulsion Laboratory, 1961-. California Institute, 1967-. (Spalding)

Justin J. Rennilson, A.B., *Senior Research Fellow in Planetary Science*

A.B., University of California, 1950. California Institute, 1969-. (Arms)

Bernard Marie Révet, Ph.D., *Research Fellow in Biology*

Ph.D., University of Paris, 1967. California Institute, 1969-70.

John Hall Richards, Ph.D., *Professor of Organic Chemistry*

B.A. University of California, 1951; B.Sc., Oxford University, 1953; Ph.D., University of California, 1955. Assistant Professor, California Institute, 1957-61; Associate Professor, 1961-70; Professor, 1970-. (Crellin)

Charles Francis Richter, Ph.D., *Professor of Seismology, Emeritus*

A.B., Stanford University, 1920; Ph.D., California Institute, 1928. Assistant Professor, 1937-47; Associate Professor, 1947-52; Professor, 1952-70; Professor Emeritus, 1970-. (Seismo Lab.)

Guenter Rudolf Riegler, Ph.D., *Research Fellow in Physics*

B.S., Vienna Institute of Technology, 1964; Ph.D., University of Maryland, 1969. California Institute, 1969-. (Downs)

Heinrich Rinderknecht,** Ph.D., *Senior Research Fellow in Chemistry*

Dipl.Sc., Federal Institute of Technology, Zurich, 1936; Ph.D., University of London, 1939. Associate Professor, University of Southern California School of Medicine, 1964-. Research Fellow, California Institute, 1947-48; 1949-54; Senior Research Fellow, 1962-64; 1965; 1966; 1967-.

John D. Roberts, Ph.D., Dr.rer.nat., Sc.D., *Professor of Organic Chemistry*

B.A., University of California (Los Angeles), 1941; Ph.D., 1944; Dr.rer.nat., University of Munich, 1962; Sc.D., Temple University, 1964. Professor, California Institute, 1953-; Division Chairman, 1963-68. (Crellin)

George Wilse Robinson, Ph.D., *Professor of Physical Chemistry*

B.S., Georgia Institute of Technology, 1947; M.S., 1949; Ph.D., State University of Iowa, 1952. Associate Professor, California Institute, 1959-61; Professor, 1961-. (Noyes)

Robert S. Rodgers, Ph.D., *Research Fellow in Chemistry*

B.S., Polytechnic Institute of Brooklyn, 1966; M.S., 1968; Ph.D., Clarkson College, 1970. California Institute, 1970-71.

Lolita Sapriel Rosenstone,** B.A., *Lecturer in French*

B.A., University of California (Los Angeles), 1962. California Institute, 1963-64; 1966-. (Dabney)

Robert Allan Rosenstone, Ph.D., *Associate Professor of History*

B.A., University of California (Los Angeles), 1957; Ph.D., 1965. Visiting Assistant Professor, California Institute, 1966-68; Assistant Professor, 1968-69; Associate Professor, 1969-. (Dabney)

Anatol Roshko, Ph.D., *Professor of Aeronautics*

B.Sc., University of Alberta, 1945; M.S., California Institute, 1947; Ph.D., 1952. Research Fellow, 1952-54; Senior Research Fellow, 1954-55; Assistant Professor, 1955-58; Associate Professor, 1958-62; Professor, 1962-. (Karman)

Milton Emanuel Rubini,** M.D., *Visiting Professor of Chemical Engineering*

M.D., Tufts University School of Medicine, 1949. Professor of Medicine, University of California (Los Angeles), 1961-; Chief, Metabolism Service, Wadsworth Veterans Administration Hospital, 1961-. Visiting Associate Professor, California Institute 1967; 1968; Visiting Professor, 1969-.

Bruce Herbert Rule, B.S., *Staff Member, Chief Engineer, Hale Observatories; Staff Member, Owens Valley Radio Observatory*

B.S., California Institute, 1932. Director, Central Engineering Services, 1943-; Staff Member, Chief Engineer, 1965-. (Central Engineering Services)

**Part-time

Ralph R. Rumer, Jr., Sc.D., *Senior Research Fellow in Hydraulics*
B.S., Duke University, 1953; M.S., Rutgers University, 1959; Sc.D., Massachusetts Institute of Technology, 1962. Chairman, Department of Civil Engineering, State University of New York (Buffalo), 1966-. California Institute, 1970-71.

Mark Gilbert Rush, Ph.D., *Research Fellow in Biology*
B.S., Queens College, 1963; Ph.D., New York University, 1968. California Institute, 1969-70.

Richard Lawson Russell, Ph.D., *Assistant Professor of Biology*
A.B., Harvard College, 1962; Ph.D., California Institute, 1967. Assistant Professor, 1970-.

Herbert John Ryser, Ph.D., *Professor of Mathematics*
B.A., University of Wisconsin, 1945; Ph.D., 1948. California Institute, 1967-. (Sloan)

Rolf Heinrich Sabersky, Ph.D., *Professor of Mechanical Engineering*
B.S., California Institute, 1942; M.S., 1943; Ph.D., 1949. Assistant Professor, 1949-55; Associate Professor, 1955-61; Professor, 1961-. (Thomas)

Philip Geoffrey Saffman,* Ph.D., *Professor of Applied Mathematics*
B.A., Trinity College, University of Cambridge, 1953; M.A., Ph.D., 1956. Professor of Fluid Mechanics, California Institute, 1964-70; Professor of Applied Mathematics, 1970-.

Bruce Hornbrook Sage, Ph.D., Eng.D., *Research Associate in Chemical Engineering*
B.S., New Mexico State College, 1929; M.S., California Institute, 1931; Ph.D., 1934; Eng.D., New Mexico State College, 1953. Research Fellow, California Institute, 1934-35; Senior Fellow in Chemical Research, 1935-37; Assistant Professor of Chemical Engineering, 1937-39; Associate Professor, 1939-44; Professor, 1944-69; Research Associate, 1969-.

Miklos Sajben, Sc.D., *Assistant Professor of Aeronautics*
Dipl.Ing., Technical University of Budapest, 1953; M.S., University of Pennsylvania, 1961; Sc.D., Massachusetts Institute of Technology, 1964. California Institute, 1964-. (Firestone)

Gary Sampson, Ph.D., *Ford Foundation Research Instructor in Mathematics*
M.A., Temple University, 1965; Ph.D., Syracuse University, 1970. California Institute, 1970-71.

Sten Otto Samson, Fil.Dr., *Senior Research Fellow in Chemistry*
Fil.kand., University of Stockholm, 1953; Fil.lic., 1956; Fil.Dr., 1968. Research Fellow, California Institute, 1953-56; 1957-61; Senior Research Fellow, 1961-. (Noyes)

Allan Rex Sandage, Ph.D., Sc.D., D.Sc., *Staff Member, Hale Observatories*
A.B., University of Illinois, 1948; Ph.D., California Institute, 1953; Sc.D., Yale University, 1966; D.Sc., University of Chicago, 1967. Hale Observatories, 1948-. (Hale Office)

Gernot Sander, Ph.D., *Research Fellow in Biology*
Ph.D., University of Gottingen, 1968. California Institute, 1969-. (Kerckhoff)

Robert L. Sani, Ph.D., *Visiting Associate in Chemical Engineering*
B.S., University of California, 1958; M.S., 1960; Ph.D., 1963. California Institute, 1970-71.

Wallace Leslie William Sargent, Ph.D., *Associate Professor of Astronomy; Staff Member, Hale Observatories*
B.Sc., Manchester University, 1956; M.Sc., 1957; Ph.D., 1959. Research Fellow, California Institute, 1959-62; Assistant Professor, 1966-68; Staff Member, 1966-; Associate Professor, 1968-. (Robinson)

William Palzer Schaefer, Ph.D., *Senior Research Fellow in Chemistry; Assistant Director of Admissions*
B.S., Stanford University, 1952; M.S., University of California (Los Angeles), 1954; Ph.D., 1960. Instructor, California Institute, 1960-62; Assistant Professor, 1962-66; Senior Research Fellow, 1968-; Assistant Director, 1968-. (Crellin, Throop)

Albert William Schlueter, Ph.D., *Research Fellow in Chemistry*
B.A., Carleton College, 1962; Ph.D., Iowa State University, 1966. California Institute, 1969-70.

Bernd Johannes Friedrich Schmidt, Dr.rer.nat., *Visiting Assistant Professor of Mathematics*
Dr.Ing., Technical University of Karlsruhe, 1962; Dipl.Math., University of Mainz, 1966; Dr. rer.nat., 1969. Assistant, 1969-. Research Fellow in Aeronautics. California Institute, 1965-67; Visiting Assistant Professor of Mathematics, 1970-71.

*Leave of absence, 1970-71

Maarten Schmidt, Ph.D., Sc.D., *Professor of Astronomy; Staff Member, Hale Observatories*

Ph.D., University of Leiden, 1956; Sc.D., Yale University, 1966. Carnegie Fellow, Hale Observatories, 1956-58; Associate Professor, California Institute, 1959-64; Professor, 1964-. (Robinson)

Maurice Schmir, Ph.D., *Research Fellow in Chemistry*

A.B., Columbia College, 1964; M.A., 1965; Ph.D., 1969. California Institute, 1970-71. (Church)

Herman Fedde Rein Schöyer, Ir., *Research Fellow in Jet Propulsion*

Ir., Delft University of Technology, 1966. California Institute, 1969-70.

Walter Adolph Schroeder, Ph.D., *Research Associate in Chemistry*

B.Sc., University of Nebraska, 1939; M.A., 1940; Ph.D., California Institute, 1943. Research Fellow, 1943-46; Senior Research Fellow, 1946-56; Research Associate, 1956-. (Church)

George O. Schumann,** Ph.D., *Visiting Associate in Environmental Health Engineering*

B.A., University of Alaska, 1950; M.S., Syracuse University, 1952; Ph.D., Kiel University, 1959. President, Marine Associates, 1968-. California Institute, 1970-. (Kerckhoff Marine Lab.)

Frank Joseph Sciulli, Ph.D., *Assistant Professor of Physics*

A.B., University of Pennsylvania, 1960; M.S., 1961; Ph.D., 1965. Research Fellow, California Institute, 1966-68; Assistant Professor, 1969-. (Lauritsen)

Ronald Fraser Scott, Sc.D., *Professor of Civil Engineering*

B.Sc., Glasgow University, 1951; S.M., Massachusetts Institute of Technology, 1953; Sc.D., 1955. Assistant Professor, California Institute, 1958-62; Associate Professor, 1962-67; Professor, 1967-. (Thomas)

Thayer Scudder, Ph.D., *Professor of Anthropology*

A.B., Harvard College, 1952; Ph.D., Harvard University, 1960. Assistant Professor, California Institute, 1964-66; Associate Professor, 1966-69; Professor, 1969-. (Spalding)

Dennis Grant Searcy, Ph.D., *Research Fellow in Biology*

B.S., Oregon State University, 1964; Ph.D., University of California (Los Angeles), 1968. California Institute, 1969-. (Kerckhoff)

Leonard Searle, Ph.D., *Staff Member, Hale Observatories*

Ph.D., Princeton University, 1956. Senior Research Fellow in Astronomy, California Institute, 1960-63; Staff Member, 1968-. (Hale Office)

Ernest Edwin Sechler, Ph.D., *Professor of Aeronautics; Executive Officer for the Graduate Aeronautical Laboratories*

B.S., California Institute, 1928; M.S., 1929; Ph.D., 1934. Instructor, 1930-37; Assistant Professor, 1937-40; Associate Professor, 1940-46; Professor, 1946-; Executive Officer, 1966-. (Firestone)

Harvey Segur, Ph.D., *Research Fellow in Applied Mathematics*

B.S., Michigan State University, 1964; M.S., University of California, 1967; Ph.D., 1969. California, Institute, 1969-70.

George Andrew Seielstad, Ph.D., *Senior Research Fellow in Radio Astronomy; Staff Member, Owens Valley Radio Observatory*

A.B., Dartmouth College, 1959; Ph.D., California Institute, 1963. Research Fellow, 1964-67; Staff Member, 1966-; Senior Research Fellow, 1967-. (Robinson)

John Hersh Seinfeld, Ph.D., *Associate Professor of Chemical Engineering*

B.S., University of Rochester, 1964; Ph.D., Princeton University, 1967. Assistant Professor, California Institute, 1967-70; Associate Professor, 1970-. (Spalding)

Edwin Charles Seltzer, Ph.D., *Senior Research Fellow in Physics*

B.S., California Institute, 1959; Ph.D., 1966. Research Fellow, 1965-68; Senior Research Fellow, 1969-. (W.Bridge)

Robert G. Sener, Ph.D., *Research Fellow in Biology*

B.A., Yale University, 1966; Ph.D., University of St. Andrews (Scotland), 1970. California Institute, 1970-71.

Sengadu Rangaswamy Seshadri, Ph.D., *Visiting Associate in Electrical Engineering*

B.S., Madras University, 1950; M.A., 1951; Ph.D., Harvard University, 1959. Professor, University of Wisconsin. California Institute, 1970-71.

**Part-time.

Fredrick Harold Shair, Ph.D., *Associate Professor of Chemical Engineering*
B.S., University of Illinois, 1957; Ph.D., University of California, 1963. Assistant Professor, California Institute, 1965-69; Associate Professor, 1969-. (Spalding)

Phillip Allen Sharp, Ph.D., *Research Fellow in Chemistry*
B.A., Union College (Kentucky), 1966; Ph.D., University of Illinois, 1969. California Institute, 1969-. (Church)

Robert Phillip Sharp, Ph.D., *Professor of Geology*
B.S., California Institute, 1934; M.S., 1935; A.M., Harvard University, 1936; Ph.D., 1938. Professor, California Institute, 1947-; Division Chairman, 1952-68. (Mudd)

Tai-Ichi Shibuya, Ph.D., *Research Fellow in Chemistry*
B.S., Tokyo University of Education, 1962; M.S., University of the Pacific, 1965; Ph.D., Yale University, 1968. California Institute, 1969-. (Noyes)

Eugene Merle Shoemaker, Ph.D., *Professor of Geology; Chairman of the Division of Geological Sciences*
B.S., California Institute, 1947; M.S., 1948; M.A., Princeton University, 1954; Ph.D., 1960. Visiting Professor of Geology, California Institute, 1962; Research Associate in Astrogeology, 1964-68; Professor, Division Chairman, 1969-. (Arms)

Helmut E. Siekmann, Dr.Ing., *Research Fellow in Mechanical Engineering*
Dipl.Ing., Technical University of Karlsruhe, 1960; Dr.Ing., 1968. California Institute, 1969.

Leon Theodore Silver, Ph.D., *Professor of Geology*
B.S., University of Colorado, 1945; M.S., University of New Mexico, 1948; Ph.D., California Institute, 1955. Assistant Professor, 1955-62; Associate Professor, 1962-65; Professor, 1965-. (Mudd)

Robert Louis Sinsheimer, Ph.D., *Professor of Biophysics; Chairman of the Division of Biology*
S.B., Massachusetts Institute of Technology, 1941; S.M., 1942; Ph.D., 1948. Senior Research Fellow, California Institute, 1953; Professor, 1957-; Division Chairman, 1968-. (Church)

Yuriy Mihailovich Sivolap, Ph.D., *Research Fellow in Biology*
Ph.D., All-Union Institute of Genetics and Plant Breeding (USSR), 1966. Staff Member, Timirjazev Academy of Agriculture, 1969-. California Institute, 1969-70.

Robert Louis Slighton,** Ph.D., *Lecturer in Economics*
A.B., Princeton University, 1953; Ph.D., Johns Hopkins University, 1959. Staff Economist, The RAND Corporation, 1962-. California Institute, 1969-70.

Stephen Hugh Smallcombe, Ph.D., *Research Fellow in Chemistry*
B.S., Alma College, 1965; Ph.D., University of California (Irvine), 1970. California Institute, 1970-71. (Church)

John Edward Smart, Ph.D., *Research Fellow in Biology*
B.S., The Ohio State University, 1965; Ph.D., California Institute, 1970. Research Fellow, 1969-70.

Stephen Chester Smelser, Ph.D., *Research Fellow in Chemical Engineering*
B.S., University of Michigan, 1964; Ph.D., California Institute, 1969. Research Fellow, 1969.

Alan Gilbert Smith, Ph.D., *Research Fellow in Geology and Geophysics*
B.A., University of Cambridge, 1958; Ph.D., Princeton University, 1963. Lecturer, University of Cambridge, 1969-. California Institute, 1970.

Annette Jacqueline Smith, M.A., *Visiting Assistant Professor of French*
M.A., University of Paris (Sorbonne), 1947. Assistant Professor of French, Claremont Men's College, 1964-. California Institute, 1970-71.

Bradford Adelbert Smith, B.Sc., *Visiting Associate in Planetary Science*
B.Sc., Northeastern University, 1954. Director, New Mexico State University Planetary Observatory, 1964-. California Institute, 1969-.

David Rodman Smith, Ph.D., *Associate Professor of English; Master of Student Houses*
B.A., Pomona College, 1944; M.A., Claremont Colleges, 1950; Ph.D., 1960. Instructor, California Institute, 1958-60; Assistant Professor, 1960-66; Associate Professor, 1966-; Master of Student Houses, 1969-. (Dabney, Lloyd House)

**Part-time

Hallett D. Smith, Ph.D., L.H.D., *Professor of English; Chairman of the Division of Humanities and Social Sciences*

B.A., University of Colorado, 1928; Ph.D., Yale University, 1934; L.H.D., University of Colorado, 1968. California Institute, 1949-. (Dabney)

Robert Alan Smith, Ph.D., *Research Fellow in Chemistry*

B.S., University of California (Los Angeles), 1962; Ph.D., State University of New York (Buffalo), 1968. California Institute, 1969-70.

Stewart Wilson Smith, Ph.D., *Associate Professor of Geophysics*

S.B., Massachusetts Institute of Technology, 1954; M.S., California Institute, 1958; Ph.D., 1961. Assistant Professor, 1961-64; Associate Professor, 1964-. (Seismo Lab.)

William Ralph Smythe, Ph.D., *Professor of Physics, Emeritus*

A.B., Colorado College, 1916; A.M., Dartmouth College, 1919; Ph.D., University of Chicago, 1921. National Research Fellow, California Institute, 1923-26; Research Fellow, 1926-27; Assistant Professor, 1927-34; Associate Professor, 1934-40; Professor, 1940-64; Professor Emeritus, 1964-. (E. Bridge)

Laurence Albert Soderblom, Ph.D., *Research Fellow in Planetary Science*

B.S., New Mexico Institute of Mining and Technology, 1966; Ph.D., California Institute, 1970. Research Fellow, 1970-71. (Arms)

Roger Wolcott Sperry, Ph.D., *Hixon Professor of Psychobiology*

A.B., Oberlin College, 1935; A.M., 1937; Ph.D., University of Chicago, 1941. California Institute, 1954-. (Alles)

Peter Whitney Sprague, Ph.D., *Research Fellow in Chemistry*

B.A., Adelburt College, Case Western Reserve University, 1963; Ph.D., 1966. Assistant Professor of Chemistry, California State College (San Bernardino), 1967-. California Institute, 1970.

Larry M. Stacey, Ph.D., *Research Fellow in Chemical Engineering*

B.S., University of North Carolina (Chapel Hill), 1962; Ph.D., 1968. California Institute, 1970-71.

John David Stack, Ph.D., *Visiting Associate in Theoretical Physics*

B.Sc., California Institute, 1959; Ph.D., University of California, 1965. Associate Professor, University of Illinois, 1969-. California Institute, 1969-70.

Richard Henry Stanford, Jr., Ph.D., *Senior Research Fellow in Chemistry*

B.A., Rice University, 1954; Ph.D., 1958. Research Fellow, California Institute, 1958-66; Senior Research Fellow, 1966-. (Church)

Gordon James Stanley, Dipl., *Research Associate in Radio Astronomy; Director, Owens Valley Radio Observatory*

Dipl., New South Wales University of Technology, 1946. Research Engineer, California Institute, 1955-58; Senior Research Fellow, 1958-62; Research Associate, 1962-; Director, Owens Valley Radio Observatory, 1965-. (Robinson)

Roger Fellows Stanton, Ph.D., *Professor of English, Emeritus*

B.S., Colgate University, 1920; M.A., Princeton University, 1924; Ph.D., 1931. Instructor, California Institute, 1925-31; Assistant Professor, 1931-47; Associate Professor, 1947-55; Professor, 1955-65; Director of Institute Libraries, 1949-63; Professor Emeritus, 1966-.

Gary Steigman, Ph.D., *Research Fellow in Physics*

B.S., City College of New York, 1961; M.S., New York University, 1963; Ph.D., 1968. California Institute, 1970-71.

Reiner Ludwig Stenzel, Ph.D., *Research Fellow in Applied Science*

Dipl.Ing., Technical University of Braunschweig, 1965; M.S., California Institute, 1966; Ph.D., 1969. Research Fellow, 1969-70.

Alfred Stern, Ph.D., *Professor of Philosophy, Emeritus*

Ph.D., University of Vienna, 1923. Instructor, California Institute, 1947-48; Lecturer, 1948-50; Assistant Professor, 1950-53; Associate Professor, 1953-60; Professor, 1960-68; Professor Emeritus, 1968-.

Eli Sternberg,*** Ph.D., D.Sc., *Professor of Mechanics*

B.C.E., University of North Carolina, 1941; M.S., Illinois Institute of Technology, 1942; Ph.D., 1945; D.Sc., University of North Carolina, 1963. Professor of Applied Mechanics, California Institute, 1964-70; Professor of Mechanics, 1970-. (Thomas)

***Leave of absence, first term, 1970-71

James Ronald Stevenson, Ph.D., *Research Fellow in Chemistry*
B.Sc., University of Glasgow, 1966; Ph.D., 1969. California Institute, 1969-70.

Glenn Alexander Stewart, Ph.D., *Research Fellow in Physics*
B.A., Amherst College, 1962; M.S., University of Washington, 1963; M.S.E., 1965; Ph.D., 1969. California Institute, 1970-71.

Homer Joseph Stewart, Ph.D., *Professor of Aeronautics*
B.Aero.E., University of Minnesota, 1936; Ph.D., California Institute, 1940. Instructor, 1939-42; Assistant Professor, 1942-46; Associate Professor, 1946-49; Professor, 1949-. (Firestone)

Le Baron O. Stockford,** B.A., *Lecturer in Industrial Relations*
B.A., University of Southern California, 1938. Assistant Director, Management Development, California Institute, 1965-; Lecturer, 1966-. (Ind. Rel. Center)

Edward Carroll Stone, Jr., Ph.D., *Assistant Professor of Physics*
M.S., University of Chicago, 1957; Ph.D., 1963. Research Fellow, California Institute, 1964-66; Senior Research Fellow, 1967; Assistant Professor, 1967-. (Downs)

Leo Stoolman,** Ph.D, *Visiting Professor of Aeronautics*
B.S., Illinois Institute of Technology, 1941; M.S., California Institute, 1942; Ph.D., 1953. Staff Member, Hughes Aircraft Company, 1949-. California Institute, 1970-71.

Ellen Glowacki Strauss, Ph.D., *Research Fellow in Biology*
B.A., Swarthmore College, 1960; Ph.D., California Institute, 1966. Research Fellow, 1969-. (Church)

James Henry Strauss, Jr., Ph.D., *Assistant Professor of Biology*
B.S., Saint Mary's University, 1960; Ph.D., California Institute, 1967. Assistant Professor, 1969-. (Church)

Thomas Foster Strong, M.S., *Dean of Freshmen, Emeritus*
B.S., University of Wisconsin, 1922; M.S., California Institute, 1937. Assistant Professor of Physics, 1944-65; Associate Professor, 1965-69; Dean of Freshmen, 1946-68; Dean Emeritus, 1969-. (Bridge)

Robert M. Stroud, Ph.D., *Research Fellow in Chemistry*
B.A., University of Cambridge, 1964; M.S., Birkbeck College (London), 1965; Ph.D., 1968. California Institute, 1968-. (Church)

Felix Strumwasser, Ph.D., *Professor of Biology*
B.A., University of California (Los Angeles), 1953; Ph.D., 1957. Associate Professor, California Institute, 1964-69; Professor, 1969-. (Kerckhoff)

James Holmes Sturdivant, Ph.D., *Professor of Chemistry*
B.A., University of Texas, 1926; M.A., 1927; Ph.D., California Institute, 1930. Research Fellow, 1930-35; Senior Research Fellow, 1935-38; Assistant Professor, 1938-45; Associate Professor, 1945-47; Professor, 1947-. (Noyes)

Bradford Sturtevant, Ph.D., *Associate Professor of Aeronautics*
B.E., Yale University, 1955; M.S., California Institute, 1956; Ph.D., 1960. Research Fellow, 1960-62; Assistant Professor, 1962-66; Associate Professor, 1966-. (Karman)

Alan R. Sweezy, Ph.D., *Professor of Economics*
B.A., Harvard University, 1929; Ph.D., 1934. Visiting Professor, California Institute, 1949-50; Professor, 1950-. (Dabney)

Ernest Haywood Swift, Ph.D., LL.D., *Professor of Analytical Chemistry, Emeritus*
B.S., University of Virginia, 1918; M.S., California Institute, 1920; Ph.D., 1924; LL.D., Randolph-Macon College, 1960. Instructor, California Institute, 1920-28; Assistant Professor, 1928-39; Associate Professor, 1939-43; Professor, 1943-67; Division Chairman, 1958-63; Professor Emeritus, 1967-. (Gates)

Jean Pierre Swings, Ph.D., *Research Fellow in Astronomy*
B.S., University of Liege, 1965; Ph.D., 1969. California Institute, 1970-71.

Henry T. Tai, Ph.D., *Research Fellow in Biology*
A.B., Harvard College, 1965; Ph.D., University of Southern California, 1969. California Institute, 1970. (Church)

Taro Takahashi, Ph.D., *Visiting Associate Professor of Geophysics*
B.Eng., University of Tokyo, 1953; Ph.D., Columbia University, 1957. Professor, University of Rochester, 1969-. California Institute, 1970. (Seismo Lab.)

**Part-time

Tsunehiro Takano, Ph.D., *Research Fellow in Chemistry*
B.S., Osaka University, 1960; M.S., 1962; Ph.D., 1965. California Institute, 1969-. (Church)

Takahiko Tanahashi, Ph.D., *Research Fellow in Engineering Science*
B.S., Keio University, 1964; M.E., 1966; Ph.D., 1969. Assistant Professor of Engineering, 1969-. California Institute, 1970-71.

Hugh Pettingill Taylor, Jr., Ph.D., *Professor of Geology*
B.S., California Institute, 1954; A.M., Harvard University, 1955; Ph.D., California Institute, 1959. Assistant Professor, 1959-61; Research Fellow, 1961; Assistant Professor, 1962-64; Associate Professor, 1964-69; Professor, 1969-. (Mudd)

Fouad Tera, Ph.D., *Senior Research Fellow in Geochemistry*
B.S., University of Cairo, 1957; Ph.D., University of Vienna, 1962. Research Fellow, California Institute, 1966-67; Senior Research Fellow, 1967-. (Arms)

Harry George Thode, Ph.D., *Visiting Professor of Geochemistry*
B.S., University of Saskatchewan, 1930; M.S., 1932; Ph.D., University of Chicago, 1934. Professor of Physical Chemistry, McMaster University, 1944-; President, Vice-Chancellor, 1961-. California Institute, 1970.

Anthony Richard Thompson,** Ph.D., *Senior Research Fellow in Radio Astronomy*
B.Sc., University of Manchester, 1952; Ph.D., 1956. Staff Member, Radio Astronomy Institute, Stanford University, 1962-. California Institute, 1966-.

Frederick Burtis Thompson, Ph.D., *Professor of Applied Science and Philosophy*
A.B., University of California (Los Angeles), 1946; M.A., 1947; Ph.D., University of California, 1952. California Institute, 1965-. (Steele)

Captain Richard A. Thompson, M.S., *Lecturer in Aerospace Studies*
B.S., Oklahoma State University, 1963; M.S., 1966. California Institute, 1970-. (1107 San Pasqual)

Leon Thomsen, Ph.D., *Research Fellow in Geophysics*
B.S., California Institute, 1964; Ph.D., Columbia University, 1969. California Institute, 1970-71.

Kip Stephen Thorne, Ph.D., *Professor of Theoretical Physics*
B.S., California Institute, 1962; Ph.D., Princeton University, 1965. Research Fellow in Physics, California Institute, 1966-67; Associate Professor of Theoretical Physics, 1967-70; Professor, 1970-. (E.Bridge)

John Todd, B.Sc., *Professor of Mathematics*
B.Sc., Queen's University, Ireland, 1931. California Institute, 1957-. (Sloan)

Olga Taussky Todd, Ph.D., *Research Associate in Mathematics*
Ph.D., University of Vienna, 1930; M.A., University of Cambridge, 1937. California Institute, 1957-. (Sloan)

Alvin Virgil Tollestrup, Ph.D., *Professor of Physics*
B.S., University of Utah, 1944; Ph.D., California Institute, 1950. Research Fellow, 1950-53; Assistant Professor, 1953-58; Associate Professor, 1958-62; Professor, 1962-. (Lauritsen)

Thomas Anthony Tombrello, Jr., Ph.D., *Associate Professor of Physics*
B.A., Rice University, 1958; M.A., 1960; Ph.D., 1961. Research Fellow, California Institute, 1961-62; 1964-65; Assistant Professor, 1965-67; Associate Professor, 1967-. (Kellogg)

Alar Toomre, Ph.D., *Visiting Associate in Astrophysics*
S.B., Massachusetts Institute of Technology, 1957; Ph.D., University of Manchester (England), 1960. Associate Professor of Applied Mathematics, Massachusetts Institute of Technology, 1965-. California Institute, 1969-70.

Sandor Trajmar,** Ph.D., *Research Fellow in Chemistry*
Dipl., University of Science, Hungary, 1955; Ph.D., University of California, 1961. Senior Scientist, Jet Propulsion Laboratory, 1961-. California Institute, 1964-67; 1968-.

Natalia Pisker Trifunac, Ph.D., *Research Fellow in Chemistry*
B.S., University of Belgrade, 1965; Ph.D., California Institute, 1970. Research Fellow, 1969-70.

Janett Trubatch, Ph.D., *Research Fellow in Biology*
B.Sc., Polytechnic Institute of Brooklyn, 1962; M.A., Brandeis University, 1964; Ph.D., 1967. California Institute, 1968-. (Kerckhoff)

Nicole Truffaut, Ph.D., *Research Fellow in Biology*
Lic., Science Faculties of Paris, 1961; Ph.D., 1969. California Institute, 1970-71.

**Part-time

Nien-Chien Tsai, Ph.D., *Research Fellow in Civil Engineering*
B.S., National Taiwan University, 1961; M.S., California Institute, 1965; Ph.D., 1969. Research Fellow, 1969-70.

Fun Dow Tsay, Ph.D., *Research Fellow in Chemistry*
B.S., National Taiwan University, 1961; M.A., Washington University, 1965; Ph.D., 1968. California Institute, 1968-. (Noyes)

Nicholas William Tschoegl, Ph.D., *Professor of Chemical Engineering*
B.Sc., New South Wales University of Technology, 1954; Ph.D., University of New South Wales, 1958. Associate Professor of Materials Science, California Institute, 1965-67; Professor of Chemical Engineering, 1967-. (Spalding)

Chang-Chyi Tsuei, Ph.D., *Senior Research Fellow in Materials Science*
B.S., National Taiwan University, 1960; M.S., California Institute, 1963; Ph.D., 1966. Research Fellow, 1966-69; Senior Research Fellow, 1969-. (Keck)

Bruno Turi, Ph.D., *Research Fellow in Geochemistry*
Ph.D., University of Rome, 1960. Assistant Professor, Institute of Geochemistry, University of Rome, 1963-. California Institute, 1969-70.

Ray Edward Untereiner, Ph.D., *Professor of Economics, Emeritus*
A.B., University of Redlands, 1920; M.A., Harvard University, 1921; J. D., Mayo College of Law, 1925; Ph.D., Northwestern University, 1932. Professor, California Institute, 1925-68; Professor Emeritus, 1968- .

Johannes Cornelis Vanderleeden, Ph.D., *Senior Research Fellow in Physics*
B.S., The Ohio State University, 1957; M.S., 1959; Ph.D., 1966. Research Fellow, California Institute, 1966-69; Senior Research Fellow, 1969-. (W.Bridge)

Anthonie van Harreveld, Ph.D., M.D., *Professor of Physiology*
B.A., Amsterdam University, 1925; M.A. 1928; Ph.D., 1929; M.D., 1931. Research Assistant, California Institute, 1934-35; Instructor, 1935-40; Assistant Professor, 1940-42; Associate Professor, 1942-47; Professor, 1947-. (Kerckhoff)

Jacobus H. van Lint, Ph.D., *Morgan Ward Visiting Professor of Mathematics*
Ph.D., University of Utrecht, 1957. Professor of Mathematics, Technological University at Eindhoven, 1959-. California Institute, 1970-71.

Vito August Vanoni, Ph.D., *Professor of Hydraulics*
B.S., California Institute, 1926; M.S., 1932; Ph.D., 1940. Associate Professor, 1942-55; Professor, 1955-. (Keck)

James M. Varah, Ph.D., *Assistant Professor of Applied Mathematics*
B.S., University of British Columbia, 1963; M.Sc., Stanford University, 1965; Ph.D., 1967. California Institute, 1969-.

Larry Shelton Varnell, Ph.D., *Research Fellow in Physics*
B.S., University of the South, 1961; Ph.D., California Institute, 1969. Research Fellow, 1969.

Giulio Varsi,** Ph.D., *Research Fellow in Jet Propulsion*
Ph.D., Polytechnic Institute of Milan, 1964; M.S., University of California, 1966; Ph.D., 1969. California Institute, 1969-. (Karman)

Arthur Harris Vaughan, Jr., Ph.D., *Staff Member, Hale Observatories*
B.E., Cornell University, 1958; Ph.D., University of Rochester, 1964. Research Fellow, California Institute, 1964-66; Staff Associate, 1966-67; Staff Member, 1967-. (Hale Office)

Robert Walton Vaughan, Ph.D., *Assistant Professor of Chemical Engineering*
B.S., University of Oklahoma, 1963; M.S., University of Illinois, 1965; Ph.D., 1967. Lecturer, California Institute, 1968-69; Assistant Professor, 1969-. (Spalding)

Robert Emerick Villagrana, Ph.D., *Assistant Professor of Materials Science*
Met. Eng., Colorado School of Mines, 1963; M.S., University of California, 1965; Ph.D., 1967. California Institute, 1968-. (Keck)

Jerome Vinograd, Ph.D., *Professor of Chemistry and Biology*
M.A., University of California (Los Angeles), 1937; Ph.D., Stanford University, 1939. Senior Research Fellow in Chemistry, California Institute, 1951-56; Research Associate, 1956-64; Research Associate in Chemistry and Biology, 1964-65; Professor, 1965-. (Church)

**Part-time

Rochus E. Vogt, Ph.D., *Professor of Physics*
S.M., University of Chicago, 1957; Ph.D., 1961. Assistant Professor, California Institute, 1962-65; Associate Professor, 1965-70; Professor, 1970-. (Downs)

Peter Weber von Ostwalden, Ph.D., *Visiting Associate in Chemistry*
M.A., Columbia University, 1957; Ph.D., 1958. Associate Professor, Youngstown State University. California Institute, 1970-71.

Thad Vreeland, Jr., Ph.D., *Professor of Materials Science*
B.S., California Institute, 1949; M.S., 1950; Ph.D., 1952. Research Fellow in Engineering, 1952-54; Assistant Professor of Mechanical Engineering, 1954-58; Associate Professor, 1958-63; Associate Professor of Materials Science, 1963-67; Professor, 1968-. (Keck)

David Bertram Wales, Ph.D., *Assistant Professor of Mathematics*
B.S., University of British Columbia, 1961; M.A., 1962; Ph.D., Harvard University, 1967. Bateman Research Fellow, California Institute, 1967-68; Assistant Professor, 1968-. (Sloan)

Robert Lee Walker, Ph.D., *Professor of Physics*
B.S., University of Chicago, 1941; Ph.D., Cornell University, 1948. Assistant Professor, California Institute, 1949-53; Associate Professor, 1953-59; Professor, 1959-. (Lauritsen)

Robert Rodger Wark,** Ph.D., *Lecturer in Art*
B.A., University of Alberta, 1944; M.A., 1946; M.A., Harvard University, 1949; Ph.D., 1952. Curator of Art, Huntington Library and Art Gallery, 1956-. California Institute, 1961-. (Dabney)

Jürg Waser, Ph.D., *Professor of Chemistry*
B.S., University of Zurich, 1939; Ph.D., California Institute, 1944. Professor, 1958-. (Gates)

Gerald J. Wasserburg, Ph.D., *Professor of Geology and Geophysics*
S.B., University of Chicago, 1951; S.M., 1952; Ph.D., 1954. Assistant Professor of Geology, California Institute, 1955-59; Associate Professor, 1959-62; Professor, 1962-63; Professor of Geology and Geophysics, 1963-. (Arms)

Michael Derek Waterfield, Ph.D., *Senior Research Fellow in Biology*
Ph.D., University of London, 1967. California Institute, 1970-71.

Earnest Charles Watson, Sc.D., *Professor of Physics, Emeritus*
Ph.B., Lafayette College, 1914; Sc.D., 1958. Assistant Professor, California Institute, 1919-20; Associate Professor, 1920-30; Professor, 1930-62; Dean of the Faculty, 1945-60; Professor Emeritus, 1962-.

J. Harold Wayland, Ph.D., *Professor of Engineering Science*
B.S., University of Idaho, 1931; M.S., California Institute, 1935; Ph.D., 1937. Research Fellow in Applied Mechanics, 1939-41; Associate Professor, 1949-57; Professor, 1957-63; Professor of Engineering Science, 1963-. (Thomas)

Robert D. Wayne, M.A., *Associate Professor of German*
Ph.B., Dickinson College, 1935; M.A., Columbia University, 1940. Instructor, California Institute, 1952-62; Assistant Professor, 1962-69; Associate Professor, 1969-. (Dabney)

Spencer R. Weart, Ph.D., *Research Fellow in Astrophysics*
B.A., Cornell University, 1963; Ph.D., University of Colorado, 1968. California Institute, 1968-. (Robinson)

Richard Fouke Webb, M.D., *Director of Health Service*
A.B., Stanford University, 1932; M.D., University of Pennsylvania, 1936. California Institute, 1953-. (Health Center)

Kurt Walter Weiler, Ph.D., *Research Fellow in Radio Astronomy*
B.S., University of Arizona, 1964; Ph.D., California Institute, 1970. Research Fellow, 1969-70.

Richard G. Weiss, Ph.D., *Research Fellow in Chemistry*
B.Sc., Brown University, 1965; M.S., University of Connecticut, 1967; Ph.D., 1969. California Institute, 1969-. (Crellin)

Stanley Allen Weiss, Ph.D., *Harry Bateman Research Fellow in Mathematics*
S.B., Loyola College, 1965; A.M., University of Chicago, 1966; Ph.D., 1969. California Institute, 1969-70.

David F. Welch, I.D., *Associate Professor of Engineering Design*
A.B., Stanford University, 1941; I.D., California Institute, 1943. Instructor in Engineering Graphics, 1943-51; Assistant Professor, 1951-61; Associate Professor of Engineering Design, 1961-. (Thomas)

**Part-time

John Brewer Weldon, M.A., *Registrar*
A.B., Culver-Stockton College, 1924; M.A., University of Nebraska, 1934. California Institute, 1964-. (Throop)

Leonid Nicolas Weliachew, Ph.D., *Research Fellow in Radio Astronomy*
Lic.Sc., University of Paris, 1963; Ph.D., 1969. California Institute, 1969-. (Robinson)

Mogens Westergaard, Ph.D., *Gosney Research Fellow in Biology*
Mag.Scient., University of Copenhagen, 1936; Ph.D., 1940. Research Associate, Carlsberg Foundation, Copenhagen, 1962-. California Institute, 1963-64; 1969-70.

James Adolph Westphal, B.S., *Senior Research Fellow in Planetary Science; Staff Associate, Hale Observatories*
B.S., University of Tulsa, 1954. Senior Research Fellow, California Institute; Staff Associate, 1966-. (Arms)

Ward Whaling, Ph.D., *Professor of Physics*
B.A., Rice University, 1944; M.A., 1947; Ph.D., 1949. Research Fellow, California Institute, 1949-52; Assistant Professor, 1952-58; Associate Professor, 1958-62; Professor, 1962-. (Kellogg)

John Craig Wheeler, Ph.D., *Research Fellow in Physics*
S.B., Massachusetts Institute of Technology, 1965; Ph.D., University of Colorado, 1969. California Institute, 1969-. (Kellogg)

Donald Henry White, Ph.D., *Visiting Associate in Chemical Engineering*
B.Ch.E., The Ohio State University, 1940; M.S., Iowa State University, 1942; Ph.D., 1949. Professor of Chemical Engineering; Department Head, University of Arizona, 1958-. California Institute, 1969-70.

Richard E. White, Ph.D., *Research Fellow in Astronomy*
B.S., St. Joseph's College, 1965; Ph.D., Columbia University, 1970. California Institute, 1970-71. (Hale Office)

Gerald Beresford Whitham, Ph.D., *Professor of Applied Mathematics*
B.Sc., University of Manchester, 1948; M.Sc., 1949; Ph.D., 1953. Visiting Professor of Applied Mechanics, California Institute, 1961-62; Professor of Aeronautics and Mathematics, 1962-67; Professor of Applied Mathematics, 1967-. (Firestone)

Arthur Karl Whitney, Ph.D., *Research Fellow in Engineering Science*
B.Sc., Washington University (St. Louis), 1964; Ph.D., California Institute, 1969. Research Fellow, 1968-. (Karman)

Cornelis A. G. Wiersma, Ph.D., *Professor of Biology*
B.A., University of Leiden, 1926; M.A., University of Utrecht, 1929; Ph.D., 1933. Associate Professor, California Institute, 1933-47; Professor, 1947-. (Kerckhoff)

Hayden R. Williams,** M.S., *Research Fellow in Environmental Health Engineering*
B.S., Arkansas State University, 1950; M.S., Louisiana State University, 1958. Instructor, Chairman, Mathematics and Science Division, Golden West College, 1966-. California Institute, 1969-. (Kerckhoff Marine Lab.)

David L. Wilson, Ph.D., *Research Fellow in Biology*
B.S., University of Maryland, 1964; Ph D., University of Chicago, 1969. California Institute, 1969-. (Kerckhoff)

Olin Chaddock Wilson, Ph.D., *Staff Member, Hale Observatories*
A.B., University of California, 1929; Ph.D., California Institute, 1934. Mt. Wilson Observatory, 1931-. (Hale Office)

Charles Harold Wilts, Ph.D., *Professor of Electrical Engineering*
B.S., California Institute, 1940; M.S., 1941; Ph.D., 1948. Assistant Professor, 1947-52; Associate Professor, 1952-57; Professor, 1957-. (Steele)

Howard Winet, Ph.D., *Research Fellow in Engineering Science*
B.S., University of Illinois, 1959; M.A., University of California (Los Angeles), 1962; Ph.D., 1969. California Institute, 1969-. (Thomas)

Hubert Christian Winkler, Ph.D., *Visiting Associate in Physics*
Ph.D., University of Zurich, 1954. Associate Professor of Physics, California State College (Los Angeles), 1967-. Research Fellow, California Institute, 1962-64; Senior Research Fellow, 1965-67; Visiting Associate, 1969.

**Part-time

Mitchell A. Winnik, Ph.D., *Research Fellow in Chemistry*

B.A., Yale University, 1965; Ph.D., Columbia University, 1969. California Institute, 1969-70.

David Shotwell Wood, Ph.D., *Professor of Materials Science; Associate Dean of Students*

B.S., California Institute, 1941; M.S., 1946; Ph.D., 1949. Lecturer in Mechanical Engineering, 1949-50; Assistant Professor, 1950-55; Associate Professor, 1955-61; Professor, 1961-63; Professor of Materials Science, 1963-; Acting Associate Dean, 1968-69; Associate Dean, 1969-. (Keck, Throop)

William Barry Wood III, Ph.D., *Professor of Biology*

A.B., Harvard College, 1959; Ph.D., Stanford University, 1963. Assistant Professor, California Institute, 1964-68; Associate Professor, 1968-70; Professor, 1970-. (Kerckhoff)

Dean Everett Wooldridge, Ph.D., *Research Associate in Engineering*

B.A., University of Oklahoma, 1932; M.S., 1933; Ph.D., California Institute, 1936. Director, Thompson Ramo Wooldridge, Inc., 1958-. Lecturer in Electrical Engineering, California Institute, 1947-49; Research Associate, 1950-52; 1962-.

Fulton Wright, Jr., Ph.D., *Research Fellow in Physics*

A.B., Pomona College, 1959; Ph.D., University of California, 1966. California Institute, 1970.

Wiley John Wright,** M.A., *Instructor in Speech and Director of Debate*

B.S., University of Oregon, 1964; M.A., University of Hawaii, 1967. California Institute, 1968-. (Dabney)

Chin-Hua Wu, Ph.D., *Research Fellow in Chemistry*

B.S., Chiao-Tung University, China, 1949; Ph.D., University of California (Los Angeles), 1955. California Institute, 1955-57; 1958-. (Crellin)

Jung-Rung Wu, Ph.D., *Research Fellow in Biology*

B.S., National Taiwan University, 1962; Ph.D., University of Texas, 1969. California Institute, 1969-. (Kerckhoff)

Madeline Chang-Sun Wu, Ph.D., *Research Fellow in Chemistry*

B.S., National Taiwan University, 1962; Ph.D., University of Texas, 1966. California Institute, 1969-. (Church)

Theodore Yao-Tsu Wu, Ph.D., *Professor of Engineering Science*

B.S., Chiao-Tung University, 1946; M.S., Iowa State University, 1948; Ph.D., California Institute, 1952. Research Fellow in Hydrodynamics, 1952-55; Assistant Professor of Applied Mechanics, 1955-57; Associate Professor, 1957-61; Professor, 1961-66; Professor of Engineering Science, 1966-. (Thomas)

Oliver Reynolds Wulf, Ph.D., *Research Associate in Physical Chemistry, Emeritus*

B.S., Worcester Polytechnic Institute, 1920; M.S., American University, 1922; Ph.D., California Institute, 1926. Research Associate, 1945-67; Research Associate Emeritus, 1967-. (Noyes)

Cheng-Chih Yan, Ph.D., *Research Fellow in Engineering Science*

B.S., National Taiwan University, 1960; M.S., National Tsing Hua University, 1962; Ph.D., University of Oregon, 1968. California Institute, 1969-. (Thomas)

Keiji Yanagisawa, M.D., Ph.D., *Research Fellow in Biology*

M.D., Tokyo Medical and Dental University, 1963; Ph.D., 1967. Senior Fellow, East-West Center, University of Hawaii, 1967-. California Institute, 1968-. (Kerckhoff)

Amnon Yariv, Ph.D., *Professor of Electrical Engineering*

B.S., University of California, 1954; M.S., 1956; Ph.D., 1958. Associate Professor, California Institute, 1964-66; Professor, 1966-. (Steele)

Uri Yinon, Ph.D., *Research Fellow in Biology*

B.Sc., The Hebrew University of Jerusalem, 1962; M.Sc., 1964; Ph.D., 1968. California Institute, 1970-71.

Myonggeun Yoon, Ph.D., *Research Fellow in Biology*

B.S., Seoul National University, 1962; Ph.D., University of California, 1969. California Institute, 1969-. (Alles)

Barbara York, Ph.D., *Research Fellow in Biology*

B.Sc., University of Southampton, 1966; Ph.D., 1969. California Institute, 1970-71.

**Part-time

Sheldon Stafford York, Ph.D., *Research Fellow in Chemistry*
B.S., Bates College, 1965; Ph.D., Stanford University, 1970. California Institute, 1970-71.

Don M. Yost, Ph.D., *Professor of Inorganic Chemistry, Emeritus*
B.S., University of California, 1923; Ph.D., California Institute, 1926. Instructor, 1927-29; Assistant Professor, 1929-35; Associate Professor, 1935-41; Professor, 1941-64; Professor Emeritus, 1964-. (Gates)

Leo Fang-Hung Yuan, Ph.D., *Research Fellow in Chemistry*
B.S., Southern Illinois University, 1961; M.S., Northern Illinois University, 1963; Ph.D., Illinois Institute of Technology, 1968. California Institute, 1968-. (Church)

Fredrik Zachariasen,* Ph.D., *Professor of Theoretical Physics*
B.S., University of Chicago, 1951; Ph.D., California Institute, 1956. Assistant Professor, 1960-62; Associate Professor, 1962-66; Professor, 1966-. (Lauritsen)

O. L. Zangwill, M.A., *Visiting Associate in Biology*
M.A., Cambridge University, 1939. Head, Psychological Laboratory, Cambridge University. California Institute, 1970.

Yair Zarmi, Ph.D., *Research Fellow in Theoretical Physics*
B.S., The Hebrew University of Jerusalem, 1962; M.S., 1964; Ph.D., Weizmann Institute of Science, 1970. California Institute, 1970-71.

Laszlo Zechmeister, Dr.Ing., *Professor of Organic Chemistry, Emeritus*
Diploma of Chemical Federal Institute of Technology, Zurich, 1911; Dr.Ing., 1913. Professor, California Institute, 1940-59; Professor Emeritus, 1959-. (Church)

John Stoufer Zeigel,* Ph.D., *Assistant Professor of English*
B.A., Pomona College, 1956; M.A., Claremont College, 1959; Ph.D., 1967. Instructor, California Institute, 1962-67; Assistant Professor, 1967-. (Spalding)

Harold Zirin, Ph.D., *Professor of Astrophysics; Staff Member, Hale Observatories*
A.B., Harvard College, 1950; A.M., Harvard University, 1951; Ph.D., 1953. Visiting Associate, California Institute, 1963; Professor, 1964-. (Robinson)

Mary Fleming Zirin, M.A., *Lecturer in Russian*
B.A., University of Colorado, 1953; M.A., 1962. California Institute, 1969-. (Dabney)

Edward Edom Zukoski, Ph.D., *Professor of Jet Propulsion*
B.S., Harvard College, 1950; M.S., California Institute, 1951; Ph.D., 1954. Research Engineer, Jet Propulsion Laboratory, 1950-57; Lecturer, California Institute, 1956-57; Assistant Professor, 1957-60; Associate Professor, 1960-66; Professor, 1966-. (Karman)

George Zweig, Ph.D., *Professor of Physics*
B.S., University of Michigan, 1959; Ph.D., California Institute, 1964. Research Fellow, 1963; Assistant Professor, 1964-66; Associate Professor, 1966-67; Professor, 1967-. (Lauritsen)

Fritz Zwicky, Ph.D., *Professor of Astrophysics, Emeritus*
B.S., Federal Institute of Technology, Zurich, 1920; Ph.D., 1922. Research Fellow, California Institute, 1925-27; Assistant Professor of Theoretical Physics, 1927-29; Associate Professor, 1929-41; Professor of Astrophysics, 1941-68; Staff Member, Hale Observatories, 1948-68; Professor Emeritus, 1968-. (Robinson)

*Leave of absence, 1970-71

GRADUATE FELLOWS, SCHOLARS, AND ASSISTANTS 1969-70

Division of Biology

Barbara Joan Furman Attardi, *Special Fellow*
B.S. Cornell University, 1964

Steven Kent Beckendorf, *Special Fellow, Graduate Teaching Assistant*
A.B. University of California, Los Angeles, 1966

Robert Michael Benbow, *Earle C. Anthony Fellow*
B.S. Yale University, 1967

Larry Ira Benowitz, *Special Fellow, Graduate Teaching Assistant*
B.ChE. Cooper Union, 1966

Kostia Bergman, *Special Fellow, Graduate Teaching Assistant*
B.A. Johns Hopkins University, 1965

Charles Ray Birdwell, *Special Fellow, Graduate Teaching Assistant*
B.S. University of Chicago, 1969

Steven Allen Bissell, *Special Fellow*
B.S. Harvey Mudd College, 1965; M.S. CIT, 1967

Alan Brian Blumenthal, *Special Fellow*
A.B. Lafayette College, 1964

Wesley Monroe Brown, *NDEA Fellow, Graduate Teaching Assistant*
B.A. University of Colorado, 1963: M.A. 1967

Patricia Virginia Norgorden Burke, *Special Fellow*
B.A. Pomona College, 1964; M.S. CIT, 1967

Ming Ta Chong, *McCallum Fellow, Graduate Teaching Assistant*
M.B. Medical College of National Taiwan University, 1968

David Alvin Clayton, *Special Fellow*
B.S. Northern Illinois University, 1965

John Lee Compton, *USPHS Trainee*
B.S. Yale University, 1969

Sydney Pollock Craig, *NSF Trainee*
B.S. Purdue University, 1966

Jane Mary Harris Cramer, *Special Fellow*
B.A. Carleton College, 1964

John William Cross, Jr., *Special Fellow, Graduate Teaching Assistant*
B.A. Vanderbilt University, 1969

Stephen Garland Dennis, *Special Fellow, Graduate Teaching Assistant*
S.B. Mass. Inst. of Tech., 1969

Tommy Charles Douglas, *NDEA Fellow*
A.B. Princeton University, 1969

William Jack Driskell, *Special Fellow, Graduate Teaching Assistant*
B.S. University of Georgia, 1967; M.S. CIT, 1968

Moises Eisenberg-Grunberg, *Rockefeller Foundation Fellow*
Faculty of Sciences of University of Chile, 1967

Sarah Carlisle Elgin, *NSF Fellow*
B.A. Pomona College, 1967

*Assistantship so marked carries a tuition award.

Ellen Jeanne Elliott, *NSF Fellow, Graduate Teaching Assistant*
B.A. Centre College of Kentucky, 1969

Richard Alan Firtel, *NSF Fellow, Graduate Teaching Assistant*
A.B. Dartmouth College, 1966

Paul John Flory, Jr., *Special Fellow, Graduate Teaching Assistant*
A.B. Harvard University, 1967

Kenneth William Foster, *Special Fellow*
B.Sc. (Hons) University of Victoria, 1965

Jeffrey Allen Frelinger, *Special Fellow, Graduate Teaching Assistant*
B.S. University of California, San Diego, 1969

Stanley Charles Froehner, *Special Fellow, Graduate Teaching Assistant*
B.S. University of Texas, Austin, 1968

John Edward Geltosky, *NDEA Fellow, Graduate Teaching Assistant*
B.S. Memphis State University, 1967

Ernest William Goodell, *Special Fellow*
B.S. Colorado State University, 1964

Harold William Gordon, *Special Fellow, Graduate Teaching Assistant*
B.S. Case Institute of Technology, 1967

David Ellis Hiatt, *Special Fellow, Graduate Teaching Assistant*
B.A. Harvard University, 1967; M.A. University of Michigan, 1969

William Aro Hill, *Special Fellow, Graduate Teaching Assistant*
B.A. Cornell University, 1965

David Salway Holmes, *Special Fellow, Graduate Teaching Assistant*
B.A. Trinity College, Dublin, 1969

Wray Hughes Huestis, *NSF Fellow, Graduate Teaching Assistant*
B.A. Macalester College, 1967

John Berkeley Jamieson, *Special Fellow, Graduate Teaching Assistant*
B.A. University of California, Berkeley, 1967

Algirdas Joseph Jesaitis, *NDEA Fellow, Graduate Teaching Assistant*
B.A. New York University, 1967

Richard Douglas Kerr Josslin, *USPHS Trainee*
S.B. Mass. Inst. of Tech., 1965

Michael Byer Klayman, *Special Fellow, Graduate Teaching Assistant*
B.S. Union College, 1969

Ronald Jerome Konopka, *NSF Fellow, Graduate Teaching Assistant*
B.S. University of Dayton, 1967

Carol Lee Kornblith, *Special Fellow, Graduate Teaching Assistant*
A.B. University of Michigan, 1966; M.A. 1968

Lee-Ming Kow, *Special Fellow, Graduate Teaching Assistant*
B.S. National Taiwan University, 1962; M.S. University of Florida, 1968

Paul Townsend Langstroth, *Special Fellow, Graduate Teaching Assistant*
B.A. Wabash College, 1969

Jane Elinor Latta, *Special Fellow, Graduate Teaching Assistant*
A.B. Goucher College, 1968

Mary Ann Linseman, *Special Fellow, Graduate Teaching Assistant*
B.A. University of Toronto, 1967

Cary Lu, *NIH Fellow*
A.B. University of California, Berkeley, 1966

John Geoffrey Magnus, *Graduate Student*
B.A. Bard College, 1964; M.S. University of Chicago, 1968

David John McConnell, *Special Fellow, Graduate Teaching Assistant*
B.A. (Hons) Trinity College, Dublin, 1966

Paul Stuart Meltzer, *NSF Fellow*
A.B. Dartmouth College, 1967

Susan Leah Melvin, *Special Fellow, Graduate Teaching Assistant*
B.A. State University of New York, Buffalo, 1968

Ronald Leo Meyer, *NDEA Fellow*
B.A. Don Bosco College, 1967

Mark James Miller, *NSF Trainee, Graduate Teaching Assistant*
B.A. University of Colorado, 1969

William Ignatius Murphy, *NSF Fellow, Graduate Teaching Assistant*
B.S. Fordham University, 1967

Jerre L. Basch Nagylaki, *Bennett Scholar*
B.A. University of Miami, 1962; M.S. 1965

Robert David Nebes, *Special Fellow, Graduate Teaching Assistant*
B.S. Tufts University, 1965

John Edward Newbold, *Special Fellow*
B.Sc. Birmingham University, 1962

Charles Edward Novitski, *NSF Trainee*
B.A. Columbia College, 1969

John Stansfield Parkinson, Jr., *Special Fellow*
B.A. Haverford College, 1965

Jeffrey Lewis Ram, *NSF Fellow, Graduate Teaching Assistant*
A.B. University of Pennsylvania, 1967

Donald Lewis Robberson, *NSF Trainee*
B.S. Oklahoma Baptist University, 1963

Robert George Rohwer, *Special Fellow, Graduate Teaching Assistant*
B.S. University of Wisconsin, 1967

Barry Samuel Rothman, *Special Fellow, Graduate Teaching Assistant*
B.A. Haverford College, 1969

Gary Carl Scheidt, *NSF Fellow*
B.S. Michigan State University, 1967

John William Sedat, *Special Fellow*
B.A. Pasadena College, 1963

William Davidson Seybold, *Special Fellow, Graduate Teaching Assistant*
B.Sc. McGill University, 1967

Daniel Tawil Simmons, *Special Fellow, Graduate Teaching Assistant*
B.S. Colorado College, 1969

Charles Allen Smith, *Special Fellow, Graduate Teaching Assistant*
S.B. Mass. Inst. of Tech., 1966

Lloyd Herbert Smith, *NDEA Fellow*
B.S. University of California, Davis, 1969

Brian Storrie, *NDEA Fellow, Graduate Teaching Assistant*
B.S. Cornell University, 1968

David Tang, *Special Fellow, Graduate Teaching Assistant*
A.B. University of California, Berkeley, 1969

William Alvis Thomasson, *USPHS Fellow*
B.A. University of Chicago, 1955; M.A. California State College, Long Beach, 1965

Clark Joseph Bullock Tibbetts, *Special Fellow, Graduate Teaching Assistant*
B.A. Amherst College, 1968

Lois Anne Toevs, *Special Fellow*
B.A. University of Colorado, 1964

Zoltan Andras Tökes, *Special Fellow*
B.S. University of Southern California, 1964

Jessica Tuchman, *Special Fellow, Graduate Teaching Assistant*
B.A. Radcliffe College, 1967

Samuel Ward, *Special Fellow*
A.B. Princeton University, 1965

John Howard Wilson, *Earle C. Anthony Fellow*
A.B. Wabash College, 1966

Sandra Winicur, *Special Fellow.*
B.A. Hunter College, 1960; M.S. University of Connecticut, 1963

Anthony Joseph Zuccarelli, *NSF Fellow*
B.S. Cornell University, 1966; M.S. Loma Linda University, 1968

Division of Chemistry and Chemical Engineering

Roger Henry Abel, *Danforth Scholar, Chemistry*
B.A. Hope College, 1965

William Michael Anthony, *NIH Trainee, Chemistry*
B.S. Case Institute of Technology, 1969

David Lawrence Arkin, *Graduate Teaching Assistant*, Chemistry*
B.S. The City College of New York, 1969

James Henry Barbee, *Graduate Research Assistant*, Chemical Engineering*
B.S. University of Washington, 1965; M.S. California Institute of Technology, 1967

Alan Joseph Barnett, *Graduate Teaching Assistant*, Chemistry*
B.S. The City College of New York, 1967

Karl Ammon Bell, *NSF Trainee, Graduate Research Assistant, Chemical Engineering*
B.S. Lehigh University, 1969

William Beranek, Jr., *NIH Trainee, Chemistry*
B.S. University of Wisconsin, 1967

Bruce Allan Berentsen, *Fluor Foundation Fellow, Chemical Engineering*
B.S. Rutgers University, 1969

Paula Kreisman Bernstein, *Graduate Research Assistant*, Chemistry*
B.S. Barnard College, 1965; M.S. Columbia University, 1966

Michael Dean Bertolucci, *NDEA Fellow, Graduate Teaching Assistant, Chemistry*
B.S. San Jose State College, 1967

Jeanette Betts, *Graduate Research Assistant*, Chemistry*
B.A. University of Utah, 1965

Timothy Charles Betts, *Graduate Research Assistant*, Chemistry*
A.B. Humboldt State College, 1966

James Edwin Blakemore, *Graduate Research Assistant*, Chemical Engineering*
B.S. The University of Tennessee, 1966

Richard Joseph Blint, *NDEA Fellow, Graduate Teaching Assistant, Chemistry*
B.A. St. Mary's College, 1967

Michael Blumenstein, *NSF Trainee, Graduate Teaching Assistant, Chemistry*
B.S. The City College of New York, 1968

Frank Wilhelm Bobrowicz, *Graduate Teaching Assistant*, Chemistry*
B.S. Seton Hall University, 1969

James Leon Bolen, Jr., *NIH Trainee, Chemistry*
B.S. Clemson University, 1966

Joel Mark Bowman, *NSF Trainee, Graduate Teaching Assistant, Chemistry*
A.B. University of California, Berkeley, 1969

Ray Douglas Bowman, *NIH Trainee, Chemistry*
A.B. Indiana University, 1964

Ronald Jerome Brown, *NSF Trainee, Graduate Research Assistant, Chemical Engineering*
B.S. Stanford University, 1969

Joseph Robert Bruckner, *Graduate Teaching Assistant*, Chemistry*
B.S. Loyola University, Chicago, 1969

Donald Maxwell Burland, *Graduate Research Assistant,* Chemistry*
A.B. Dartmouth College, 1965

Raymond Edgar Carhart, *NSF Fellow, Graduate Teaching Assistant, Chemistry*
B.A., Northwestern University, 1968

Felix Alvin Carroll, Jr., *NSF Fellow, Graduate Teaching Assistant, Chemistry*
B.S. University of North Carolina, 1969

Wen-Ji Victor Chang, *Earle C. Anthony Fellow, Graduate Research Assistant, Chemical Engineering*
B.S. National Taiwan University, 1966; M.S., 1968

Wen Hsiung Chen, *Graduate Teaching Assistant,* Chemical Engineering*
B.S. Tunghai University, 1963; M.S., Illinois Institute of Technology, 1968

Dennis Don Chilcote, *U. S. Public Health Service Trainee, Chemical Engineering*
B.S. University of Minnesota, 1965

Louise Tsi Chow, *Graduate Research Assistant,* Chemistry*
B.S. National Taiwan University, 1965

Mildred Janet Clarke, *NSF Fellow, Graduate Teaching Assistant, Chemistry*
B.A. Rice University, 1969

Thomas Carl Clarke, *NSF Fellow, Graduate Teaching Assistant, Chemistry*
B.A. Rice University, 1969

Michael John Coggiola, *Graduate Teaching Assistant,* Chemistry*
B.S. University of California, Berkeley, 1969

Robert Edward Cohen, *Graduate Teaching Assistant,* Chemical Engineering*
B.S. Cornell University, 1968; M.S. California Institute of Technology, 1969

Robert Sanderson Cooke, *NIH Fellow, Chemistry*
A.B. Wesleyan University, 1966

Charles Dane Cowman, Jr., *NSF Trainee, Chemistry*
B.S. Case Western Reserve, 1969

Jane Ellen Crawford, *NDEA Fellow, Graduate Teaching Assistant, Chemistry*
A.B. University of California, Santa Barbara, 1966

Robert John Czarny, *NIH Trainee, Chemistry*
B.S. Providence College, 1969

Michael Brian D'Amore, *Graduate Teaching Assistant*, Chemistry*
B.S. Providence College, 1967

Ronald Wayne Davis, *NIH Trainee, Chemistry*
B.S. Eastern Illinois University, 1964

Daniel Joseph Dawson, *NSF Fellow, Graduate Teaching Assistant, Chemistry*
B.S. University of North Carolina, 1967

Phoebe Kin-Kin Dea, *Graduate Research Assistant*, Chemistry*
B.S. University of California, Los Angeles, 1967

William Robert Devereaux, *NSF Fellow, Graduate Teaching Assistant, Chemistry*
S.B. Massachusetts Institute of Technology, 1964

Kevin Gerard Donohoe, *Fluor Foundation Fellow, Chemical Engineering*
B.S. Newark College of Engineering, 1969

Thomas Harold Dunning, *Jr., Graduate Research Assistant*, Chemistry*
B.S. University of Missouri, 1965

Robert Gouldman Eagar, Jr., *NIH Trainee, Graduate Teaching Assistant, Chemistry*
B.S. Virginia Polytechnic Institute, 1969

David Fielder Eaton, *NDEA Title IV Fellow, Chemistry*
B.A. Wesleyan University, 1968

James Bernard Ellern, *NSF Fellow, Graduate Teaching Assistant, Chemistry*
B.S. University of Illinois, 1962

Christopher England, *Graduate Research Assistant*, Chemical Engineering*
B.S. University of Southern California, 1965, M.S. Calif. Inst. of Tech., 1967

Paul Lee Fehder, *Graduate Research Assistant,* Chemistry*
S.B. Massachusetts Institute of Technology, 1964

Gerald W. Feigenson, *NIH Trainee, Chemistry*
B.S. Rensselaer Polytechnic Institute, 1968; M.S. 1969

Donald George Fesko, *NSF Fellow, Graduate Research Assistant, Chemical Engineering*
B.S.ChE. Clarkson College, 1966

Robert Wallace Fillers, *Atlantic-Richfield Fellow, Chemical Engineering*
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B.S. CIT, 1969

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B.S. Cornell University, 1969

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B.Sc. National Taiwan University, 1968

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B.S. National Taiwan University, 1963; M.A. Rice University, 1966

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B.S. Miami University, 1969

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B.S. Loyola University, 1966

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B.A. Pomona College, 1966

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B.S.E. University of Michigan, 1965

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S.B., S.M. Massachusetts Institute of Technology, 1969

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B.A. Wesleyan University, 1968

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B.S. University of Notre Dame, 1966

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B.A. Colgate University, 1968

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B.Sc. Technion Israel, 1965; M.Sc., 1969

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B.Sc. McMaster University, 1966; M.S. CIT, 1969

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B.S. Clarkson College, 1966

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Siv.ing. Norwegian Institute of Technology, 1966; Lic.techn., 1968

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B.Sc. McMaster University, 1969

Stephen Alan Shectman, *NSF Fellow, Astronomy*
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B.A. University of Wisconsin, 1968

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David Richard Smith, *Earle C. Anthony Fellow, Physics*
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Robert Carroll Smithson, *Graduate Research Assistant,* Physics*
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Harold Matthew Spinka, Jr., *NSF Fellow, Physics*
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Richard Anthony Sramek, *Graduate Teaching Assistant,* Astronomy*
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John Charles Stevens, *NSF Fellow, Physics*
B.S. CIT, 1968

John Randolph Stonesifer, *NDEA Fellow, Mathematics*
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Donald Lionel Strange, *NRC of Canada Fellow, Physics*
B.Sc. Carleton University, 1966

Keith Duncan Stroyan, *NDEA Fellow, Graduate Teaching Assistant, Mathematics*
B.S. Drexel Institute of Technology, 1967

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B.Sc. Hebrew University, Israel, 1966

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B.S. CIT, 1963

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THE ASSOCIATES OF THE CALIFORNIA INSTITUTE OF TECHNOLOGY

The Associates of the California Institute of Technology are a group of public-spirited citizens, interested in the advancement of learning, who were incorporated in 1926 as a non-profit organization for the purpose of promoting the interests of the California Institute of Technology. Information concerning the terms and privileges of membership is available from the Assistant Secretary of The Associates, on the Institute campus.

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Section II

GENERAL INFORMATION

THE California Institute of Technology is an independent, privately supported and privately controlled institution, officially classed as a university, carrying on undergraduate and graduate instruction and research, principally in the various fields of science and engineering. It is fully accredited by the Western Association of Schools and Colleges.

The primary purpose of the undergraduate school of the California Institute of Technology, as stated by the Trustees, is "to provide a collegiate education which will best train the creative type of scientist or engineer so urgently needed in our educational, governmental, and industrial development." It is believed that this end will be more readily attained at the Institute because of the contacts of its relatively small group of undergraduate students with the members of its relatively large research staff. Advancement in understanding is best acquired by intimate association with creative workers who are, through research and reflection, extending the boundaries of knowledge.

Caltech offers a four-year undergraduate course with options available in various fields of science, engineering, applied science, and certain humanities subjects, all leading to the degree of Bachelor of Science. The curricula are planned so that interchange between options is not too difficult to the end of the second year. During the first year, the work of all undergraduates is almost identical, but there is opportunity for some differentiation between the various options during the second year.

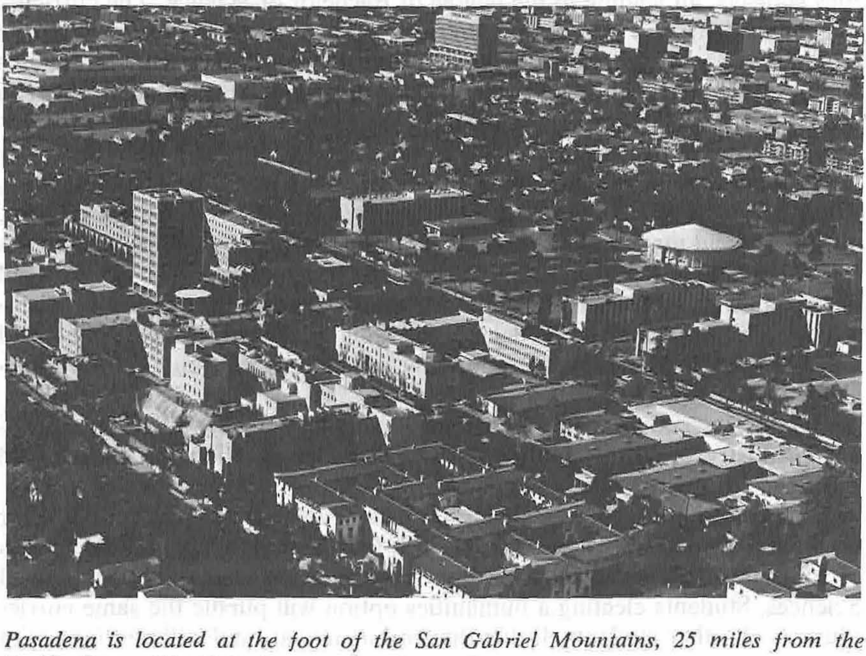
The courses in engineering and applied science are of a general fundamental character, with a minimum of specialization in the separate branches. There is an unusually thorough training in the basic sciences of physics, chemistry, and mathematics, as well as in the professional subjects common to all branches of engineering. The major concentration in a chosen field occurs during the fourth year. The Master of Science curriculum in Aeronautics and the Bachelor's degree curricula in Engineering Science and Chemical Engineering are accredited by the Engineers' Council for Professional Development.

The science courses afford even more fully an intensive training in physics, chemistry, and mathematics, with further specialization in a chosen field of science during the third and fourth years.

Since the fall of 1965, Caltech has offered options toward the Bachelor of Science degree in the fields of English literature, history, and economics — subjects which are included in the Division of the Humanities and Social Sciences. Students electing a humanities option will pursue the same curriculum as all other students during the freshman year, and will continue with the regular sophomore courses in mathematics, physics, and chemistry. During the last two years, they may specialize in a chosen field of humanities but will continue substantial work in science and engineering subjects.

The undergraduate options in science, engineering, and applied science themselves contain a large proportion of humanistic and cultural studies – with 20 percent, or more, of the time during the entire four years being devoted to such subjects. The purpose of this requirement is to provide a combination of fundamental scientific training with a broad human outlook and to enlarge the student's mental horizon beyond the limits of his immediate professional interest. This combination of cultural and scientific training – first offered by Caltech in 1920 – is now being followed by other leading institutions of science and engineering, for it provides students with the opportunity to prepare themselves to fulfill their responsibilities as citizens and members of the community.

It is in the Division of the Humanities and Social Sciences that Caltech offers its work in nonscientific subjects, including literature, history, political science, economics, philosophy, geography, psychology, and anthropology. One hundred and eight units are required, of which only 27 units are specified – in English. A wide range of elective courses is available, to which students devote approximately one-quarter of their time, and many choose to take more than the required number of units. Formal instruction in the humanities and social sciences is supplemented by lectures and conferences



Pasadena is located at the foot of the San Gabriel Mountains, 25 miles from the Pacific Ocean. The Caltech campus is shown above.

with distinguished visiting scholars, some of whom are carrying on research at the Huntington Library and Art Gallery, and others, including scholars in international fields who are members of the American Universities Field Staff.

Caltech also encourages a reasonable participation in extracurricular activities, largely managed by the students themselves. These include student publications, debating, dramatics, music, and public affairs. All freshmen and sophomores are required to take physical education, and juniors and seniors may elect to take such work largely through participation in a well-rounded program of intercollegiate and intramural sports.

In short, every effort is made to provide the undergraduate student with a well-rounded, well-integrated program which will not only give him sound training in his professional field, but which will also develop character, breadth of view, general culture, and physical well-being.

In the graduate section Caltech offers courses leading to the degree of Master of Science, which normally involves one year of graduate work; the engineer's degree in certain branches of engineering, with a minimum of two years; and the degree of Doctor of Philosophy. In all the graduate work, research is strongly emphasized, not only because of its importance in contributing to the advancement of science and thus to the intellectual and material welfare of mankind, but also because research activities add vitality to the educational work of Caltech. Graduate students constitute a comparatively large portion (over 50 percent) of the total student body. Engaged themselves in research problems of varying degrees of complexity, and taught by faculty members who are also actively engaged in research, they contribute materially to the general atmosphere of intellectual curiosity and creative activity which is engendered on the Institute campus.

In order to utilize Caltech's resources most effectively, two general lines of procedure are followed. First, the Institute restricts the number of fields in engineering and science in which it offers undergraduate and graduate study, believing that it is better to provide thoroughly for a limited number of curricula than to risk diffusion of personnel, facilities, and funds in attempting to cover a wide variety of fields. Second, and in line with this policy of conservation of resources, the student body is strictly limited to that number which can be satisfactorily provided for. The size of the undergraduate group is limited by the admission of approximately 200 freshmen each September. Admission is granted, not on the basis of priority of application, but on a careful study of the merits of each applicant, including the results of competitive entrance examinations, high school records, and interviews by members of the Caltech staff. Applicants for admission with advanced standing from other institutions and for admission to graduate study are given the same careful scrutiny. These procedures result, it is believed, in a body of students of exceptionally high ability. A high standard of scholarship is also maintained, as is appropriate for students of such high competence.

The California Institute of Technology, as it has been called since 1920, developed from a local school of arts and crafts, founded in Pasadena in 1891 by the Honorable Amos G. Throop and named, after him, Throop Polytechnic Institute. It had at first been called Throop University, but the title was soon considered too pretentious. The Institute included, during its first two decades, a college, a normal school, an academy, and, for a time, an elementary school and a commercial school. It enjoyed the loyal support of the citizens of Pasadena, and by 1908 the Board of Trustees had as members Dr. Norman Bridge, Arthur H. Fleming, Henry M. Robinson, J. A. Culbertson, C. W. Gates, and Dr. George Ellery Hale. It was the dedication, by these men, of their time, their brains, and their fortunes that transformed a modest vocational school into a university capable of attracting to its faculty some of the most eminent of the world's scholars and scientists. A statement in the Throop Institute Bulletin of December 1908 shows the situation at this time and the optimism of the friends of the Institute:

"Although Throop Institute requires from $80,000 to $90,000 a year to pay its operating expenses and meet its current obligations, the financial condition of the school was never sounder than at present. Its revenues are not sufficient to pay its expenses, but good friends are each year found willing and able to contribute to its deficiency fund. It is in the certainty of a continuance of this confidence in its work and mission that its officers and trustees are pressing forward toward a realization of larger plans for the Institute."

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

The realization of these aims meant specializing, so the Trustees decided in 1907 to separate the elementary department, the normal school, and the academy, leaving only a college of technology which 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 twenty-two acres on the southeastern edge of town, the gift of Arthur H. Fleming and his daughter Marjorie. The president, Dr. James A. B. Scherer, and his faculty of 16 members, opened the doors to 31 students that September. When, on March 21, 1911, Theodore Roosevelt delivered an address at Throop Institute, he declared, "I want to see institutions like Throop turn out perhaps ninety-nine of every hundred students as men who are to do given pieces of industrial work better than any one else can do them; I want to see those men do the kind of work that is now being done on the Panama Canal and on the great irrigation projects in the interior of this country – and the one hundredth man I want to see with cultural scientific training."

It would have surprised Roosevelt to know that within a decade the little Institute, known beginning in 1914 as Throop College of Technology, would have again raised its sights, leaving to others the training of mere 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."

Hale

Noyes

Millikan

Perhaps some causes of this change were the rapid growth of southern California between 1911 and 1921, the springing up everywhere of high schools and vocational schools which relieved Throop of some of its responsibilities, and the increasing public interest in scientific research as the implications of modern physics became better known. But the immediate causes of the change in the Institute at Pasadena were men. George Ellery Hale still held to his dream. Arthur Amos Noyes, Professor of Physical Chemistry and former Acting President of the Massachusetts Institute of Technology, served part of each year as Professor of General Chemistry and Research Associate from 1913 to 1919, when he resigned from M.I.T. 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 fom the University of Chicago and became administrative head of the Institute as well as director of the Norman Bridge Laboratory. The name of the Institute was changed in 1920 to its present one.

The great period of the Institute's life began, then, under the guidance of three men of vision – Hale, Noyes, and Millikan. They were distinguished research scientists, and they soon attracted graduate students. In 1920 the enrollment was 9 graduate students and 359 undergraduates under a faculty of 60; a decade later there were 138 graduate students, 510 undergraduates, and a faculty of 180. At the present time there are about 750 undergraduates, 750 graduate students, and a faculty (including postdoctoral fellows) of about 600.

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. (Within two years, if anyone had known where to look, he could have found four future Nobel Laureates on the campus.) 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. Later gifts, especially from Mr. and Mrs. Allan C. Balch and the gift of the Arms and Mudd laboratories, contributed further to the establishment of the geological sciences at Caltech.

In 1928 the California Institute began its program of research and instruction in biology. There had been a chair of biology, named for Charles Frederick Holder, in the old Throop Institute, but it was not until the efforts of the Caltech Trustees, the General Education Board, the Carnegie Insti-

CALTECH'S NOBEL LAUREATES

Robert A. Millikan, physics, 1923.

Thomas Hunt Morgan, medicine, 1933.

Carl D. Anderson, physics, 1936.

Edwin D. McMillan, chemistry, 1951.

Linus Pauling, chemistry, 1954; 1962, Peace Prize.

William Shockley, physics, 1956.

George W. Beadle, medicine, 1958.

Rudolf Mössbauer, physics, 1961.

Donald A. Glaser, physics, 1960.

Charles H. Townes, physics, 1964.

Richard Feynman, physics, 1965.

Murray Gell-Mann, physics, 1969.

Max Delbrück, physiology and medicine, 1969.

tution of Washington, and William G. Kerckhoff were combined that a program of research and teaching at the highest level was inaugurated. Thomas Hunt Morgan became the first chairman of the new Division of Biology and a member of Caltech's Executive Council. Under Morgan's direction the work in biology developed rapidly, especially in genetics and biochemistry. Morgan received the Nobel Prize in 1933.

The Guggenheim Graduate School of Aeronautics was founded at Caltech in the summer of 1926 and a laboratory was built in 1929, but courses in theoretical aerodynamics had been given at the Institute for many years by Professors Harry Bateman and P. S. Epstein. As early as 1917 Throop Institute had had 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 Karman, included graduate study and research at the level of the other scientific work at the Institute, and GALCIT (Guggenheim Aeronautical Laboratory 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, and the Mount Wilson and Palomar Observatories are now operated jointly as the Hale Observatories through an agreement between Caltech and the Carnegie Institution of Washington. Teaching and research in astronomy and astrophysics thus became a part of the Caltech program.

Although the emphasis upon the humanities or liberal arts as an important part of the education of every scientist and engineer was traditional even in the Throop College days, a reiterated insistence upon this principle was made when Hale, Noyes, and Millikan created the modern Caltech. In 1924, when a five-year engineering course leading to the M.S. degree was offered, the humanities requirement was included. In 1925 William Bennett Munro, chairman of the Division of History, Government and Economics at Harvard, joined the Institute staff, and soon became a member of the Executive Council. In 1928 Mr. and Mrs. Joseph B. Dabney gave the Dabney Hall of Humanities, and friends of Caltech provided an endowment of $400,000 for the support of instruction in humanistic subjects. Later, Mr. Edward S. Harkness added a gift of $750,000 for the same purpose.

Largely on the initiative of Henry M. Robinson, the Associates of the California Institute of Technology were organized in 1925. These men and women, now numbering about 400, are the successors of those early dedicated pioneers who saw in Throop College the potentiality of becoming a great and famous institution. The Associates, by their continued support, have played a vital part in Caltech's progress. In 1949 the Industrial Associates Program was organized as a mechanism for providing corporations with the opportunity of supporting fundamental research at Caltech and of keeping in touch with new developments in science and engineering.

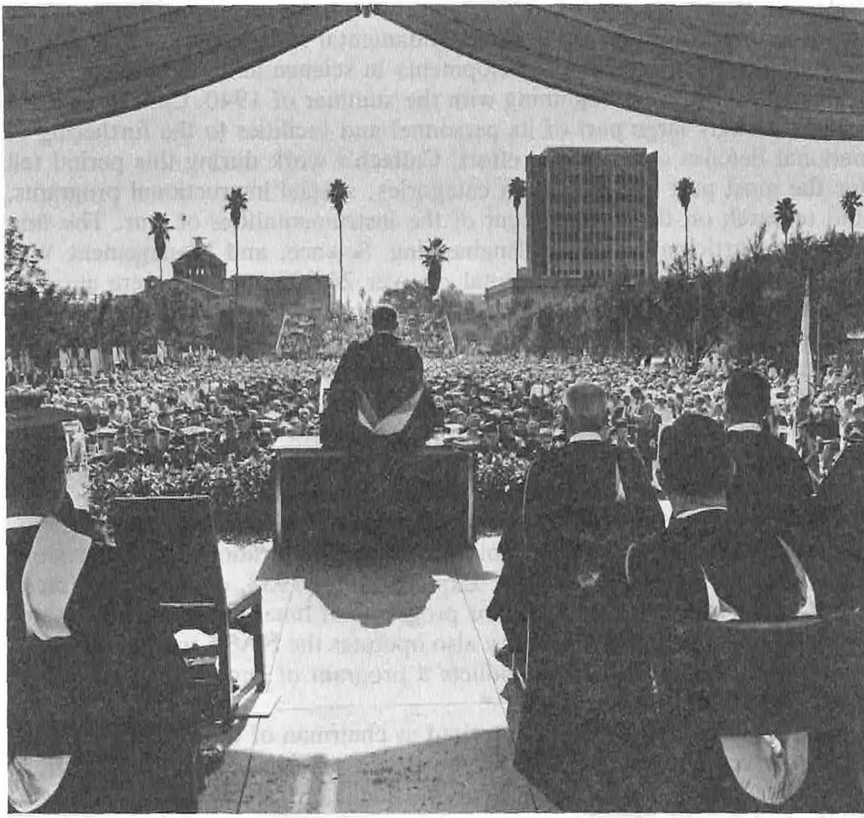
For the five years beginning with the summer of 1940, Caltech devoted an increasingly large part of its personnel and facilities to the furthering of national defense and the war effort. Caltech's work during this period fell for the most part into two main categories: special instructional programs, and research on the development of the instrumentalities of war. The first included participation in the Engineering, Science, and Management War Training Program, in which a total of over 24,000 students were enrolled in Caltech-supervised courses. The research and development work was carried on for the most part under nonprofit contracts with the Office of Scientific Research and Development. These contracts had a total value of more than $80,000,000 and at their peak involved the employment of more than 4,000 persons. Rockets, jet propulsion, and anti-submarine 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 space exploration. The Laboratory launched the first U. S. satellite, Explorer I, in 1958, and has conducted the Ranger, Mariner, and Surveyor programs of lunar and planetary exploration for NASA. The Laboratory also operates the NASA worldwide deep-space tracking network and conducts a program of supporting research in space science and engineering.

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, and served until his retirement in 1969 to become Science Adviser to the President of the United States. On February 15, 1969, Dr. Harold Brown became president of the California Institute.

Today Caltech has over 10,000 alumni scattered all over the world, many eminent in their fields of engineering and science. Six of them have received Nobel Prizes: Carl D. Anderson (B.S. '27, Ph.D. '30), Edwin M. McMillan (B.S. '27, M.S. '29), Linus Pauling (Ph.D. '25), William Shockley (B.S. '32), Donald A. Glaser (Ph.D. '50), and Charles H. Townes (Ph.D. '39).

As Caltech has developed in effectiveness and in prestige, it has attracted a steady flow of gifts for buildings, for endowment, and for current operations. The gifts invested in plant now total $81,000,000 and those invested in endowment about $105,000,000. Very substantial grants and contracts from the federal government support many important research activities.

In recent years new developments have taken place in all of the divisions. In 1948 the Palomar Observatory and the 200-inch Hale telescope were dedicated. In 1949 the Earhart Plant Research Laboratory was com-



pleted; in 1950 the Thomas Laboratory of Engineering; and in 1951 a cosmic ray laboratory. The next year a synchrotron was constructed for the study of atomic nuclei. In 1954 the generosity of the alumni and of the late Scott Brown, a member of the Associates, provided a gymnasium and swimming pool. In 1955 the completion of the Norman W. Church Laboratory for Chemical Biology pointed to new activities in an important field of science. The Eudora Hull Spalding Laboratory of Engineering, an important addition to the facilities available for instruction and research in chemical and electrical engineering, was completed in 1957. A new radio astronomy observatory – one of the finest in the world – was completed in the Owens Valley in 1959 and is now being substantially enlarged.

In February 1958 the Trustees announced the launching of a drive to finance 18 needed buildings and an enlarged faculty salary fund. Since 1958 the following new buildings have been completed and placed into service: physical plant building (1959); Alfred P. Sloan Laboratory of Mathematics and Physics (1960); Gordon A. Alles Laboratory for Molecular Biology (1960); Campbell Plant Research Laboratory (1960); W. M. Keck Engineering Laboratories (1960); three undergraduate student houses – Page, Lloyd, and Ruddock Houses (1960); Harry Chandler Dining Hall (1960); four graduate houses – Braun, Keck, Mosher-Jorgensen, Marks (1961); Karman Laboratory of Fluid Mechanics and Jet Propulsion (1961); Firestone Flight Sciences Laboratory (1962); P. G. Winnett Student Center (1962); Willis H. Booth Computing Center (1963); Arnold O. Beckman Auditorium (1964); Harry G. Steele Laboratory of Electrical Sciences (1965); Robert A. Millikan Memorial Library – gift of Dr. Seeley G. Mudd (1967); the Arthur Amos Noyes Laboratory of Chemical Physics (1968); a new central heating and refrigerating plant to serve the entire campus (1968); George W. Downs Laboratory of Physics and Charles C. Lauritsen Laboratory of High Energy Physics (1969); Business Services Building (1969).

In November 1967 the Trustees announced the launching of a new development campaign to be known as the "Science for Mankind Program," with the goal of raising $85.4 million during the coming five years. Forty million dollars in gifts and pledges had been secured by May 1, 1970. The funds sought include approximately $30 million for additional buildings and rehabilitation of existing structures, about $20 million in new endowment funds, and about $35 million for current operating funds over the next five years.

The new buildings will provide facilities for behavorial biology, the humanities and social sciences, the computing center, geophysics and planetary science, engineering and applied science, astronomy and astrophysics, applied mathematics, and physical education. In addition, four new student houses are urgently needed. The private funds that are needed for several of these buildings have already been pledged, and federal funds for certain of them are now being sought. Both private and federal funds have already been assured to cover the full costs of the humanities and social sciences building, a gift of Mrs. Donald E. Baxter, to be known as the Donald E. Baxter, M.D., Hall of the Humanities and Social Sciences, now under construction. A 30,000-square-foot addition to the Willis H. Booth Computing Center is also under construction.

The Science for Mankind campaign, if fully successful, will allow the Institute to meet rising needs for additional teaching and research enterprises, and especially to meet the rising costs of normal operations. The operating funds will allow modest expansion in each of the six academic divisions and will also help in meeting the rising costs of administration and maintenance.

As the theme suggests, Caltech has always had the belief that the advance of scientific knowledge and its practical application redounds to the benefit of mankind. The new program will focus further attention on this theme.

THROOP HALL, 1910. The administration building; erected with funds supplied by a large number of donors, and named for the Honorable Amos G. Throop, founder of Throop Polytechnic Institute from which the California Institute of Technology developed.

GATES AND CRELLIN LABORATORIES OF CHEMISTRY: first unit, 1917; second unit, 1927; third unit, 1937. The first two units were the gift 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.

CULBERTSON HALL, 1922. Named in honor of Mr. James A. Culbertson of Pasadena, vice president of the Board of Trustees, 1908-1915.

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. Erected 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 OF THE HUMANITIES, 1928. The gift of Mr. and Mrs. Joseph B. Dabney of Los Angeles.

GUGGENHEIM AERONAUTICAL LABORATORY, 1929. Erected with funds provided by the Daniel Guggenheim Fund for the Promotion of Aeronautics. A substantial addition was erected in 1947.

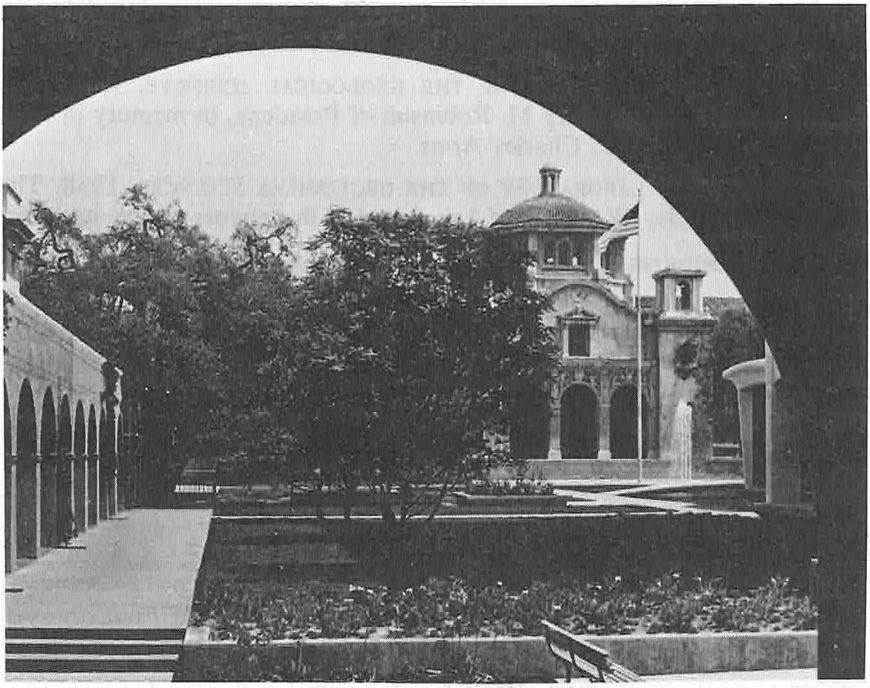
WILLIAM G. KERCKHOFF LABORATORIES OF THE BIOLOGICAL SCIENCES: first unit, 1928; second unit, 1939; annex, 1948. The gift of Mr. and Mrs. William G. Kerckhoff of Los Angeles.

DOLK PLANT PHYSIOLOGY LABORATORY, 1930. Named in memory of Herman E. Dolk, Assistant Professor of Plant Physiology from 1930 until his death in 1932.

ATHENAEUM, 1930. A clubhouse for the use of the teaching, research, and administrative staffs of the Institute, the Huntington Library and Art Gallery, and the Hale Observatories; of the Associates of the California Institute of Technology; and of others who have demonstrated their interest in advancing the educational 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.



Throop Hall

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

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

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

W. K. KELLOGG RADIATION LABORATORY (Nuclear Physics), 1932. The gift of Mr. W. K. Kellogg of Battle Creek, Michigan.

HENRY M. ROBINSON LABORATORY OF ASTROPHYSICS, 1932. Erected 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.

SYNCHROTRON LABORATORY, 1933. Originally Optical Shop, erected with funds provided by the International Education Board and the General Education Board. Following completion of the 200-inch Hale telescope the building was converted into the Synchrotron Laboratory.

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.

CLARK GREENHOUSE, 1940. The gift of Miss Lucy Mason Clark of Santa Barbara.

FRANKLIN THOMAS LABORATORY OF ENGINEERING: first unit, 1945; second unit, 1950. Funds for the first unit were allocated from the Eudora Hull Spalding Trust with the approval of Mr. Keith Spalding, Trustee. Named in honor of Dean Franklin Thomas, Professor of Civil Engineering and first chairman of the Division of Engineering, 1924-1945.

EARHART PLANT RESEARCH LABORATORY, 1949. The gift of the Earhart Foundation of Ann Arbor, Michigan.

COSMIC RAY LABORATORY, 1952.

ALUMNI SWIMMING POOL, 1954. Provided by the Alumni Fund through contributions of the alumni of the Institute.

SCOTT BROWN GYMNASIUM, 1954. Erected with funds provided by a trust established by Mr. Scott Brown of Pasadena and Chicago, a member and director of the California Institute Associates.

NORMAN W. CHURCH LABORATORY FOR CHEMICAL BIOLOGY, 1955. Erected with funds provided through a gift and bequest by Mr. Norman W. Church of Los Angeles, a member of the California Institute Associates.

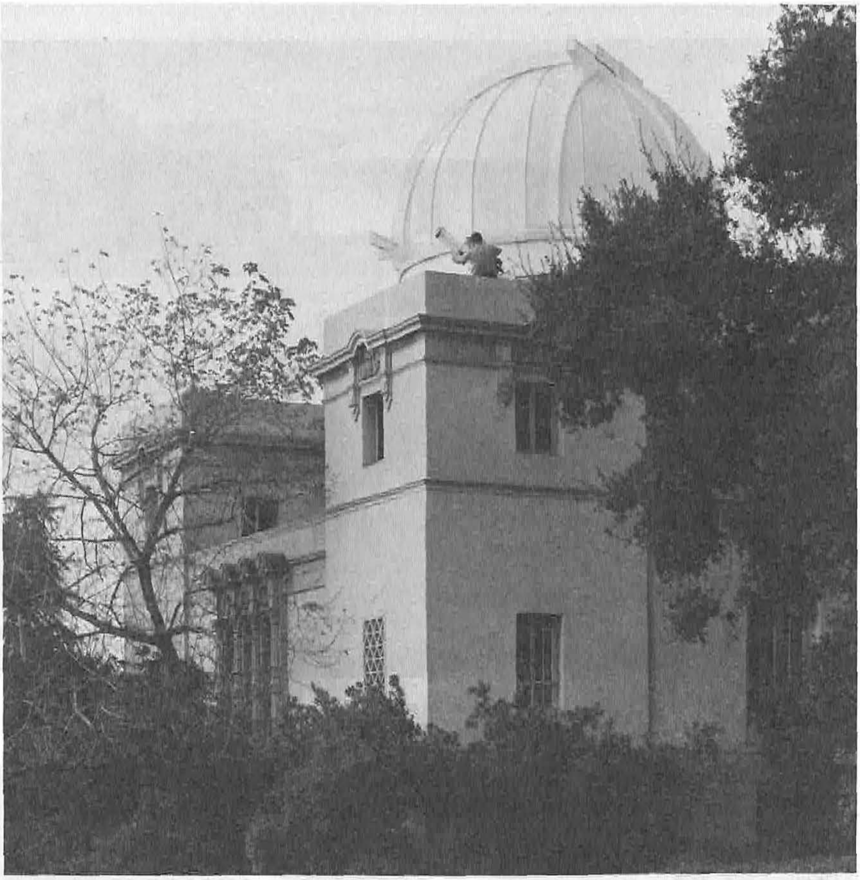
EUDORA HULL SPALDING LABORATORY OF ENGINEERING, 1957. Erected with funds allocated from the Eudora Hull Spalding Trust.

ARCHIBALD YOUNG HEALTH CENTER, 1957. The gift of Mrs. Archibald Young of Pasadena, in memory of her husband, a member and director of the California Institute Associates.

PHYSICAL PLANT BUILDING AND SHOPS, 1959. Erected with funds provided by many donors to the Caltech Development Program.

CAMPBELL PLANT RESEARCH LABORATORY, 1960. Erected with funds given by the Campbell Soup Company of Camden, New Jersey, and by the Health Research Facilities Branch of the National Institutes of Health, Bethesda, Maryland.

GORDON A. ALLES LABORATORY FOR MOLECULAR BIOLOGY, 1960. Erected with the gift of Dr. Gordon A. Alles of Pasadena, Research Associate in



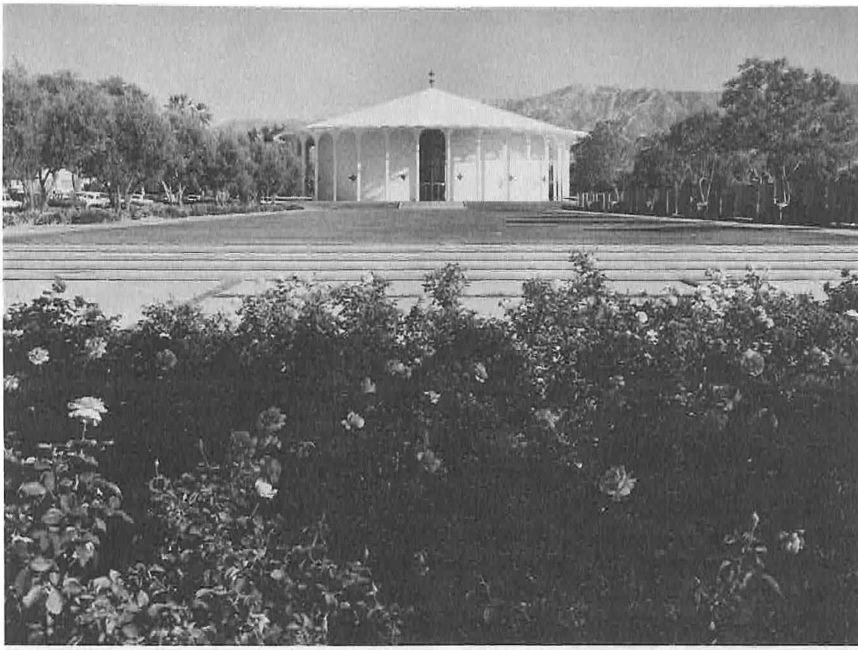
Henry M. Robinson Laboratory of Astrophysics

Biology at the Institute, an alumnus and a member of the California Institute Associates, 1947-1963; and with funds provided by the Health Research Facilities Branch of the National Institutes of Health.

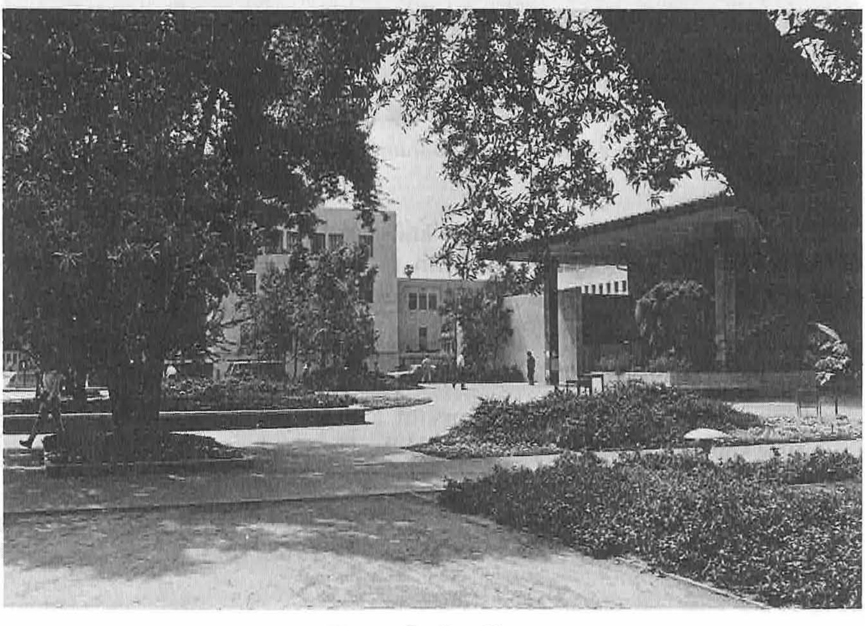
UNDERGRADUATE HOUSES, 1960. Erected with funds provided by the Lloyd Foundation and other donors to the Caltech Development Program.

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

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



Beckman Auditorium



Winnett Student Center

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

HARRY CHANDLER DINING HALL, 1960. The gift of the Chandler family, the Pfaffinger Foundation, and the Times Mirror Company of Los Angeles.

W. M. KECK ENGINEERING LABORATORIES, 1960. The gift of the W. M. Keck Foundation, and the Superior Oil Company of Los Angeles.

GRADUATE HOUSES, 1961:

Braun House. Erected 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.

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.

KARMAN LABORATORY OF FLUID MECHANICS AND JET PROPULSION, 1961. The gift of the Aerojet-General Corporation and named in honor of Dr. Theodore von Karman, 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.

WILLIS H. BOOTH COMPUTING CENTER, 1963. Erected with funds given by the Booth-Ferris Foundation of New York, and by the National Science Foundation. Named in memory of Mr. Willis H. Booth, a member of the California Institute 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, and is now chairman of the Board of Trustees.

HARRY G. STEELE LABORATORY OF ELECTRICAL SCIENCES, 1965. Erected 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. Erected with the gift of Dr. Seeley G. Mudd and named in honor of Dr. Robert Andrews Millikan, Director of the Bridge Laboratory of Physics and Chairman of the Executive Council of the Institute, 1921-1945.

ARTHUR A. NOYES LABORATORY OF CHEMICAL PHYSICS, 1967. Erected with funds provided by an anonymous donor and the National Science Foundation and named in honor of Arthur Amos Noyes, Director of the Gates and Crellin Laboratories of Chemistry and Chairman of the Division of Chemistry and Chemical Engineering, 1917-1936.

CENTRAL PLANT, 1967.

GEORGE W. DOWNS LABORATORY OF PHYSICS AND CHARLES C. LAURITSEN LABORATORY OF HIGH ENERGY PHYSICS, 1969. The Downs wing was erected with funds provided by George W. Downs and the National Science Foundation. The Lauritsen wing was erected with Atomic Energy Commission funds and named in honor of Dr. Charles C. Lauritsen, a member of the Institute faculty, 1930-1968.

BUSINESS SERVICES, 1969.

Off-Campus Facilities

KRESGE SEISMOLOGICAL LABORATORY, 1928 (of the Division of the Geological Sciences), 220 North San Rafael Avenue, Pasadena. Named in recognition of a gift from The Kresge Foundation of Detroit, Michigan.

WILLIAM G. KERCKHOFF MARINE BIOLOGICAL LABORATORY, CORONA DEL MAR, 1930. Rehabilitated with funds provided by the National Science Foundation in 1966.

PALOMAR OBSERVATORY, SAN DIEGO COUNTY, 1948. Owned by the Institute and, with the Mount Wilson Observatory, operated jointly by the Carnegie Institution of Washington and the Institute.

DONNELLEY SEISMOLOGICAL LABORATORY, 1957 (of the Division of the Geological Sciences), 295 North San Rafael Avenue, Pasadena. The gift of Mr. and Mrs. C. Pardee Erdman of Santa Barbara, The Kresge Foundation of Detroit, and the James Irvine Foundation of San Francisco. Named in honor of Mrs. Erdman's father, Mr. Reuben H. Donnelley.

OWENS VALLEY RADIO OBSERVATORY, near Bishop, 1958.

BIG BEAR SOLAR OBSERVATORY, Big Bear Lake, 1969. Built with funds provided by the National Science Foundation and the Max C. Fleischmann Foundation of Nevada.

LIBRARIES

The Robert A. Millikan Memorial Library houses the general administrative activities of the Institute's library system as well as the following divisional collections: biology, chemistry, engineering, humanities and social sciences, mathematics, and physics.

Millikan Memorial, completed in 1967, is a nine-story building with 63,000 feet of floor space. It has an eventual capacity of 400,000 volumes and provides seats for about 250 students. Book collections have been distributed throughout the building in such a way that each major subject has its own area and retains its identity and its close relationship with its parent academic division. Library administrative services are concentrated on the second floor; here also are the catalog of campus libraries and general reference and information services. The first floor reception area also houses the reserve book services. The various divisional collections are on floors three through nine. The basement contains a branch of the Institute's Graphic Arts facility with reproduction equipment, the Institute's archives, and mail and distribution facilities. A small microfilm reading room is located on the fifth floor. Millikan Memorial is open daily throughout the school year from 8 a.m. to 2 a.m. and during the summer from 8 a.m. to midnight.

In addition to this central library there are library collections elsewhere on campus in aeronautics, astrophysics, chemical engineering, electrical engineering, geology, hydraulics and environmental engineering, and industrial relations. The libraries collectively subscribe to about 4,600 journals and contain about 215,000 volumes.

THE INDUSTRIAL RELATIONS CENTER

The Industrial Relations Center was established in 1939 through special gifts from a substantial number of individuals, companies, and labor unions. Currently, its basic support is from the annual contributions of Sponsors. The objectives of the Center are to increase and disseminate a knowledge and understanding of the philosophies, principles, policies, and procedures affecting employer-employee relationships, including the motivation, development, compensation, and supervision of rank-and-file, professional, and managerial personnel, without duplicating unnecessarily the work of other organizations. Its program is guided by the Committee on the Industrial Relations Center, consisting of Trustees and Faculty.

The Center provides a variety of services to its Sponsors in return for their regular financial support: (1) The Center assists Sponsors in the development and self-development of (a) supervisors and other line or operating management at various levels and (b) members of the personnel administrative staff. This assistance is through regular meetings and conferences held on campus or through special programs developed for specific companies. (2) The Center helps representatives of Sponsors, who participate in special conferences and workshops, develop and improve specific personnel programs for use in their companies. (3) It counsels with representatives of Sponsors, on request, concerning individual company problems of management and personnel administration, but it does not consult or arbitrate. (4) The Center maintains a library of materials on industrial relations and management, with emphasis on the personnel practices of many companies. Reference assistance is available.

Each of these services supplements, and is supplemented by, the other services. As a result of its activities, the Center issues a variety of publications including bulletins, circulars, and research monographs.

One of its special services is conducting employee opinion polls for specific companies. The individual surveys have proved of value to organizations of various sizes in many industries. The general results supplement the other research and teaching activities of the Center.

The staff of the Center participates in the education of undergraduate and graduate students of the California Institute of Technology, stressing the fundamentals of management and employer-employee relations.

The increasing complexity and the rising labor costs of business operations have resulted in a growing recognition of the fact that a manager must know how to do the work being supervised and, in addition, he must know how to supervise – a separate and distinct function requiring other knowledge and skills.

The Center offers training in the field of managment in general and in the specialized field of personnel administration. Special attention is given to programs for technical supervisors and managers who function in engineering and research laboratories. Other series are designed for the first- and second-line supervisors of non-exempt employees. This wide range of courses is presented on a number of bases: on-campus or off-campus; full-time or part-time; and for representatives of a variety of companies, or specially designed for the management of a specific company. These courses do not carry academic credit.

The Center cooperates with a large number of trade and professional organizations and with other colleges and universities to pool resources and to avoid unnecessary duplication of effort. The Caltech Industrial Relations Center is affiliated with the Industrial Relations Center of The University of Chicago.

The office, library, and conference rooms of the Center are located on the campus at 383 South Hill Avenue, but the mailing address is Industrial Relations Center, California Institute of Technology, Pasadena, California 91109.

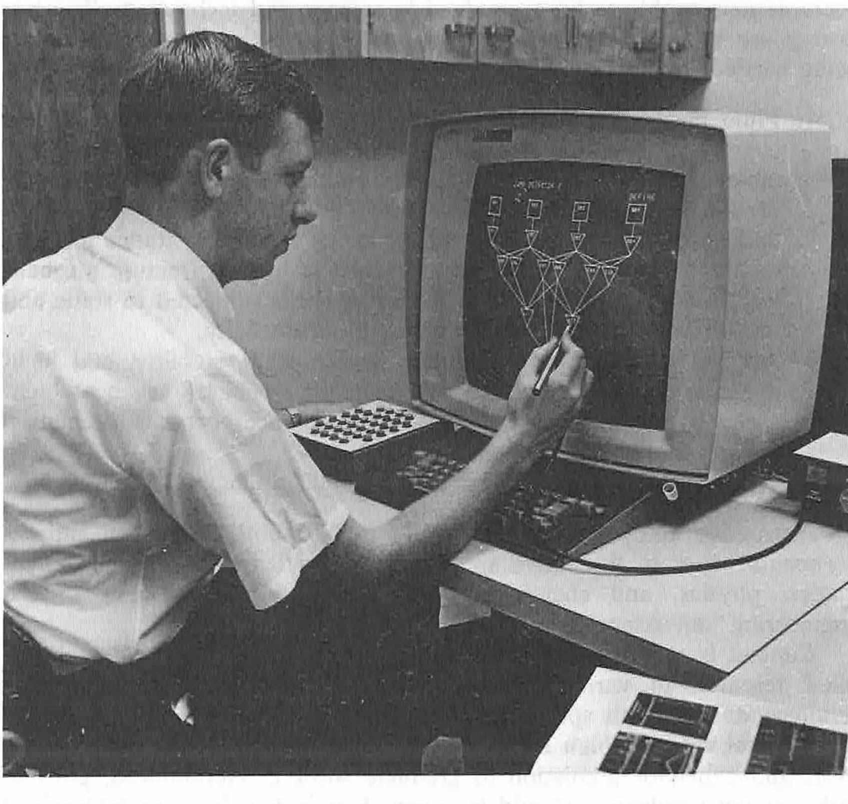
Detailed information about the specific services of the Center and the fees involved can be secured from the Director of the Industrial Relations Center.

THE WILLIS H. BOOTH COMPUTING CENTER

The Computing Center offers a comprehensive integrated set of facilities for the research and educational use of all divisions of the Institute.

One of these is an IBM 360/75 computer which, in addition to servicing batch processing functions, provides for a variety of user communication modes through 40 remote typewriter consoles at various locations on the campus.

Another important system mode of operation (in addition to production computing, compiling modes, and modes for directly collecting experimental data) employs a combination of communication media including keyboards and cathode ray display consoles. It emphasizes the use of richer, more general computers as adjuncts to human thought processes in the examination and conceptual analysis of data. This employs an IBM 360/44 computer.



AERONAUTICS

The Guggenheim Aeronautical Laboratory (1929), the Karman Laboratory of Fluid Mechanics and Jet Propulsion (1961), and the Firestone Flight Sciences Laboratory (1962) form the Graduate Aeronautical Laboratories, widely known as GALCIT. In this complex are housed the Applied Mathematics group, the Jet Propulsion Center, and part of the Hydrodynamics Laboratory, as well as the various disciplines making up the broad field known as Aeronautics.

Areas of Research

The traditional subject matter of aeronautics has been aerodynamics and aircraft structures; however, this field has expanded rapidly in recent years as new problems have emerged in science and technology. The following are typical areas in which graduate instruction and research are being carried out at GALCIT:

1. Fluid mechanics, including hydrodynamics and aerodynamics; mechanics of rotating or stratified fluids; turbulence; stochastic and molecular processes; low density and hypersonic gas dynamics; plasma physics, and fluid mechanics of liquid helium.
2. Solid mechanics, including properties of materials; statics and dynamics of elastic, plastic, and viscoelastic bodies; fracture mechanics; finite strain problems; buckling of shells subjected to static and impact loading; static and dynamic photoelasticity.
3. Applied aerodynamics, including performance, stability, and flight dynamics of aircraft, spacecraft, and other vehicles (such as high-speed ground vehicles); rocket performance; orbital mechanics; reentry mechanics and thermodynamics.
4. Jet and rocket propulsion and associated problems (see page 166).

Instruction and research at GALCIT include both theoretical and experimental work in the above areas, together with the underlying mathematics, physics, and chemistry which contribute to solutions of the engineering and scientific problems involved.

Contact is maintained with design problems in industry and with applied research in various research laboratories through three regular seminars and through special courses in subjects such as systems design and control theory which are not part of the standard curriculum. However, applicants for admission to graduate work in Aeronautics, particularly foreign applicants, should be aware that instruction and research at GALCIT emphasize fundamental fluid and solid mechanics and flight mechanics, rather than the detailed design and performance of aircraft,

aircraft structures, and propulsion systems. Additional breadth is given to research options through cooperation with other disciplines such as applied mathematics, applied physics, and environmental engineering science.

Physical Facilities

The Graduate Aeronautical Laboratories contain diversified facilities in support of the above programs. Low-speed wind tunnels are available for basic research on programs of low-velocity flow and for testing of aircraft, automobiles, and other devices and structures affected by flight or wind conditions. Problems of supersonic and hypersonic flows may be investigated in other tunnels specifically designed for such purposes. Shock tubes, plasma tunnels, and other special facilities are available for the study of extreme temperatures, rarefied and ionized gases, and cryogenic flow.

The solid mechanics laboratories contain standards and special testing machines for research in aircraft and spacecraft structures and materials under static and dynamic loads. Fatigue machines and photoelastic equipment are available. Special apparatus, including laser equipment and a number of high-speed cameras, is available for study of elastic waves, dynamic buckling, and the mechanics of static and dynamic fracture.

The laboratory facilities for jet propulsion and hydrodynamics are described in the section on Jet Propulsion (p. 166). Two of the water tunnels are housed in the GALCIT complex and their operation is integrated with the operation of the 10-foot wind tunnel.

The facilities of the Jet Propulsion laboratory may, under certain conditions, be used for research in aeronautics and jet propulsion. This off-campus laboratory is owned and supported by NASA and is administered by Caltech. In addition to its continuing effort in unmanned space exploration, JPL has recently initiated programs in urban transportation and air pollution. Among the experimental facilities are space-environment simulators, large supersonic and hypersonic wind tunnels and test cells for rockets and thermal jets, as well as facilities for the study of refractory materials, hydraulics, combustion and other chemical processes. With the support of discretionary funds administered by the President of Caltech and by the Director of JPL, several investigations by Caltech faculty and graduate students are currently in progress.

APPLIED MATHEMATICS

General Description

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

This program is a joint effort of the Division of Physics, Mathematics and Astronomy and the Division of Engineering and Applied Science. Students majoring in applied mathematics are enrolled in either division and the professors of applied mathematics are also in these two divisions. Further, professors from various other divisions take part supervising research and offering courses of special interest. Close contact is maintained with experimental programs in fluid and solid mechanics. The present program is a graduate one leading mainly to the Ph.D. degree. The curriculum consists in two types of courses: those which survey the methods used in applied mathematics, and those which 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, stochastic processes, linear programming, numerical analysis of partial differential equations, group theory applied to physics, and advanced elasticity. Further, by study outside of applied mathematics each student is expected to become competent in some special physical or non-mathematical field. In this way subjects for research appear naturally, and a broad educational program is provided. In addition to the connections mentioned above, especial notice should be taken of the existence of a computer and information science group at Caltech which provides the chance for practical experience with the most modern computers and further fields of research. Library facilities are excellent, comprising all the journals, a complete general library, and a special research library in applied mathematics.

The present group primarily interested in applied mathematics consists of approximately twenty-five students and eight professors. Also, each year many distinguished visitors come either to present lectures or remain in residence for larger parts of the academic year. There is much stimulating activity in the form of research, courses, working seminars, and colloquia. Applied mathematics at Caltech is a living and growing activity.

Areas of Research

Research is particularly strong in fluid dynamics (including magnetohydrodynamics, plasma physics, and kinetic theory), elasticity, dynamics and celestial mechanics, numerical analysis, differential equations, integral equations, asymptotic methods, and other 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, dynamics and mechanical vibrations, stability and control, and certain areas in the fields of propulsion, and heat transfer.

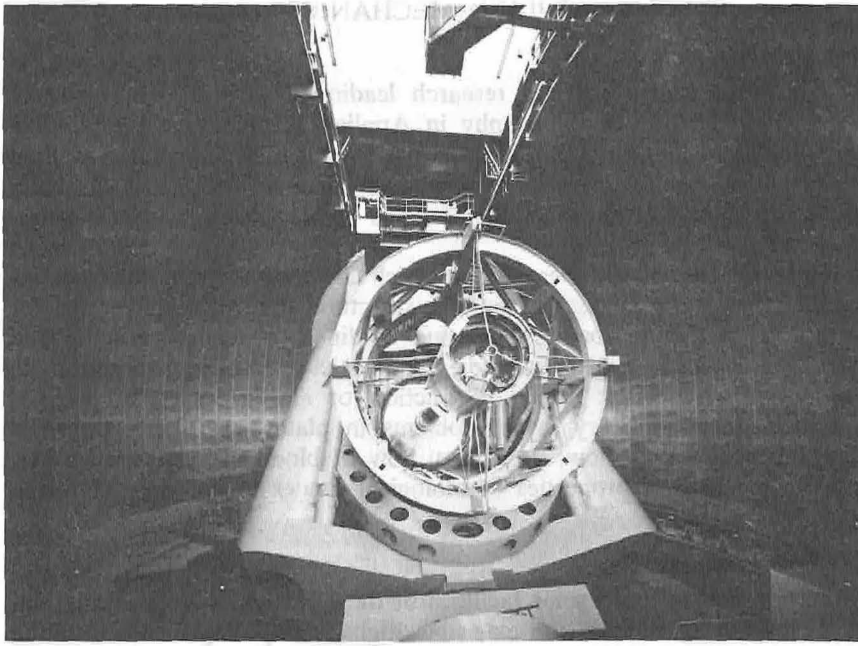
Research studies in these areas which illustrate current interests include: linear and nonlinear vibrations, structural dynamics and design for earthquake and blast loads, linear and nonlinear problems in static and dynamic elasticity, plasticity and viscoelasticity, wave propagation in elastic and viscoelastic media, diffraction of elastic waves by cavities and inclusions, boundary layer problems in plates and shells, stratified flow, unsteady cavity flow, oscillatory flow of blood in very small tubes, and the mechanical properties of biological tissues under large deformations.

Research Facilities

In addition to the regular facilities of the Division of Engineering and Applied Science, such as the extensive digital computing facilities of the Computing Center, and the special facilities for studies in solid and fluid mechanics of the Graduate Aeronautical Laboratories, certain special facilities have grown up in connection with applied mechanics activities. The Dynamics 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 the analysis of complex transient loading problems, and for the recording and analysis of strong-motion earthquakes. Other specialized laboratories include the Heat Transfer Laboratory, which contains a forced convection heat transfer loop, and the Hemorheology Laboratory with equipment for quantitative study of blood flow in living microvessels and related model systems and of the mechanical properties of biological tissues.

APPLIED PHYSICS

A program of study in applied physics is being organized jointly by the Division of Engineering and Applied Science and the Division of Physics, Mathematics and Astronomy. Both an undergraduate option leading to the Bachelor of Science degree and a course of graduate study leading to the Ph.D. degree are being planned. This program will provide students with the necessary background and training for pursuing careers in the application and extension of modern and classical physics concepts to developing technologies.



A special bulletin describing the details of the graduate program in applied physics will be published in the fall of 1970. Interested students should write to the Dean of Graduate Studies for further information.

ASTRONOMY

The Mount Wilson and Palomar Observatories constitute a unique and unprecedented concentration of scientific facilities in astronomy. Outstanding scientific talent is present both in the field of astronomy and in the related fields of physics. The California Institute of Technology and the Carnegie Institution of Washington recognized the advantages in the creation of a great astronomical center in which a unified scientific program would be pursued under favorable circumstances, and which would draw young men of ability to graduate studies where they might familiarize themselves with powerful tools of exploration. The two observatories function as a single scientific research organization, as the Hale Observatories. All the equipment and facilities of both observatories are made available for the astronomical investigations of the combined staff and students. The unified research program is paralleled by undergraduate and graduate training in astronomy and astrophysics by members of the Institute faculty, the staff of the Hale Observatories, the Radio Observatory, and the new Solar Observatory at Big Bear Lake.

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. Work in physics and geology is expanding in the field of astronomical research in space and in the ground-based study of the planetary system. There will be 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, astrophysics, and radio astronomy, unsurpassed opportunities exist at the California Institute for advanced study and research. The instructional program is connected with a broad and thorough preparation in physics, mathematics and other relevant subjects, as well as instruction in astronomy, solar physics, planetary physics, radio astronomy, astrophysics, and observations with large telescopes.

Areas of Research

Both observational and theoretical astrophysics are actively pursued at Caltech. Topics of current interest in optical astronomy include chemical abundance of normal and peculiar stars, spectroscopic and spectrophotometric studies of quasars, compact and Seyfert galaxies and related objects; 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.

In addition, active research in infrared and planetary astronomy is done in cooperation with groups in Physics and Geology.

The research in radio astronomy covers the physical properties of galactic and extragalactic radio sources including quasars, radio galaxies, supernova remnants, pulsars and the planets. The properties of the interstellar medium in our own and other nearby galaxies are investigated in spectroscopic studies of the 21 cm hydrogen line and various 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 atmospheres, interstellar and intergalactic matter, the physics of radio sources, nucleosynthesis, relativity, and cosmology.

Physical Facilities

The Rockefeller Boards provided in 1928 for the construction by the Institute of an astronomical observatory on Palomar Mountain, equipped with a 200-inch reflecting telescope, 48-inch, and 18-inch Schmidt wide-angle telescopes, and other auxiliary instruments, together with an astrophysical laboratory on the Institute campus. This observatory is supplemented by the facilities of the Mount Wilson Observatory of the Carnegie Institution of Washington, which, while not a part of the California Institute, is located even closer to Pasadena than is Palomar Mountain. Much of the graduate student thesis research is carried out at Mount

Wilson. The increased light-collecting power of the 200-inch telescope permits further studies of the size, structure, and motion of the galactic system; of the distance, motion, radiation, composition, and evolution of the stars; the interstellar gas; the distance, motion, and nature of remote galaxies and quasi-stellar radio sources; and of many phenomena bearing directly on the constitution of matter. The 48-inch Schmidt has made possible a complete survey of the sky, as well as an attack upon such problems as the structure of clusters of galaxies, the luminosity function of galaxies, extended gaseous nebulae, and the stellar content of the Milky Way. These two unique instruments at Palomar supplement each other as well as the telescopes on Mount Wilson; the one reaches as far as possible into space in a given direction, while the other photographs upon a single plate an entire cluster of distant galaxies, or a star cloud in our own galaxy.

A new multi-purpose solar equatorial telescope has been installed at a new observing station at Big Bear Lake. The work of this facility will be coordinated with work with the two solar coelostats in Pasadena (20-inch and 36-inch apertures) and the 60-foot and 150-foot towers on Mount Wilson. 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 new 60-inch telescope is being completed for photoelectric observations at Palomar, and an astroelectronics laboratory is continuously developing sophisticated data-handling systems.

Another new installation on Mount Wilson is a special-purpose, 62-inch infrared telescope used to study very cool stars and planets. Special apparatus for the far infrared has been fitted to various telescopes.

Work in radio astronomy was begun at the Institute in 1956 with the founding of the Owens Valley Radio Observatory, near Big Pine, 250 miles north of Pasadena. Research instruments include a 32-foot paraboloid and a pair of very accurate 90-foot paraboloids. The two 90-foot radio telescopes are used together as a variable-spacing interferometer for studies of all aspects of discrete radio sources at centimeter and decimeter wavelengths. Construction of a 130-foot radio telescope has been completed; this instrument is the prototype unit for an eight-element, variable-spacing interferometer array which has been proposed for construction at the Radio Observatory. The array, when completed, will permit studies of the most remote radio sources with a resolution approaching that of the largest optical telescopes. Until further elements of the array are completed, the first 130-foot telescope is used in interferometric combinations with the two 90-foot telescopes and by itself for high-resolution, pencil-beam studies at centimeter wavelengths.

The Owens Valley Radio Observatory constitutes one of the most advanced facilities for research in this rapidly-growing field. Sensitive receivers, maser amplifiers and sophisticated techniques for digital recording and analysis of data permit study of the positions, spatial distribution, polarization and other physical properties of the most distant radio galaxies and quasi-stellar sources. Similar studies may be made of the radio emission from most of the planets. Multi-channel filter banks permit work on radio spectral lines.

Theoretical studies are facilitated by an IBM 360 Model 75 for batch processing and a Model 50 for time-shared conversational computing, both operated by the Computing Center.

BIOLOGY

The 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, and chemistry are providing deep insight into basic biological problems such as the manner in which molecules, genes, and viruses multiply themselves; the nature of enzyme action and of enzymatic pathways; the organization of cellular activity; the mechanisms of growth and development; and the nature and interactions of nerve activity, brain function, and behavior. There is increasing demand for experimental biologists; qualified individuals will find opportunities for challenging work in basic research and in the applied fields of medicine, agriculture, and the chemical or pharmaceutical industries.

Because of the eminent position of the California Institute of Technology in both the physical and biological sciences and the current expansion of our programs in the study of behavior and experimental psychology, 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, experimental psychology, genetics, immunology, neurophysiology, psychobiology and virology. Most of these fields are approached at the molecular as well as higher levels of organization. The disciplines of biochemistry and biophysics encompass most directly and professionally the area of molecular biology. There is extensive interaction with relevant programs in chemical biology within the Division of Chemistry.

The programs in cell and developmental biology are based upon approaches derived from biochemistry, biophysics and genetics which offer new possibilities for expanded insight into long-standing problems.

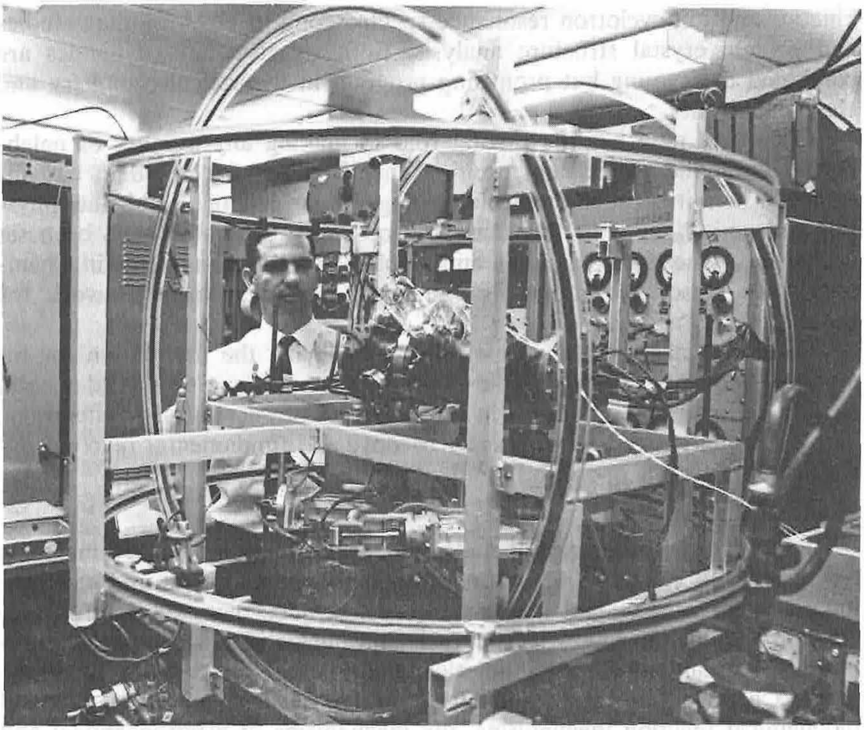
Neurobiology, experimental psychology and behavioral biology are receiving increasing emphasis within the Division. A comprehensive program of research and instruction has been formulated to span the disciplines from neuron physiology to the study of animal and human behavior. Expansion and development of this program are in process. Related developments in the Divisions of Engineering, and Humanities and Social Science serve to fortify doctoral programs concerned with the study of brain and behavior.

Physical Facilities

The campus biological laboratories are housed in three interconnected buildings, the William G. Kerckhoff Laboratories of the Biological Sciences, the Gordan A. Alles Laboratory for Molecular Biology, and the Norman W. Church Laboratory for Chemical Biology. The three laboratories contain classrooms and undergraduate laboratories, an annex housing experimental animals, and numerous laboratories equipped for biological, biochemical, biophysical, physiological, and psychological research at the graduate and doctoral level. The constant-temperature equipment includes rooms for the culturing of the Institute's valuable collection of mutant types of Drosophila and Neurospora and complete facilities for plant and animal tissue culture.

Adjacent to the campus the Plant Research Center consists of the Campbell Plant Research Laboratory, and the Dolk and Clark Greenhouses.

About 50 miles from Pasadena, at Corona del Mar, is the William G. Kerckhoff Marine Laboratory. The building houses several laboratories for teaching and research in marine zoology, embryology, and physiology. It is equipped with its own shop, has boats and tackle for collecting marine



animals, and running seawater aquaria for keeping them. The proximity of the marine station to Pasadena makes it possible to supply the biological laboratories with living material for research and teaching. The fauna at Corona del Mar and at nearby Laguna Beach is exceptionally rich and varied, and is easily accessible. In 1966 the Laboratory was extensively rehabilitated for work in modern biology.

The Biological Systems Laboratory in the Booth Computing Center houses the joint research program of the Biology and Engineering Divisions dealing with data processing systems and systems theory as they relate to the nervous system and sensory perception.

CHEMISTRY

Caltech has long had a reputation for preeminence in chemistry in the areas of molecular structure and the nature of chemical bonding. It has benefited from the close cooperative relationships it shares with Biology. More recent is the development of programs aimed at understanding the nature of chemical reactions: chemical kinetics and dynamics. These interests are reflected in a broad range of research, from molecular beam kinetics and ion cyclotron resonance spectroscopy to DNA binding studies and protein crystal structure analysis. Both structure and dynamics are combined in a young but promising program in theoretical chemistry and chemical physics.

Chemistry now has the pivotal role of making any number of neighboring disciplines work, and exciting chemistry will be found in circumstances where it is called molecular biology, lunar geology, solid state physics, and cosmology. For this reason, cooperative programs have been set up between Chemistry, Biology, and Geology. Graduate students in Chemistry with reasonable proposals can cross divisional lines to work for non-chemistry faculty.

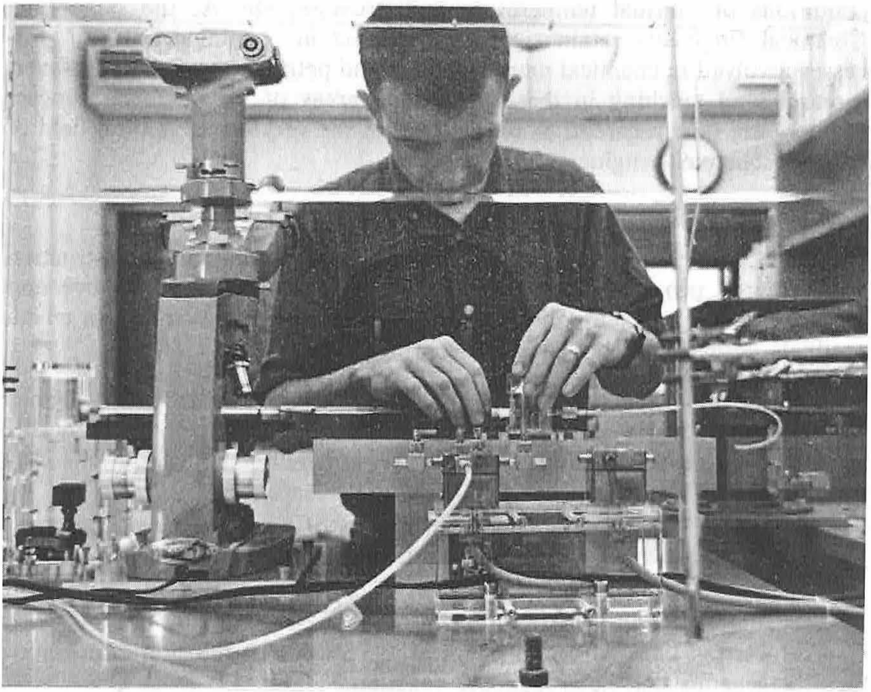
Chemistry also has the responsibility of laying the foundation for tomorrow's advances in other fields. For this reason, we have fundamental research efforts, among others, in synthetic and physical organic chemistry, electronic energy transfer and spectroscopy, and fundamental reaction dynamics.

Areas of Research

1. Structural chemistry, including x-ray diffraction, nuclear magnetic resonance and electron-spin resonance spectroscopy, optical and electron-impact spectroscopy, and mass spectrometry. Substances under study include crystalline enzymes, nucleic acids and nucleotides, intermetallic compounds, inorganic chelates, antibiotics, and liquids.
2. Chemical dynamics, including studies of organic, inorganic, and biochemical reaction mechanisms, the mechanisms of electrochemical and photochemical processes, and molecular beam kinetics.
3. Theoretical chemistry, involving molecular quantum mechanics, computer "experiments" in chemical kinetics, and the theory of relaxation processes.
4. Biochemistry and molecular biology, including studies of oxidative and proteolytic enzymes, the determination of amino acid sequences and three-dimensional structures of proteins, the systematic modification of proteins, the physical chemistry of solutions of DNA and other macromolecules, immunochemistry, and the fundamental processes of photosynthesis.
5. Synthetic chemistry, with recently increased emphasis on the synthesis of natural products and also including synthesis of theoretically interesting small molecules. In addition, research on the synthesis of new transition-metal and rare-earth complexes is under way.

Physical Facilities

The laboratories of chemistry consist of five units. Gates Laboratory and Gates Annex are the gift of Messrs. C. W. Gates and P. G. Gates. Crellin Laboratory affords space approximately equal to that of the first two units and is the gift of Mr. and Mrs. E. W. Crellin. The Norman W. Church Laboratory for Chemical Biology is shared equally with the Divi-



sion of Biology. The new Arthur Amos Noyes Laboratory of Chemical Physics is the largest of the chemical laboratories and was built with funds supplied by the National Science Foundation and an anonymous donor.

The first three units include laboratories and other facilities for undergraduate and graduate instruction and research in inorganic, analytical, and organic chemistry. Church Laboratory is used primarily for research on the applications of chemistry to biological and medical problems. The Noyes Laboratory of Chemical Physics has space to house large and complex instruments and contains the undergraduate instructional laboratory in physical chemistry. Research in chemical physics and physical inorganic chemistry is carried out in this new building. These five laboratories provide space for about 225 graduate students and postdoctoral fellows.

CHEMICAL ENGINEERING

The research and teaching interests of the Chemical Engineering Faculty are directed towards broad applications of chemical principles, and to the design, understanding, and improvement of large-scale chemical systems. This leads the faculty and students into problems as diverse as the chemical processes carried out in various organs of the body, the chemistry of polluted atmospheres, synthesis and behavior of materials under conditions of unusual temperature and pressure, etc. At the same time Chemical Engineers retain significant interest in the engineering of processes involved in chemical manufacturing and petroleum refining; however, research and teaching in these traditional areas of the chemical process industry are now regarded as only a part of the very broad natural field of study in chemical engineering.

Areas of Research

The Chemical Engineering program is well equipped for instruction and research programs leading to the degrees of Master of Science and Doctor of Philosophy in Chemical Engineering. The major areas in which graduate research is currently concentrated are:

1. Reaction kinetics and combustion, including both homogeneous and catalytic oxidation reactions and reactions involving oxides of nitrogen and hydrocarbons in parts-per-million concentrations. Design of periodically operated catalytic reactors.
2. Liquid state physics involving studies of forces and configurations at the molecular level in simple systems; determination of structure by x-ray diffraction; other studies of local order by optical, magnetic, and ultrasonic experiments; statistical mechanics.
3. Plasma chemistry and engineering, including diffusion and homogeneous and heterogeneous reaction.
4. Dynamics and control of chemical systems; application of estimation techniques to the filtering and control of stochastic dynamic systems.
5. Mechanics of suspensions and dispersions; chemistry and physics of aerosols.
6. Air pollution studies including simulation and control; atmospheric chemical reactions; atmospheric fluid mechanics; computer simulation of the urban atmosphere; coupling of chemical and physical rates in furnaces; oscillatory combustion.
7. Turbulent transport in gases at moderate Reynolds numbers.
8. Mechanical and ultimate properties of polymers, particularly filled elastomers and block copolymers. Mechanical properties of dialysis membranes; behavior of elastomers under pressure; physics of elastomer networks.
9. Solid-state chemistry and physics involving the use of high pressure to determine the effect of changing the interatomic distance in a solid on its chemical and electronic properties.
10. Biomedical problems especially involving transport studies.
11. Theoretical and experimental fluid mechanics; rheology of suspensions.

Physical Facilities

Chemical Engineering is housed in the Eudora Hull Spalding Laboratory of Engineering. The laboratories are well equipped both for instruction and for research and include the following major sub-divisions:

The Kinetics Laboratory, which contains several research-scale chemical reactors, chiefly of the flow type, and appropriate equipment for the measurement of pressures, temperatures, and flow rates. Extensive use is made of gas chromatography for analysis.

The Liquid-State Physics Laboratory, which is equipped for x-ray diffraction measurements on cryogenic fluids at moderate pressures. Apparatus is also available for refractive index, ultrasonic velocity and absorption, light scattering, and magnetic experiments over a range of temperature and pressure.

The Plasma Chemistry Laboratory, which includes equipment for the generation of various equilibrium and non-equilibrium plasmas. Associated diagnostic equipment includes spectrometers, microwave cavities, and Langmuir probes.

The Polymer Laboratory, which has extensive apparatus for the study of the mechanical behavior and the failure properties of polymeric materials under both uniaxial and multiaxial loads. Apparatus for polymer synthesis and characterization as well as molding and casting equipment for specimen preparation is also available.

The High Pressure Laboratory, which is equipped to study the effects of pressures up to several million psi on solids using electrical and magnetic techniques including nuclear magnetic resonance.

CIVIL ENGINEERING

Civil engineering is a branch of engineering covering a broad spectrum of interests concerned with man's relationship to the environment. Problems which the profession is called upon to handle range from the analysis of structures subjected to earthquake loadings to wastewater reclamation or disposal, from arctic soil problems to sediment transportation in streams.

Advances in recent years in the general field of engineering have encouraged a reappraisal of civil engineering education and increased the scope of research in that field. New problems have presented exciting challenges to the civil engineer well trained in the fundamentals of his profession. For this reason, in the advanced study of civil engineering at the Institute, emphasis is placed on the application of basic scientific principles and mathematics to the solution of civil engineering problems.

Areas of Research

Graduate work leading to advanced degrees is chiefly in the following fields: structural engineering and applied mechanics; earthquake engineering; soil mechanics and foundation engineering; hydraulics, which includes hydrodynamics, hydraulic engineering, hydrology and coastal engineering; and environmental health engineering (see also Environmental Engineering Science). In recent years, graduate students and members of the staff have pursued a variety of research programs including analysis of structures subjected to earthquakes and other dynamic loadings; the use of digital computers for structural analysis; soil deformation under stress; lunar soils studies; permafrost; investigation of laws of sediment transportation and dispersion in streams; turbulent mixing in density stratified flows; wave-induced harbor oscillations; design criteria for various hydraulic structures; aerosol filtration; radioactive waste disposal; water reclamation; and the disposal of wastes in the ocean.

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, the dynamics and vibrations laboratory, and an analog computer laboratory, and the W. M. Keck Engineering Laboratories which contain the laboratory of hydraulics and water resources and the environmental health engineering laboratory.

Excellent digital computing facilities are housed in the Booth Computing Center Building.

ELECTRICAL ENGINEERING

Electrical engineering at the Institute is a growing, dynamic field. It has expanded into several diverse and exciting areas. New materials and techniques are being applied in a wide variety of studies, including plasma dynamics, electromagnetic radiation, quantum electronics, new solid state materials and devices, circuit function design. The broad spectrum of problems falling within this branch of engineering provides exceptional and challenging opportunities for both theoretical and experimental work.

Areas of Research and Physical Facilities

Laboratory facilities are available for a wide variety of research activities. At present electrical engineering activities are housed mainly in one building, the Harry G. Steele Laboratory of Electrical Sciences. This is a modern, 55,000-square-foot laboratory building designed specifically for the research needs of the electrical engineering faculty and students.

The Plasma Laboratory is involved in studying wave phenomena in plasmas and methods of producing laboratory plasmas. Facilities are available for the generation and diagnosis of a variety of plasmas. Current studies involve theoretical and experimental investigations of microwave radiation from plasmas, echoes in plasmas, and wave propagation.

The Antenna Laboratory is a center for the mathematical study of problems in electromagnetic theory. Its activities include problems in antenna theory, scattering theory, the propagation of waves in continuous moving media, boundary-value theory for moving boundaries, shielding theory, and problems in cosmical electrodynamics.

The Quantum Electronics Laboratory is engaged in research in the area of generation and control of coherent radiation and in the study of related physical phenomena. Research projects now in progress include: Superradiance in extremely high gain lasers, generation and control of chirped ultrashort pulses, tunable optical parametric oscillation, integrated optical circuits, injection lasers, non-linear optics, optical data processing, and holography. Up-to-date facilities for carrying out these experiments are available.

The Solid State Electronics Laboratories engage in studies of the physical properties of solids, device electronics, and circuit applications. Research projects now in progress include tunneling phenomena in thin dielectric layers, generation of infrared radiation in small-gap semiconductors, recombination noise and injection mechanisms in semiconductors, and generalized theory of field-effect and diffusion transistors.

The Electronic Circuits Laboratory deals with modern problems in analysis, design, and synthesis of electronic circuits. Applications of new

and current devices and analysis techniques for a better understanding of existing devices are emphasized. Facilities are available for experimental confirmation of theoretical results over a wide frequency range. Projects now in progress include analysis and design of multiple-loop feedback systems, and optimization of pulse-width controlled regulators.

Research in the Magnetics Laboratory centers around the investigation of ferromagnetic anisotropy and flux reversal, the two effects which are the basis of modern digital magnetic devices. Anisotropy studies in thin films of nickel, iron, cobalt, and gadolinium alloys are concerned with both field-induced and magneto-crystalline anisotropy, with a goal of understanding both the origin and consequences of the anisotropy. Studies of the flux-reversal mechanism in films and toroids and ferromagnetic resonance experiments are used to investigate the loss mechanism in ferromagnetically ordered atomic structures.

ENGINEERING SCIENCE

Advanced programs of study leading to the degree 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 the traditional barriers between engineering and what was once called "pure science" have disappeared. Engineers are quick to learn of new research in plasma dynamics or the kinetic theory of gases, while designers of nuclear reactors may find it worthwhile to look into the distribution of nuclear energy levels, the theory of dynamical stability, or the motion ot charged particles in solids. In the past these subjects lay exclusively in the domain of university departments of physics and mathematics.

Areas of Research

The study program of the Engineering Science student at Caltech emphasizes physics, applied mathematics, and those scientific disciplines which underlie the current development of technology. Its scope contains a broad range of subjects. Fields of study may include such topics as fluid mechanics with applications to geophysical and biomechanical problems, physics of fluids, structure and properties of solids, dynamics of deformable solids, rheology of biological fluids, plasma physics, the physics underlying nuclear reactors, fission and fusion engineering, and information science.

INFORMATION SCIENCE

Areas of Research

Information Science can be described as a number of scientific interests which are gathered around the study of information processing. These can be classified broadly as follows along lines reflecting the research and educational interests of the associated faculty:

Mathematical theory of languages and the synthesis of information processing systems.

Computational mathematics and the analysis of data.

Information processing in living systems.

Physical Facilities

Research laboratories important to this field are the Willis H. Booth Computing Center and the Biological Systems Laboratory. This laboratory contains facilities for research on living nervous systems. It is close to and integrated with the Willis H. Booth computer facilities and includes newly developed experiment control and data analysis systems. In addition, special facilities have been developed for advanced research on stimulus and response instrumentation. Present experimental research is concentrating on the sensory and motor nervous systems of insects and the visual systems of vertebrates, including humans.

BIOLOGICAL ENGINEERING SCIENCES

Graduate study and research in areas involving the application of the engineering sciences to problems of health and biology are of continually increasing importance at the California Institute of Technology.

Areas of Research and Physical Facilities

The primary areas of interest at present are in the fields of biosystems, environmental health engineering, transport processes, and circulatory mechanics. Close cooperation exists among the different groups, and joint seminars are held frequently.

Environmental Health Engineering. The environmental health group is concerned with the protection and control of our air environment and water supplies, now under increasing strain because of population growth and industrial expansion. Several of the research projects under way in this program have significant biological components.

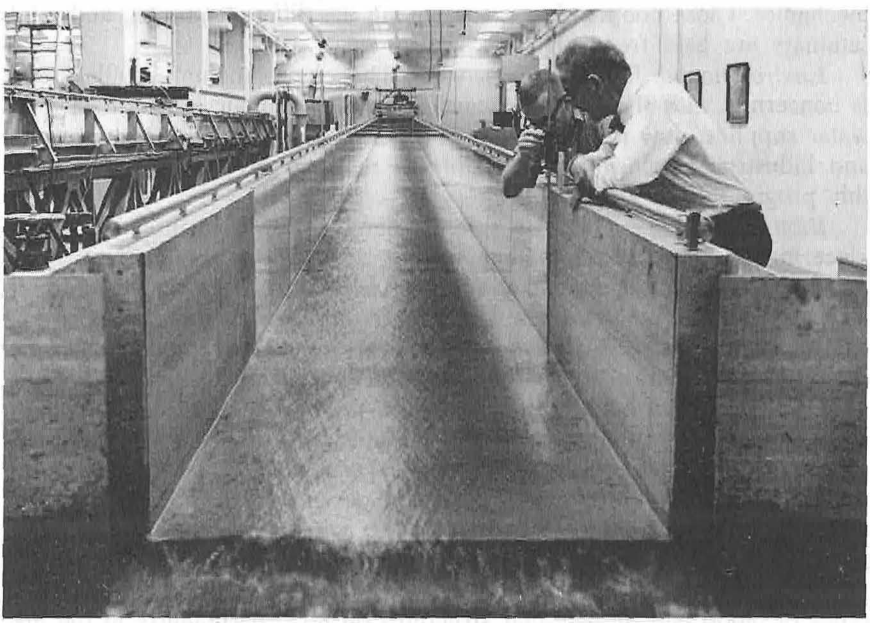
Biomedical Transport Processes. Research in this field in chemical engineering and environmental engineering science has application to the design of artificial organs and to other problems involving the handling of biological fluids, and to certain aspects of respiratory physiology. A recent study of gas exchange with flowing blood has immediate application to the design of membrane oxygenators (artificial lungs) employed in heart surgery. Other studies have been initiated on the development of mathematical models for the prediction of particle and gas transport in the lungs. A collaborative effort between the chemical engineering group and local medical institutions on some aspects of the design of the artificial kidney is also under way. Blood gas instruments are available as well as the other facilities of the Environmental Health Engineering Laboratory.

Circulatory Dynamics. Studies on the effects of the rheological properties of blood and the vascular structures on flow, particularly in the microcirculation, are being carried on in collaboration with the L. A. County Heart Association-University of Southern California Cardiovascular Research Laboratory. Research is in progress at Caltech on the flow of blood in tubes of diameters in the size range of interest in microcirculatory studies (5 to 200 micra) and in living microbeds in small animals. This research is correlated with blood flow studies made with larger animals in collaboration with the Cardiovascular Laboratory located at the L. A. County-USC Medical Center, about nine miles from Caltech.

The Hemorheology and Microcirculation Laboratory, located in the sub-basement of the Thomas Engineering Laboratories, is equipped with an unusually versatile precision animal table and intravital microscope system for quantitative measurements in living microbeds of velocity, vessel dimensions and pressure drop. Additional facilities for still and cine photomicrography permit the study of blood rheology in flow in small tubes. Methods have also been developed for measuring the mechanical response of biological tissues and of small blood vessels.

ENVIRONMENTAL ENGINEERING SCIENCE

This new interdisciplinary graduate program is concerned with the protection and control of man's environment; historically, it has grown from activities in air and water pollution control which have been in existence at Caltech for many years.



Research and education in the environmental field stress basic studies which can help answer such questions as: How can we improve the quality of the air in the great basin areas in which lie our urban and industrial centers? How can we insure the availability of water of adequate quality and quantity for population centers and industry? How can we protect our off-shore waters from pollution? How can thermal pollution from power plants be controlled? How does a polluted environment affect man's health? How does society make decisions about environmental control measures, and allocate the costs?

The academic disciplines of importance include the chemistry of natural waters and of the atmosphere; the physics and physical chemistry of disperse systems; biological fluid mechanics; biomedical transport processes; marine biology and ecology; fluid mechanics of the natural environment; hydrology; sedimentation and erosion; the theory and design of complex environmental control systems; combustion; environmental modeling and information systems; and environmental economics. Courses in these fields are offered in the environmental engineering science program and in other departments of the Institute.

The majority of the faculty members in this interdisciplinary program are from the Division of Engineering and Applied Science. There is also participation from the Divisions of Chemistry and Chemical Engineering, Humanities and Social Sciences, Geological Sciences, and Biology.

Areas of Research

Examples of recent and current research are: the development of chemical reactor models for urban air basins; the use of polymers in the removal of particulates from natural waters; dispersion of contaminants in rivers and estuaries; mixing of buoyant jets in lakes and oceans; generation and propagation of tsunamis; the effects of pollution on the ecology of nearshore waters; kelp restoration; the development of economic methods for wastewater reclamation; the investigation of the interaction of beams of small particles with surfaces at reduced pressures; particle deposition in lungs; gas exchange with blood; rheology of blood in small tubes and microcirculation; low pollution vehicles; and power-plant siting.

Physical Facilities

Facilities in the W. M. Keck Laboratory of Environmental Health Engineering include a Zeiss electron microscope (together with associated equipment for preparation of electron micrographs), a Coulter particle size analyzer, and an ultracentrifuge. A condensation nuclei counter and other instruments for studies in aerosol physics are available. A well-equipped chemical instrumentation laboratory is maintained with facilities for tracer studies including a liquid scintillation detector. Facilities for microbiological work include incubators, constant temperature rooms, autoclave, microscopes, and lesser equipment.

The W. M. Keck Laboratory of Hydraulics and Water Resources is well equipped for research into a wide variety of fluid flows which are important in environmental control. The facilities include large flumes for studies in diffusion, turbulence, sediment transport, and stratified flow; a wave tank and wave basin; a water tunnel; and specialized instrumentation, such as a digital data-processing system to record experimental analogue data directly on digital tapes for high-speed computing.

The Hemorheology Laboratory, located in the sub-basement of the Thomas Engineering Laboratories, is equipped with an unusually versatile precision animal table and intravital microscope system for quantitative measurements in living microbeds of velocity, vessel dimensions and pressure drop. Additional facilities for still and cine photomicrography permit the study of blood rheology in flow in small tubes. Blood flow studies with larger animals are done in collaboration with the Cardiovascular Laboratory located at the L.A. County-USC Medical Center, about nine miles from Caltech.

The W. G. Kerckhoff Marine Laboratory, operated by the Division of Biology, at Corona del Mar (50 miles from Pasadena), is the base for the work in marine ecology. Running sea water with temperature control is available, as well as a diving vessel, scuba gear, workshop, darkroom, aquarium, dry labs, and a small library and reference collection. The marine laboratory has four apartments for visiting researchers.

Except for the marine laboratory, the facilities described above are part of the Division of Engineering and Applied Science, which is the principal sponsor of the program. Students may also elect to do thesis research in appropriate laboratories in other divisions of the Institute with professors who participate in this interdisciplinary program.

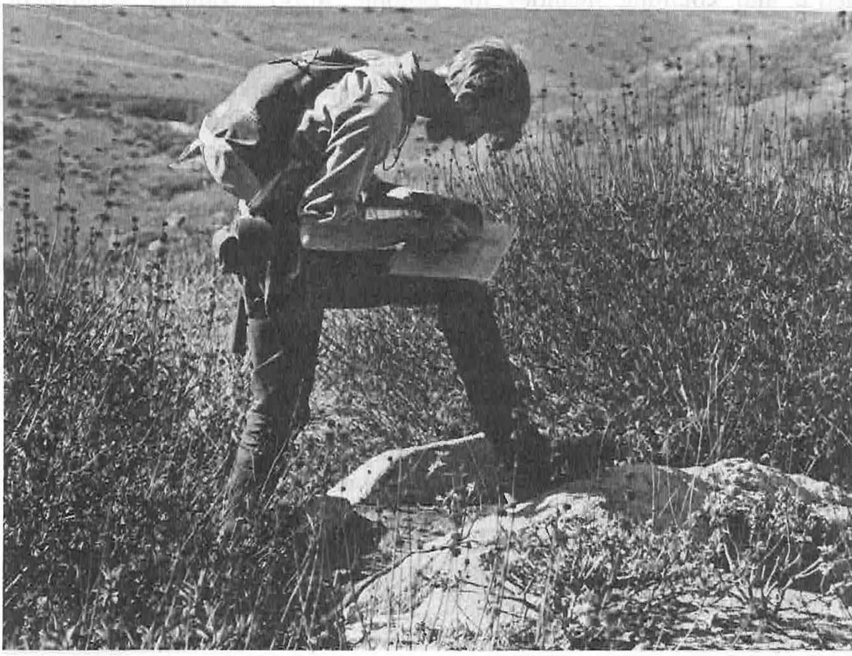
GEOLOGICAL AND PLANETARY SCIENCES

The Division of Geological Sciences is closely allied with the other active and creative fields of science and engineering at Caltech. Accordingly, a favorable intellectual atmosphere exists for education and research in geology, geobiology, geochemistry, geophysics, and planetary science. The geographical position and geological setting of the Institute are nearly ideal for students and research workers, who can derive materials, ideas, and inspiration from the wide variety of easily accessible field environments.

The student body is purposely kept small and usually consists of no more than 60 graduate students and 15-20 undergraduates. The small size of the student group and large size of the staff give a highly favorable ratio of students to staff and result in close associations and contacts which enhance the value of the educational program.

Areas of Research

The staff represents a variety of allied and integrated interests and is active in both teaching and research.



Physical Facilities

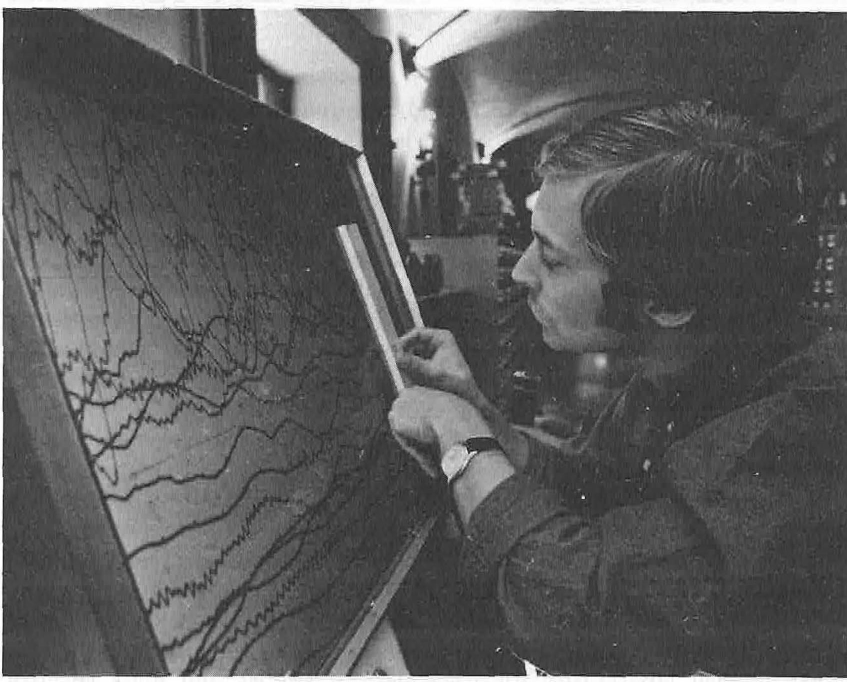
Physical facilities, both natural and man-made, are excellent. All the classroom instruction and most of the laboratory research in geology and geochemistry, as well as part of that in geophysics, are carried on in the Arms and Mudd laboratories. These are modern, five-story buildings which were specifically designed for these activities and to provide office space for the staff and students. They also house the division library; paleontologic, rock, and mineral collections; a laboratory for planetary studies; spectrographic, x-ray diffraction and x-ray fluorescent equipment; wet chemical laboratories; an electron microprobe facility; and facilities for rock and mineral analysis, thin- and polished-section work, and other requirements for comprehensive studies in the earth sciences.

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 occur within convenient reach of the Institute. The relatively mild climate permits field studies throughout the entire year; consequently, year-round field training is an important part of the divisional program.

Extensive facilities are provided for the application of techniques of nuclear chemistry to problems in the earth sciences. These facilities include chemical laboratories for trace-element studies and mass spectrometric and counting facilities for isotopic work. Available equipment includes mass spectrometers, emission counters, and extensive mineral separation facilities, in addition to the usual geological and chemical items.

Favorable opportunity for study of dynamic aspects of paleontology and evolution as revealed by morphology, ecology, and biogeochemistry is provided by the combination of personnel, reference collections, and modern geochemical tools and techniques. Biologic principles and processes, past and present, of significance to geology may be interpreted from experimentation and studies at the Kerckhoff Marine Laboratory at Corona del Mar, operated under the auspices of the Division of Biology.

The Seismological Laboratory of the California Institute, with ample space and excellent facilities, including computers and extensive shops in the Donnelley and Kresge laboratories, is located about three miles west of the campus on crystalline bedrock affording firm foundation for the instrument piers and tunnels. The central laboratory together with a dozen portable and seventeen permanent outlying auxiliary stations in southern California – built and maintained with the aid of cooperating companies and organizations – constitutes an outstanding center for education and research in seismology. In addition, special facilities are available at the Seismological Laboratory for both the study of heat flow in geological



materials and the behavior of rocks and minerals in the pressure and temperature environments of planetary interiors. These facilities include laboratories for performing ultrasonic and Brillouin scattering measurements of elastic constants of rocks and minerals at high pressures and temperatures. Ultra-high-pressure equations of state and shock effects in minerals are being studied in a shock-wave laboratory. Other phases of geophysical training and investigation are carried on in the regular campus buildings.

Lunar and planetary observations are being carried out at the Owens Valley Radio Observatory, JPL radar facility, and at the Hale Observatories with moderate-size reflecting telescopes especially designed and built to meet the needs of division personnel.

MATERIALS SCIENCE

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

Areas of Research

Current areas of research by the faculty and graduate students in Materials Science include:

A. Mechanical Properties
   1. Theoretical and experimental deformation studies
   2. Behavior of metals under dynamic loading
   3. Fracture mechanics

B. Physical Properties
   1. Dislocation dynamics
   2. Magnetic properties
   3. Electrical properties
   4. Electron transport properties
   5. Radiation effects

C. Chemical Properties
   1. Kinetics of phase transformations
   2. Diffusion in solids
   3. Metastable phases
   4. Catalysis on metal surfaces
   5. Corrosion

D. Structure

1. Theoretical and experimental transmission electron microscopy and diffraction studies of crystal defects and alloy phases
2. Direct crystal lattice resolution by transmission electron microscopy
3. X-ray studies of crystal defects and alloy phases.

Research Facilities

Research by the faculty and graduate students in Materials Science is conducted in the W. M. Keck Laboratory of Engineering Materials. Facilities are provided for crystal growth and alloy preparation, strain-free machining, annealing with atmosphere control, rapid quenching, optical metallography, x-ray diffraction, electron microscopy (including modifications for direct lattice resolution), 2 Mev electron irradiation, and systems to control the application of stress (from load pulses of a few microseconds' duration to static loading). Specialized equipment is available for measuring low- and high-temperature specific heat, thermoelectric power, superconductivity, magnetic susceptibility, ferromagnetic resonance, Mössbauer effect, and mechanical properties. Computing facilities are available in Booth Computing Center as well as by remote console in the laboratories.

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

MATHEMATICS

General Description

> "Mathematics is Queen of the Sciences and Arithmetic the Queen of Mathematics. She often condescends to render service to astronomy and other natural sciences, but under all circumstances the first place is her due."
>
> So said the master mathematician, astronomer, and physicist C. F. Gauss (1777-1855). Whether as history or prophecy, Gauss's declaration is far from an overstatement. Time after time in the nineteenth and twentieth centuries, major scientific theories have come into being only because the very ideas in terms of which the theories have meaning were created by mathematicians years, or decades, or even centuries before anyone foresaw possible applications to science. (from *Mathematics, Queen and Servant of Science* by E. T. Bell)

The development of Mathematics at the Institute has been significantly influenced by two outstanding mathematicians, Eric Temple Bell and Harry Bateman, who were appointed to the staff shortly after the Institution became known as the California Institute of Technology. Both of these men made major contributions to their respective fields of interest: Bell to algebra and number theory, Bateman to analysis and applied mathematics, yet both had a profound and lasting interest in the development of mathematics as a whole and in the interplay between mathematics and the sciences. Through the years the mathematics program at Caltech has reflected the dual philosophies of these two mathematicians.

Today mathematics is a rapidly developing and expanding field whose range of application is continually extending into new areas of knowledge. Subject areas such as algebraic topology which were relatively unknown a few decades ago have become major research areas in mathematics. New developments, such as that of the modern computer, have given rise to new and flourishing mathematical disciplines such as theory of algorithms, recursive function theory, and modern numerical analysis. Older areas of mathematics have been revitalized and significantly advanced through the use of concepts and techniques from more recent mathematical fields. One may say that most of the current research in mathematics is characterized by the development of powerful abstract methods which are applicable to broad areas of mathematics and its applications.

Areas of Research

Areas of current research interest of the mathematics faculty include the following: Algebraic number fields; analytic number theory; approximation theory; asymptotic theory of testing and estimation; combinatorial theory; complex function theory; finite group theory; fixed point and coincidence theory; harmonic analysis; infinite abelian groups; lattice theory; matrix theory; measure and integration theory; non-standard analysis and model theory; number theory in orders; numerical analysis; operator algebras; partial differential equations and pseudo-differential operators; ordinary differential equations on manifolds; potential theory on Riemannian manifolds; sequential decision theory.

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 containing the books and periodicals most frequently consulted by the students and faculty. The main mathematics library with its outstanding collection of journals is housed nearby in the Robert A. Millikan Memorial Library.

A central computing facility serves the entire campus. The principal computer in the Center is an IBM 360-75. Students are encouraged to use the computer as a research tool; a remote console is located in Sloan Laboratory.

MECHANICAL ENGINEERING

The way in which the term "Mechanical Engineering" is being used today embraces essentially all of those engineering aspects of a project which have to do with fluid flow, heat and mass transport, combustion, power, propulsion, structural integrity, mechanical design, optimization, and systems analysis. Projects in which mechanical engineers play a large role include the space missions, nuclear and fossil fuel power plants, transportation systems, airplane propulsion engines, and low pollution vehicles. At the Institute, many of the basic disciplines are offered which are required for applications such as the above. They are described in the following under the headings of Design, Mechanics, Thermal and Fluids Engineering, Nuclear Energy, and Jet Propulsion.

DESIGN

Engineering Design is regarded as an interdisciplinary activity providing an opportunity for putting theory into practice and bringing together on a common ground some of the more specialized branches of engineering. It serves to emphasize the importance of a sound, broad, theoretical background and its relevance to actual engineering practice. Emphasis is placed on the imaginative practical approach in the solution of real problems involving various disciplines. The human, sociological, and economic aspects as related to a particular design project are carefully considered in their proper perspective. System design in the broad sense, automatic control, problem modeling, and the appropriate use of analog and digital techniques in optimization are general areas of interest. Projects have included the design and development of apparatus for scientific investigation in different areas of research such as earthquake engineering, hydraulics, heat transfer, etc. Faculty members from other disciplines are invited to participate in the design activity offering specific design problems involved in their current investigations. A close relationship with those working in the design area at the Jet Propulsion Laboratory, as well as those in industry, is maintained through seminars, visits, and a free exchange of ideas on current design problems.

MECHANICS

Studies in the broad field of mechanics may be undertaken in either the Applied Mechanics option or the Mechanical Engineering option. In general, work pursued within the Mechanical Engineering option will have a more physical orientation. The specific areas available for advanced study closely parallel the research interests of the faculty and presently include: linear and nonlinear problems in static and dynamic elasticity, plasticity and viscoelasticity, wave propagation in solids, load transfer problems, modeling of dynamic systems, linear and nonlinear vibrations, random vibrations, stability, structural dynamics, and design for earthquake loads.

Physical Facilities

The *Dynamics and Vibrations Laboratories* provide for the study of a wide range of problems relating to the dynamics of mechanical systems. These two laboratories contain a variety of specialized equipment including: electrodynamic shakers, shock generators, optical followers, and various electromechanical transducers.

The *Analog Computer Laboratory* is equipped with specially designed equipment for the direct simulation and analysis of both linear and nonlinear systems, with stochastic as well as deterministic excitation. Input-output systems are available for various types of signal analysis.

The *Earthquake Engineering Research Laboratory* contains specialized recording and data processing equipment for the study of complex transient loading problems. This equipment has been used extensively in the analysis of strong-motion earthquakes.

THERMAL AND FLUIDS ENGINEERING

Instruction and research are offered in these fields of mechanical engineering. Typical areas of research include free and forced convection heat transfer, friction and heat transfer in dilute polymer solutions, granular media, fluids near the critical point and other unusual media, cavitation, fluid machines and some related areas of hydrodynamics.

Physical Facilities

Several facilities are available for heat transfer studies, including free convection equipment, a forced convection loop, a blowdown facility for polymer solutions, and a liquid carbon dioxide heat transfer facility. An internal combustion engine laboratory, containing a variable compression fuel research engine, together with a conventional automotive engine dynamometer, is also available. In addition, hydrodynamic research facilities of the Division are available for work in this field. These include the low-speed flumes of the Keck Laboratory and the two water tunnels of the Karman Laboratory. The latter are particularly useful for studies of cavitation, ventilation, steady and nonsteady characteristics of hydrofoils, planing surfaces, and flow visualization.

NUCLEAR ENERGY

A graduate program in nuclear energy is available as an option in mechanical engineering as well as in engineering science. The central area of interest in the nuclear energy laboratory involves the solutions of those problems arising from the unique nature of nuclear energy. Thus, the program specializes in reactor physics – the study of the behavior of neutrons in nuclear reactors. The program is essentially that of applied physics rather than engineering. Undergraduate preparation for this option should include a good background in mathematics, and if possible, a course in modern physics. The program is available to students who have majored in engineering, physics, or mathematics, and nuclear specialization at the undergraduate level is not required.

Areas of Research and Physical Facilities

Areas of specialization include theoretical and experimental (pulsed neutron) reactor physics. Current interests in this field center around time-dependent techniques for studying transport parameters of materials. Studies have been made of the theory of propagation of neutron waves, and analyses of pulsed neutron experiments are being conducted. Experimental facilities include a pulsed neutron generator with associated detectors and recording equipment.

JET PROPULSION

During 1948, a Jet Propulsion Center was established at the California Institute of Technology by the Daniel and Florence Guggenheim Foundation. This Center was created specifically to provide facilities for postgraduate education and research in jet propulsion and rocket engineering, with particular emphasis on peacetime uses: to provide training in jet propulsion principles, to promote research and advanced thinking on rocket and jet propulsion problems, and to be a center for peacetime commercial and scientific uses of rockets and jet propulsion. The Guggenheim Jet Propulsion Center is a part of the Division of Engineering and Applied Science. All instruction in the Guggenheim Center is on the graduate level.

The solution of the engineering problems in jet propulsion requires new techniques as well as drawing on the knowledge and practice of the older branches of engineering, in particular, mechanical engineering and aeronautics. Thus, it is appropriate that the program of instruction includes material from both of these engineering fields. In general, students entering the course work in jet propulsion will have had their undergraduate preparation in mechanical engineering or aeronautics, but the courses are also available to students whose preparation has been in applied mechanics, engineering science, or physics.

Areas of Research and Physical Facilities

The Jet Propulsion Center is located in the Karman Laboratory of Fluid Mechanics and Jet Propulsion. Facilities for experimental research are available to students working toward advanced degrees. The dynamics of two-phase flows, the mechanics of jets injected into a supersonic stream, heat transfer to the electrodes of plasma accelerators, and ionization rates in gases represent a few of the topics that are currently under investigation.

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.

Experimental High Energy Physics: An active group performs various types of elementary particle experiments at the major accelerator centers, including Brookhaven, Berkeley, and Stanford. Equipment for counter and spark chamber experiments is designed and built at Caltech. Bubble chamber analysis is also done at Caltech. The group has also been involved in design and use of large magnet spectrometer systems, and is presently involved in hybrid experiments which combine bubble chamber and counter techniques.

Kellogg Radiation Laboratory: Three conventional Van de Graaff accelerators and a 12 MeV tandem accelerator are used to study the energy levels of light nuclei and to measure cross sections for reactions of astrophysical interest. The accelerators are also used for atomic studies with high velocity atomic beams and channeling investigations of the properties of crystalline solids.

Nuclear Spectroscopy: This laboratory is concerned with the study of problems in nuclear and atomic structure using beta and gamma ray spectrometers, and the Mössbauer effect.

Space Physics: There is an active observational program in infrared, x-ray, and gamma-ray astronomy. The astrophysical aspects of cosmic radiation are investigated with detectors flown in balloons and in spacecraft. Observational and theoretical studies of magnetic fields, velocity fields and active regions on the sun are carried out. Planetary and interplanetary magnetic fields are being studied with data from magnetometers carried by Mariner spacecraft.

Low Temperature: Cryogenic techniques form the basis for studies ranging from investigations of the fundamental nature of superfluidity and examinations of two-dimensional systems to the development of unique electronic systems from quantum superconductivity.

Radio Astronomy: Two 90-foot and one 130-foot antennas are used to investigate radio signals from distant galactic and extragalactic sources and from nearby planets. The antennas are movable and steerable, and are used as an interferometer to measure positions, intensities, polarizations, and sizes of radio sources, and the propagation properties of the intervening medium.

Theoretical Physics: The principal areas under theoretical investigation are the nature of elementary particles and their high energy interactions, various problems in the area of general relativity and cosmology, the physics of the interplanetary medium, problems of stellar structure and stellar evolution, the synthesis of elements in stars, and the nature of quasi-stellar radio sources.

Physical Facilities

The Physics Department is housed in six buildings grouped together on the south side of the campus: Norman Bridge Laboratory, Alfred P. Sloan Laboratory of Mathematics and Physics, W. K. Kellogg Radiation Laboratory, George W. Downs Laboratory of Physics, C. C. Lauritsen Laboratory of High Energy Physics, and the Synchrotron Laboratory. Members of the staff also carry out research with the Mt. Wilson and Mt. Palomar facilities of the Hale Observatories, and at the Owens Valley Radio Observatory.

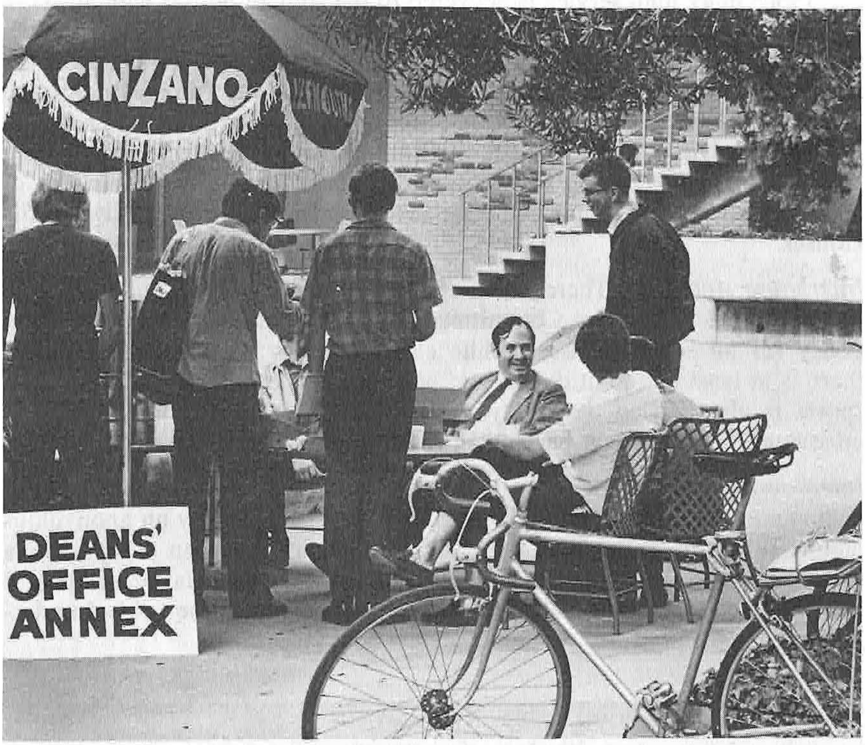
THE HUMANITIES AND SOCIAL SCIENCES

Throughout its history the California Institute has placed a strong emphasis upon the humanities as an important and necessary part of the education of a scientist or engineer. In recent years increased attention has been paid to the social sciences. At the undergraduate level all students are required to devote a substantial part (between one-fifth and one-fourth) of their curriculum to humanistic studies. At the graduate level, humanities courses are required for the Master of Science degree in Civil Engineering and Astronomy, and are recommended in other options. At the doctoral level, a Ph.D. minor may be taken in economics, philosophy, history, or English, with a Ph.D. major in any branch of science or engineering.

Since the academic year 1965-66, the Institute has offered undergraduate options in English, history and economics, leading to the B. S. degree in Humanities. Students electing one of these options will take the regular courses prescribed for all freshmen in their first year and the required courses in mathematics and physics in the sophomore year. In the last two years, students in these options will take further work in science, mathematics, or engineering courses as well as the advanced work in their humanities option. The purpose of the humanities options at the California Institute is to produce a special kind of student — one who has an exceptionally strong background in science or engineering, yet who is well prepared for graduate work in humanities, professional schools, business, or government service.

Dabney Hall of the Humanities was given to the Institute in 1928 by Mr. and Mrs. Joseph B. Dabney. At the same time a special fund of $400,000 for the support of instruction in humanistic fields was subscribed by several friends of the Institute. In 1937 Mr. Edward S. Harkness gave the Institute an additional endowment of $750,000 for the same purpose. The Donald E. Baxter, M.D., Hall of the Humanities and Social Sciences, a gift of Mrs. Donald E. Baxter, is presently under construction.

The proximity of the Henry E. Huntington Library and Art Gallery, one of the great research libraries in the world, offers rich opportunities for the humanities staff, especially in history and literature, and a close but informal relationship is maintained between the Institute and visiting scholars at the Library.



Student Life

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, and generally consistent in appearance with the older group, were completed in 1960, and are named Page, Lloyd, and Ruddock. Each of the seven is a separate unit with its own dining room and lounge, providing accommodations for about seventy-five students.

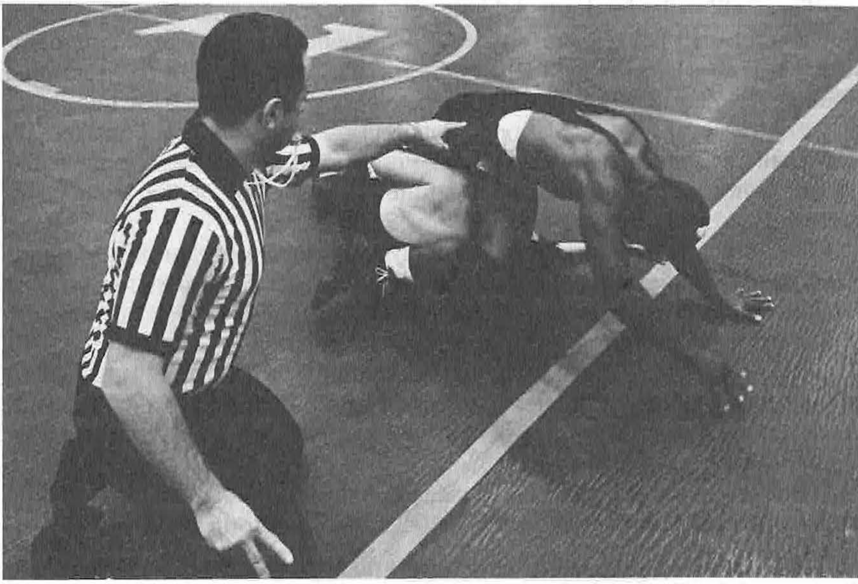
Each House has its own elective officers, and is given wide powers to arrange its own social events and preserve its own traditions. The immediate supervision of the activities of each House is the responsibility of the House Resident Associate, generally a graduate student or younger faculty member.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

Twice daily mail service is delivered to the student houses with an A.M. only trip on Saturday. Students living in houses should use their house name, 1301 E. California Blvd., Pasadena, Calif. 91109, to facilitate the handling of their mail both at the post office and in the campus mailroom.

Since the demand for rooms may exceed the supply, newly entering students are advised to file room applications with the Master of Student Houses immediately upon being notified by the Director of Admissions of admittance to the Institute. All freshmen are strongly urged to live in the Houses.

Interhouse Activities. There is representation of each of the undergraduate houses on the Interhouse Committee, which determines matters of general policy for all seven Houses. While each sponsors independent activities, there is at least one joint dance held each year. The program of intramural sports is also carried on jointly. At present it includes football, softball, crosscountry, swimming, basketball, tennis, track, and volleyball.

Interhouse Scholarship Trophy. A trophy for annual competition in scholarship among the seven Student Houses has been provided by an anonymous donor. With the approval of the donor the trophy has been designed as a memorial to the late Colonel E. Goldsworthy, who was Master of Student Houses, and it commemorates his interest and efforts in the field of undergraduate scholarship.



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

Freshman Advisers. Each member of the freshman class is assigned to a faculty adviser. The adviser interests himself in the freshman's progress and provides advice on any questions or problems which the freshman may have.

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

Athletics. The California Institute maintains a well-rounded program of athletics and, as a member of the Southern California Intercollegiate Athletic Conference, schedules contests in nine sports with the other members of the Conference – Occidental, Pomona, Redlands, Whittier, and Claremont-Harvey Mudd – as well as many other neighboring colleges. In addition, the Caltech Sailing Club sails a fleet of Institute dinghies based at Los Angeles Harbor; and the Caltech Flying Club owns a Cessna 150.

The California Institute Athletic Field of approximately 23 acres includes a football field, a standard track, a baseball stadium, and championship tennis courts. The Scott Brown Gymnasium and the Alumni Swimming Pool, completed in 1954, provide attractive modern facilities for intercollegiate, intramural, or recreational competition in badminton, basketball, volleyball, swimming, and water polo. Funds for the pool were contributed by the alumni of the California Institute; construction of the gymnasium was made possible through a bequest of Scott Brown.

The Institute sponsors an increasingly important program of intramural athletics. There is spirited competition among the seven Houses for the possession of the three trophies. The Interhouse Trophy is awarded annually to the group securing the greatest number of points in intramural competition during the year. The Varsity and Freshman Rating Trophy is presented to the group having the greatest number of men participating in intercollegiate athletics. The third trophy, "Discobolus," is a bronze replica of Myron's famous statue of the discus thrower. It is a challenge trophy, subject to competition in any sport, and it remains in the possession of one group only so long as that group can defeat the challengers from other groups.

"ASCIT." The undergraduate students are organized as the "Associated Students of the California Institute of Technology, Incorporated," (ASCIT). All students pay the student-body fees and are automatically members of this organization, which deals with affairs of general student concern and with such matters as may be delegated to it by the faculty. Membership in the corporation entitles each student to (a) admission to all regular athletic or forensic contests in which the Institute teams participate, (b) one vote in each corporate election, and (c) the right to hold a corporate office. The executive body of the ASCIT corporation is the Board of Directors, which is elected by the members in accordance with the provisions of the By-Laws. The Board interprets the By-Laws, makes awards for athletic and extracurricular activities, authorizes expenditures from the corporation funds, and exercises all other powers in connection with the corporation not otherwise delegated.

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

Board of Control. The Honor System is the fundamental principle of conduct for all students. More than merely a code applying to conduct in examinations, it extends to all phases of campus life. It is the code of behavior governing all scholastic and extracurricular activities, all relations among students, and all 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 representatives from each of the seven Houses, is charged with interpreting the Honor System. If any violations should occur, the Board of

Control investigates them and recommends appropriate disciplinary measures to the Deans.

Student Body Publications. The publications of the student body include a weekly paper, the *California Tech;* an annual; a literary magazine; and a student handbook, which gives a survey of student activities and organizations and serves as a campus directory. 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, 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 band and glee club. A series of chamber music concerts is given on Sunday evenings in the lounge of Dabney Hall. The Musicale is an organization which encourages interest in and appreciation for classical recordings. The extensive record library of the Institute provides opportunity for cultivation of this interest and for the presentation of public programs. From a special loan library, records may be borrowed for students' private use.

Student Societies and Clubs. There is at the Institute a range of undergraduate societies and clubs wide enough to satisfy the most varied interests. The American Institute of Electrical Engineers, the American Society of Civil Engineers, and the American Society of Mechanical Engineers all maintain active student branches.

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

The Institute also has a chapter of Pi Kappa Delta, the national forensic honor society. Members are elected annually from students who have represented the Institute in intercollegiate debate, or in oratorical or extempore speaking contests.

Special interests and hobbies are provided for by Chemistry, Mathematics, and Physics Clubs, the Radio, Sailing, Flying, and Ski Clubs. The Christian Fellowship Group and the Newman Club are organized on the basis of religious interests. The Inter-Nations Association is composed of foreign students from various countries, as well as interested Americans. Its object is to make the students' stay at Caltech more valuable by introducing them to Americans, their customs and way of life. Conferences, weekly teas, and trips to points of interest in the vicinity are among the activities.

Student Shop. The Student Shop is housed in the new Winnett Student Center. It is equipped by the Institute, largely through donations, and is operated by the students under faculty supervision. It has no connection with regular Institute activities, and exists only as a place where qualified students may work on private projects that require tools and equipment not otherwise available. All students are eligible to apply for membership in the Student Shop; applications are acted on by a governing committee of students. Members who are not proficient in power tools are limited to hand tools and bench work; however, instruction in power tools will be given as needed. Yearly dues are collected to provide for maintenance and replacement.

Speech Activities. Practical training in public speaking is the keynote of the Institute's forensic program. A variety of experiences ranging from intercollegiate debate tournaments to local speech events can be had by all who wish to improve their abilities. Debaters take part in an average of six intercollegiate tournaments during the year. These tournaments, including extempore speaking, oratory, impromptu speaking and discussion, comprise such events as the Western Speech Association tournament, the regional Pi Kappa Delta speech tournament, and the annual Caltech invitational debate tournament held at the Institute. Bi-annually the Institute is represented at the national Pi Kappa tournament.

YMCA. The California Institute *YMCA* is a service organization whose purpose is to supplement a technical and scientific education with a program emphasizing social and religious values. The *"Y"* is one of the most active student organizations on the campus and welcomes as members all taking an active part in its regular program of activities. The program includes weekly luncheon clubs, discussion groups which bring speakers representing many interests to the campus, forums and lectures, student-faculty firesides, intercollegiate conferences, and work with local church groups. The *"Y"* services to the student body include a used-textbook exchange, a loan fund, an all-year calendar of student events, and the use of the lounge and offices.

Beckman Auditorium. Beckman Auditorium serves as the center of the performing arts program on the Caltech campus. Each year, the Auditorium hosts over 125 public events, ranging from the traditional Monday night lecture series to professional dramatic, dance, film, and concert presentations, featuring world renowned artists. It is the site of the annual Caltech student musical show, the Caltech Glee Club Home Concert, and the Caltech Band Hunter Mead Memorial Concert. Located in the Auditorium offices are a Mutual Ticket Agency and the campus Audio-Visual Services Unit.

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

The Institute Art Program

The Institute Art Program is designed to bring art and artists to the Caltech campus and to provide the Caltech community with an art workshop. The workshop, now housed in Earhart Laboratory, features noncredit courses in drawing, painting, sculpture, and printmaking, and conducts special experiments and studies in art and science. Directed by Lukas van Vuuren, the program brings artists to the Campus to work with Caltech students and faculty. In addition to workshop activities, the program sponsors formal and informal art exhibits. It also plans the acquisition of art objects for the Institute.

Department of Air Force Aerospace Studies

The United States Air Force offers an excellent opportunity for Caltech students to fulfill their military obligations in a manner entirely harmonious with their academic and professional interests. This opportunity exists through the on-campus "Two-Year Program" of the Air Force Reserve Officers' Training Corps (AFROTC), which is administered by the Department of Air Force Aerospace Studies. Established at Caltech in 1951-1952, this department has continued since that time to offer interested Caltech students a program leading to an Air Force commission as a Second Lieutenant upon their graduation. AFROTC graduates from Caltech are generally assigned to scientific/engineering positions within the Air Force R & D complex. Those electing pilot or navigator duty can look toward assignments leading to experimental research as well as operational flying duties.

Under the present two-year program, students apply at the Department during the first and second terms of their sophomore years. Graduate students who are assured of at least two years remaining towards their degrees are also eligible to apply. Applicants are given aptitude and medical examinations, and final selection of qualified applicants is made late in the second term. Those selected are required to attend a six-week summer camp ("Field Training") at an Air Force base prior to formal enrollment in the program the following fall term. Until the time of formal enrollment in the fall, neither the student nor the Air Force is under any contractual obligation. The Air Force does agree, however, to pay mileage to and from the field training site and will pay students at the same rate as that paid Air Force Academy cadets while the students are attending field training. Beyond that, there is no obligation upon either the Air Force or student.

When the student formally enrolls in the program, he begins receiving fifty dollars per month (up to a maximum of $1,000) as a subsistence allowance, to defer incidental costs such as uniform maintenance, etc. He also receives a 1D draft classification, all uniforms and most of the books needed in the course (at the option of the instructor the student may be required to purchase a commercial textbook from his subsistence allowance.)

A special note about deferments: The Department recognizes that some students, particularly graduate students, may be experiencing Selective Service difficulty. Therefore, in such cases, a qualified student formally accepted to the program can be deferred as early as 1 April in the calendar year he will enroll in AFROTC.

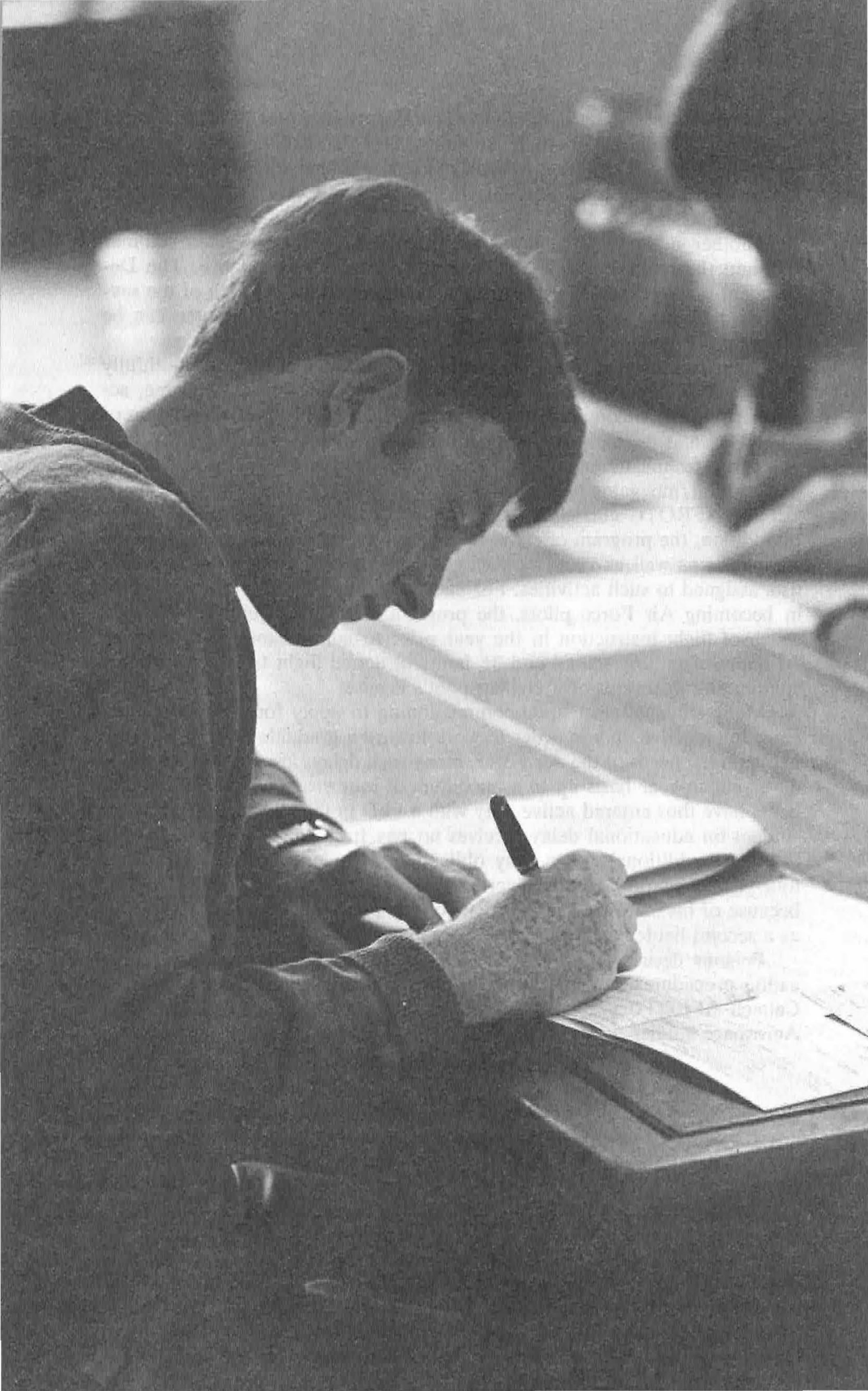
Another difficulty sometimes arises from a conflict between summer jobs and the requirement for six-week field training attendance. The Department makes every effort to meet student desires as to which of the several field training sessions he will attend. However, no guarantee can be made that he will be able to receive his first choice.

Upon formal enrollment in the program, students agree to faithfully pursue the Institute's established courses of study leading to a degree, accept an Air Force commission as a Second Lieutenant upon completion of AFROTC and degree programs, and to serve an active-duty tour of four years in a technical/managerial area or five years after successful completion of pilot/navigator training.

The AFROTC curriculum is described on page 301 of this catalogue. In addition, the program offers visits to aerospace scientific and engineering complexes as well as visits by young Air Force officer engineers or scientists assigned to such activities. For cadets who are qualified and interested in becoming Air Force pilots, the program offers the equivalent of $600 worth of flight instruction in the year prior to commissioning, comprising 30 hours of ground school and 35 hours of actual flight training, normally culminating in receipt of a civilian pilot's license.

Many students elect upon commissioning to apply for a delay of their entry upon active duty in order to work toward a graduate degree. Depending upon the needs of the Air Force, many such delays are granted, normally on a year-to-year basis up to a maximum of four years. Many Caltech students have thus entered active duty with a PhD in their specialty. While the student on educational delay receives no pay from the Air Force, he also incurs no additional active duty obligation. He merely delays his normal four-year obligation. He also accrues limited longevity while on such delays because of his status in the Inactive Reserve, and will thus spend less time as a second lieutenant when he enters active duty.

Persons desiring more specific information about the program, application procedures, and educational and professional opportunities open to Caltech AFROTC graduates should contact the Department of Air Force Aerospace Studies.



Section III

INFORMATION AND REGULATIONS FOR THE GUIDANCE OF UNDERGRADUATE STUDENTS

Requirements for Admission to Undergraduate Standing

THE undergraduate school of the California Institute of Technology becomes coeducational with the academic year 1970-71. There is no set ratio of men to women. The academic year consists of one twelve-week term and two eleven-week terms extending from late September until the middle of June. There are no summer sessions, except that undergraduates and graduate students are permitted to register for summer research. Undergraduates are admitted only once a year — in September. All undergraduates at the California Institute are expected to carry the regular program leading to the degree of Bachelor of Science in the option of their choice. Special students who wish to take only certain subjects and not seeking a degree cannot be accepted.

Admission to the Freshman Class

The freshman class of approximately 215 is selected from the group of applicants on the basis of (a) high grades in certain required high school subjects, (b) results of the College Examination Board tests, and (c) recommendation forms, and a personal interview when this is feasible. The specific requirements in each of these groups are described below. An application fee of $10 is due at the time an application for admission is submitted. No application will be considered until this fee is paid. The fee is not refundable whether or not the applicant is admitted or cancels his application, but it is applied on the first-term bills of those who are admitted and who register in September.

APPLICATION FOR ADMISSION

Application for admission is made on a form which may be obtained by writing to the Office of Admissions, California Institute of Technology, Pasadena, California 91109. It is to be returned directly to the Institute.

Completed admission application blanks and the $10 application fee must reach the Admissions Office not later than February 1. (Application to take entrance examinations must be made directly to the College Board at an earlier date, for which see page 181.)

Transcripts of records covering three and a half years of high school should be submitted as soon as the grades of the first semester of the senior year are available, but not later than March 1. Those attending schools which operate on the quarter system should submit records covering the first three years and the first quarter of the senior year. They must also arrange for a supplementary transcript showing the grades for the second quarter to be sent as soon as possible. Applicants must be sure to list in the space provided on the application blank all subjects they will take throughout the senior year.

HIGH SCHOOL CREDITS

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

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

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

The four-year program in mathematics should include the principal topics of algebra, geometry, analytic trigonometry, and the elementary concepts of analytic geometry and probability in a way which displays the underlying relationships between these branches of mathematics. The program should emphasize the principles of logical analysis and deductive reasoning and provide applications of mathematics to concrete problems.

The Admissions Committee recommends that the applicant's high school course include at least two years of foreign language, a year of geology or biology, and as much extra instruction in English grammar and composition as is available in the high school curriculum.

ENTRANCE EXAMINATIONS

In addition to the above credentials, all applicants for admission to the freshman class are required to take the following examinations given by the College Entrance Examination Board: the Scholastic Aptitude Test (morning program); the afternoon program consisting of the Level II Achievement Test in Mathematics and any two of the following: Physics, Chemistry, Biology, English Composition. The Level II Mathematics Test is designed for the students who have completed three and one-half years of a mathematics program of the type outlined above. The Level II test does not presuppose an advanced placement course in mathematics. Note that the Scholastic Aptitude and the Level II Mathematics tests must be taken,* and that the choice lies only among Physics, Chemistry, Biology, and English — of which two must be taken. No substitution of other tests can be permitted.

The Scholastic Aptitude Test and achievement tests must be taken no later than the January College Board Series. *It is important to note that no applicant can be considered who has not taken the required tests by January, but tests taken on any prior date are acceptable.* No exception can be made to the rule that all applicants must take these tests.

Full information regarding the examinations of the College Entrance Examination Board is contained in the *Bulletin of Information* which may be obtained without

*Very occasionally the applications of those who have taken the Level I instead of the Level II Mathematics Test will be considered. It should be pointed out, however, that the Institute feels it can better judge the qualifications of an applicant who has taken the Level II test, and those who have not done so will be handicapped in the competition for admission.

charge at most schools or by writing to the appropriate address given below. The tests are given at a large number of centers, but should any applicant be located more than 75 miles from a test center, special arrangements will be made to enable him to take the tests nearer home.

Applicants who wish to take the examinations in any of the following states, territories, or foreign areas should address their inquiries by mail to College Entrance Examination Board, P.O. Box 1025, Berkeley, California 94701:

Alaska	Nevada	Province of British Columbia
Arizona	New Mexico	Province of Manitoba
California	Oregon	Province of Saskatchewan
Colorado	Utah	Republic of Mexico
Hawaii	Washington	Australia
Idaho	Wyoming	Pacific Islands, including
Montana	Province of Alberta	Japan and Formosa

Candidates applying for examination in any state or foreign area not given above should write to College Entrance Examination Board, P.O. Box 592, Princeton, New Jersey 08540.

All applications to take examinations in the United States should reach the appropriate office of the Board at least four weeks in advance of the test date. Examinations to be taken abroad need to arrive at least six weeks in advance.

Candidates are urged to send their examination applications to the Board as early as possible, since early registration allows time to clear up possible irregularities which might otherwise delay the issue of reports. No candidate will be permitted to register with the supervisor of an examination center at any time. Only properly registered candidates, holding tickets of admission to the centers at which they present themselves, will be admitted to the tests. Requests for transfer of examination center cannot be considered unless these reach the Board office one week prior to the date of examination.

Please note that requests to take the examinations and all questions referring exclusively to the examinations are to be sent to the College Entrance Examination Board at the appropriate address as given above, and not to the California Institute.

PERSONAL INTERVIEWS AND RECOMMENDATION FORMS

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

NOTIFICATION OF ADMISSION

Final selections will ordinarily be made and the applicants notified of their admission or rejection well before May 1. Most College Board member colleges have agreed that they will not require any candidate to give final notice of acceptance of admission or of a scholarship before this date. Upon receipt of a notice of admission an applicant should immediately send in the registration fee of $10. In the event of subsequent cancellation of application, the registration fee is *not* refundable unless cancellation is initiated by the Institute. Places in the entering class will not be held after May 1, if the applicant could reasonably be expected to have received notice at least ten days before that date. Otherwise, places will be held not more than ten days after notification. When the registration fee has been received, each accepted applicant will be sent a registration card which will entitle him to register, provided his physical examination is satisfactory.

Checks or money orders should be made payable to the California Institute of Technology.

EARLY DECISION PLAN

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

An applicant for admission under the early decision plan must have his credentials on file by October 15 of his senior year. He will be notified by December 1 whether he has been accepted. An accepted applicant is then expected to withdraw all other applications to other colleges. An applicant who is not accepted under the early decision plan will be considered without prejudice for admission at the regular time in April, unless he receives final rejection in December.

ADVANCED PLACEMENT PROGRAM

A number of high schools and preparatory schools offer selected students the opportunity to accelerate and to take in the senior year one or more subjects which are taught at the college level and cover the material of a college course. The College Entrance Examination Board gives each year in May a set of Advanced Placement examinations covering this advanced work. The regulations governing Advanced Placement at the California Institute in the subjects concerned are as follows:

Chemistry. Students who took the College Board Advanced Placement Examination in Chemistry and received a score of 5 or 4 and who have passed an additional short departmental examination may elect to take Chemistry 2, Advanced Placement in Chemistry, 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, and 3) computations based upon equilibrium relationships. Chemistry 2 differs from Chemistry 1 chiefly in having different lectures and recitation. The required first-term laboratory is the same. There is more emphasis in Chemistry 2 on systematic treatment of reactions and chemical reactivity than in Chemistry 1. Equilibrium relationships, electrochemistry, etc., are discussed directly in terms of thermo-

*Please note that the Level II Mathematics test (required) is not given in the July series. It is given only in December, January, and May.

dynamics and used as examples of variations in chemical reactivity as a function of chemical structure.

Anyone who feels that prior to entrance he has covered the equivalent of freshman chemistry but has not taken the College Board Advanced Placement examination may take the California Institute transfer examination in chemistry covering the work of the freshman year. Units from which a student has been excused by reason of Advanced Placement (the laboratory work of the first term, e.g.) must be made up before graduation and may be taken in any subject offered in any division for which the student has the necessary prerequisites, except that those who wish to major in chemistry or chemical engineering may be required to make up the units by additional work in chemistry.

English and History. In view of the flexibility and freedom of choice available in the Humanities and Social Sciences curriculum, no advanced placement and credit are available.

NOTE: The Institute will provide appropriate opportunities for students to fulfill the State of California American History and Institutions requirements.

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

During the summer, entering freshmen will be invited to outline their advanced training in mathematics and to have their knowledge tested. They then will be placed in the course which best fits their preparation. Some students will receive credit for Math 1 abc and will be allowed to enroll in Math 2 abc. Others will take the normal course Math 1 abc or Math 1.5 abc.

Physics. As currently organized, the required course in physics in the freshman year, Ph 1 abc, contains so little that might duplicate material in advanced placement work elsewhere that for the time being it is not contemplated that any advanced placement in physics will be given to entering freshmen.

NOTE: The Advanced Placement tests are in no way a substitute for the College Board Aptitude and Achievement Tests at the ordinary high school level required for admission. The latter are the only tests considered in granting freshman admission. After admission, those who offer advanced credits and examinations will be considered for credit and advanced placement in the subjects involved.

MEDICAL EXAMINATION

Prior to final acceptance for admission, each applicant is required to submit a report of Medical History and Physical Examination on a form which will be sent him at the time he is notified of admission. It is the applicant's responsibility to have this form filled out by a Doctor of Medicine (M.D.) of his own choosing. Admission is tentative pending such examination, and is subject to cancellation if the report indicates the existence of a condition that the Director of Health Services deems unsatisfactory (see page 218).

Vaccination and a standard two-injection tetanus inoculation (or booster shot if appropriate) and tuberculosis testing are required at the time of the examination. Students will not be admitted unless the report of the physical examination bears evidence of such vaccination, inoculation, and testing.

Students who have been on leave of absence for three terms or more must submit Medical History and Physical Examination reports under the same conditions as for new students.

SCHOLARSHIPS AND LOANS

For information regarding scholarships for entering freshmen and deadline for application see pages 224-225. No one can be considered for a scholarship grant who has not sent in a scholarship form according to the instructions on page 224. In computing need the California Institute uses figures which cover all expenses of an academic year for those who live on campus or wherever they must pay for board and lodging. This figure includes tuition, board and lodging, books and supplies, incidental fees and dues, and about $400 for personal expenses. To this figure is added an allowance for travel between Pasadena and the student's home. The travel allowance varies with the distance involved but in no case exceeds $450 for one academic year. The figure for the expenses of those who live at home or with relatives or friends to whom they pay nothing for board and lodging is approximately $500 less. For further information on tuition and other costs, and on loans and the deferred payment plan see pages 220-223.

NEW STUDENT ORIENTATION

All freshmen are required to attend the New Student Orientation as a part of the regular registration procedure. Upperclass transfer students are not required to attend but are welcome to do so if they wish.

The orientation takes place during three days immediately following freshman registration for the fall term. A large number of faculty members and upperclass student leaders participate to assist the new student in his introduction into the Caltech community. The orientation period provides an opportunity for the new students to become acquainted with the campus, the Honor System governing personal conduct, and other aspects of life at Caltech. In addition the new student has the opportunity to meet his 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.

STUDENTS' DAY

The California Institute holds an annual invitational Students' Day in the spring. This popular event is conducted by invitation to allow a more intimate view of the work in the laboratories of science and engineering with the hope that this contact will assist the high school student in his choice of a future career. Science students and their teachers are invited, upon nomination by secondary schools throughout southern California, to view exhibits of the work in the various divisions of the Institute and to attend selected demonstration lectures given by students and faculty members. Student life on the campus is an important feature of Students' Day, with the undergraduate student body serving as host and responsible for the actual operation under the direction of a joint faculty-student committee. To avoid overcrowding at the exhibits and lectures it is necessary to limit attendance at this event to those who have been selected by their schools and whose names have been sent to the Students' Day Committee in advance. Because of the time of year, it is more appropriate for schools to send juniors and sophomores than seniors.

Admission to Air Force ROTC

Applicants for admission to the United States Air Force Reserve Officers Training Corps program must be citizens of the United States, and must meet all other admission requirements and regulations as specified by the California Institute of Technology. All male students who meet the requirements may apply for the two-year AFROTC program. Foreign students who will subsequently obtain U. S. citizenship may be permitted to pursue the AFROTC program upon approval by the Department of Air Force Aerospace Studies. Students who desire to take courses offered by the Department, but do not wish to formally enroll in the AFROTC program may do so with the permission of the Department.

Admission to Upper Classes by Transfer from Other Institutions

The Institute admits to its sophomore or junior year a limited number of able men who have made satisfactory records at other institutions of collegiate rank and who do satisfactorily on the transfer entrance examinations. Transfer students are not normally admitted to the senior year. In general only students whose grades, especially those in mathematics and science, are above average can be expected to be permitted to take the entrance examinations.

A student who is admitted to the upper classes pursues a full course in engineering or in one of the options in science or humanities leading to the degree of Bachelor of Science. The Institute has no special students. Men are admitted either as freshmen in accordance with the regulations set forth on pages 179-181 or as upperclassmen in the manner described below. Those who have pursued college work elsewhere, but whose preparation is such that they have not had the substantial equivalent of the freshman courses in mathematics, physics, and in addition chemistry for those wishing to major in chemistry or chemical engineering, will be classified as freshmen and should apply according to the instructions on pages 179-181. They may, however, receive credit for the subjects which have been completed in a satisfactory manner.

An applicant for admission as a transfer student must write to the Office of Admissions of the California Institute stating his desire to transfer, his choice of engineering or one of the options in science or humanities, and the number of years of college he will have completed by the date of transfer. At the same time he must present a transcript of his record to date, showing in detail the character of his previous training and the grades received both in high school and college. If the college transcript does not list subject *and grades* for high school work, the applicant must see that his high school sends the Admissions Office a transcript of this work. After the transcripts have been evaluated by the Admissions Office, an application blank will be sent, provided the grades and subjects on the transcripts meet the transfer requirements.

Please note that an application blank is not sent until the transcripts have been received and evaluated, and that the applicant must write a letter giving the information outlined in the preceding paragraph. Transcripts are held in the files until such a letter is received.

Application blanks must be on file in this office by April 1. Transcripts should, therefore, be sent no later than March 15. Applicants living in foreign countries must have applications and transcripts on file by March 1 at the latest and should understand that no information with regard to acceptance or rejection can be sent before June 20.

Applicants who are enrolled in a college at the time applications are made do not ordinarily complete the academic year until May or June. Such applicants should make sure that a list of subjects being taken during the final semester is included in the transcript sent for evaluation and that a supplementary transcript showing the grades for the final semester is sent at the end of the academic year as soon as these grades are available. All transfer applicants must arrange to have sent in their scores on the Scholastic Aptitude Test (SAT) of the College Entrance Examination Board. If they have taken the SAT in previous years, these scores will be acceptable; but applicants must instruct the College Board (see address on page 181) to send the scores to the Institute. If the SAT has not been taken previously, it must be taken by the May series at the latest. College Board Achievement Tests are not required of transfer applicants.

In addition, before their admission to the upper classes of the Institute, all students are required to take entrance examinations in mathematics and physics covering the work for which they desire credit. In addition an examination in chemistry is required of those desiring to major in chemistry or chemical engineering. Students whose native language is not English will be required to take the Test of English as a Foreign Language (TOEFL). This test is a College Entrance Examination Board test and is given all over the world, including the United States, four times a year. This test must be taken by the March series at the latest. Full information on how and where to take the test should be obtained from the College Board.

It is not possible to answer general questions regarding the acceptability of courses taken elsewhere. The nature of the work at the Institute is such as to demand that all courses offered for credit be scrutinized individually. Even when a transcript of record is submitted, it is not always possible to tell whether the courses taken are equivalent to the work at the Institute. In case the standard of the work taken elsewhere is uncertain, additional examinations may be required before the question of credit is finally determined.

Applicants are advised to read the descriptions of the freshman and sophomore courses, particularly those in physics, mathematics, and chemistry; and to note that the work in freshman mathematics includes differential and integral calculus, vector algebra, and infinite series. If an entering sophomore has not had the last two topics he will enroll in a special section of the sophomore mathematics course. Note also the references to freshman and sophomore chemistry on the following page.

The Institute's basic two-year course in physics is required of all students. It is a course in classical and modern physics in which the emphasis is on modern ideas and applications, to be introduced to the student as early as possible. The first-year course covers kinematics, the Lorentz transformation, nonrelativistic and relativistic particle mechanics, electric and magnetic forces, planetary motion, harmonic motion, geometrical optics, interference, diffraction, and scattering of radiation, kinetic theory, thermodynamics, and black body radiation. Students wishing to transfer into the sophomore class, therefore, will be expected to have covered material not found in the ordinary freshman physics course. Unless a student can demonstrate proficiency in most of the areas covered by Physics 1 abc, he would probably do well to wait another year and apply for admission as a junior. It is felt that the regular two-year program in physics at other colleges, although the sequence of topics may be different, will enable a good applicant to deal adequately with our physics test for admission to the junior level.

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

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

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

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

No application fee is charged in the case of transfer students, but only those whose records are good will be permitted to take the tests. Applicants should not come to the Institute expecting to be admitted to the examinations without first receiving definite permission to take them.

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

Applicants residing at a distance may take the examinations under the supervision of their local college authorities, provided definite arrangements are made well in advance. Arrangements for examinations in absentia should include a letter to the Director of Admissions from the person directing the tests stating that the required supervision will be given.

Physical examinations, vaccination, etc. are required as in the case of students entering the freshman class (see page 183). Admission is conditional upon a satisfactory report on the physical examination.

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

Scholarship grants for transfer students are awarded on the same basis as are those for freshmen: namely, standing on the entrance examinations and demonstrated financial need. To secure consideration for a scholarship, a transfer student must file a special form which will be sent on request and must be completely filled out by parent or guardian responsible for the applicant's support. This form should reach the Admissions Office as soon as possible after the filing of the application.

THE 3-2 PLAN

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

The list of colleges with which these arrangements exist is as follows:

Bowdoin College, Brunswick, Maine
Grinnell College, Grinnell, Iowa
Occidental College, Los Angeles, California
Ohio Wesleyan University, Delaware, Ohio
Pomona College, Claremont, California
Reed College, Portland, Oregon
Wesleyan University, Middletown, Connecticut
Whitman College, Walla Walla, Washington

EXCHANGE PROGRAM WITH OCCIDENTAL COLLEGE

An exchange program exists between Occidental College and the California Institute permitting students at one of these institutions to receive credit for courses taken at the other institution. 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 California Institute 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. Freshmen at the California Institute ordinarily cannot participate in this exchange.

REGISTRATION REGULATIONS

	Registration Dates	Fees Payable	Instruction Begins
Freshmen Students	Sept. 24, 1970	Sept. 24, 1970	Sept. 29, 1970
Upperclassmen & Graduate Students	Sept. 28, 1970	Sept. 28, 1970	Sept. 29, 1970

For Second and Third Term dates refer to the Academic Calendar on page 4.

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 adviser and has paid his tuition and other fees. A penalty fee of four dollars is assessed for failure to register on the scheduled date, and a fee is also assessed for failure to pay fees within the specified dates. These requirements apply to all three terms.

Special Students

Applicants who wish to take a special program without working toward a degree are not accepted for undergraduate admission. Undergraduates who register for programs which make it appear that they are no longer candidates for a B.S. degree may be refused further registration by the Undergraduate Academic Standards and Honors Committee.

Changes of Registration

All changes in registration must be reported 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 Institute calendar. A grade of F will be given in any course for which a student registers and which he does not either complete satisfactorily or drop. A course is considered dropped when a drop card is completed and signed by the approving signatures and returned to the Registrar's Office. A student may not at any time withdraw from a course which is required for graduation in his option without permission of the Dean. Senior students must also have the approval of the Registrar before dropping any course.

A student may not withdraw from a course after the last date for dropping courses without, in addition to his instructor's consent, the approval of the Undergraduate Academic Standards and Honors Committee. A student may, with the consent of the instructor concerned, add a course after he has completed his regular registration, provided the addition does not bring the total units for which he is registered above 55, plus Physical Education. To carry excess units he must obtain the recommendation of his Departmental Adviser and the approval of the Undergraduate Academic Standards and Honors Committee (see page 194). A student may not add a course after the last date for adding courses without, in addition to his instructor's consent, the approval of the Undergraduate Academic Standards and Honors Committee. Registration for added courses is complete when an add card has been filed in the Registrar's Office signed by the instructor and the student's adviser. No credit will be given for a course for which a student has not properly registered. The responsibility that drop cards and add cards are in 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.

Summer Research

Qualified undergradute students who are regular students in the Institute are permitted to engage in research during the whole or a part of the summer, but in order to receive academic credit the student must have the approval of his division and must file a registration card for such summer work in the Office of the Registrar *on May 17.* Students who are registered for summer research will not be required to pay tuition for the research units.

General Regulations

Every student is expected to attend all classes and to satisfy the requirements in each of the courses as the instructor may determine.

Students are held responsible for any carelessness, willful destruction, or waste. At the close of the year, or upon the severance of their connection with any part of the work of the Institute, students are required to return immediately all locker keys and other Institute property.

It is taken for granted that students enter the Institute with serious purpose. The moral tone here is exceptionally good; the honor system prevails in examinations, and in all student affairs. A student who is known to be engaging in immoral conduct or exercising a harmful influence on the student life of the Institute may be summarily dismissed, whatever his scholastic standing.

Auditing of Courses

Persons not regularly enrolled in the Institute may, with the consent of the instructor in charge of the course and the chairman of the division concerned, be permitted to audit courses upon payment of a fee in the amount of $30.00 per term, per lecture hour. The cost of auditing courses by non-academic staff members may be covered through the Institute Tuition Support Plan. Registration cards for the auditing of courses may be obtained in the Registrar's Office.

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

SCHOLASTIC GRADING AND REQUIREMENTS

Scholastic Grading

All permanent grades recorded for freshmen will be either "P," indicating passed, or "F," indicating failed. The temporary grade of "Inc," incomplete, may be used in freshman courses in accordance with the rules of "incomplete" listed below. The temporary grade of "E," conditioned, may be given to freshmen in accordance with the normal usage for upperclassmen described below. It may also be used in a continuing course in accordance with the following two rules: (a) the performance of the freshman concerned is not significantly below the current passing level, and in addition the student is maintaining a steady and substantial improvement; (b) 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 be changed 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 the freshman is enrolled in a course in which the instructor gives letter grades, the registrar will record "P" for all passing grades. The grade of "H" is given for satisfactory completion of freshman honor elective courses. No grades given to a freshman will be used in computing the cumulative grade point average.

For undergraduate students beyond the freshman year, letter grades will ordinarily be used to indicate the character of the student's work: "A" excellent, "B" good, "C" satisfactory, "D" poor, "E" conditioned, "F" failed, "Inc" incomplete. Exceptions are allowed only where the instructor assigns a grade of "P" instead of a passing letter grade, or where the student elects to take the course on a pass-fail basis as described on page 192. This rule regarding exceptions applies whether the student is repeating a course failed at an earlier time or taking the course for the first time. In addition, grades of A+ and A–, B+ and B–, C+ and C–, and D+ may, where appropriate, be used for undergraduates only.

The grade "E" or *"conditioned"* indicates deficiencies that may be made up without actually repeating the subject. If the course has been graded with letter grades, a grade of "D" is given when the work is completed; a grade of "P" is given if the student is a freshman, or if the course was taken on a Pass-Fail basis.

The grade "Inc" or "incomplete" is given only in case of sickness or other emergency which justifies non-completion of the work at the usual time. An incomplete will be recorded only if the reasons for giving it are stated on the instructor's final grade report and only if, in the opinion of the appropriate committee (Undergraduate Academic Standards and Honors Committee for undergraduates, and Graduate Study for graduate students), the reasons justify an incomplete. If, in the opinion of the committee, the incomplete is not justified, a condition will be recorded.

An incomplete or a condition in any term's work must be removed during the next term in residence by the date fixed for the removal of conditions and incompletes.

Each student receiving such grades should consult with his instructor at the beginning of his next term in residence. Any condition or incomplete not so removed becomes a failure automatically unless otherwise recommended in writing to the Registrar by the instructor prior to the date for removal of conditions and incompletes.

"Failed" means that no credit will be recorded for the course. The units, however, count in computing the student's grade-point average. He may register to repeat the subject in a subsequent term and receive credit without regard to his previous grade, the new grade and units being counted as for any other course. In special cases the Undergraduate Academic Standards and Honors Committee may, with the instructor's approval, authorize the completing of a failed course by three 3-hour examinations, the units and new grade being recorded as in the case of repeating the subject. The original "F" and units for the course remain on the record and are counted in computing the grade-point average.

Scholastic Requirements

All undergraduates are required to meet certain scholastic standards as outlined below. In addition, students who have been reinstated after having failed to make the required number of credits in the junior year are subject to these scholastic requirements in the senior year.

Each course in 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 on the basis of the number of units multiplied by four if the grade received is "A," three if "B," two if "C," and one if "D"; thus, a student receiving a grade of "B" in a twelve-unit course receives 36 credits for his course. For the assignment of credits to undergraduate grades with plus or minus designations, see the following table.

TABLE OF CREDITS CORRESPONDING TO GRADE AND NUMBER OF UNITS

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

*The units used at the California Institute may be reduced to semester hours by multiplying the Institute units by the fraction 2/9. Thus a twelve-unit course taken throughout the three terms of an academic year would total thirty-six Institute units or eight semester hours. If the course were taken for only one term, it would be the equivalent of 2.6 semester hours.

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 "F" may have subsequently been removed (see above). Units and credits in military subjects taken by Air Force ROTC students are counted in computing grade-point average. Physical education units and credits, and grades of "P" are not included in computing grade point average.

Grades of "P" may be given for undergraduate research, research conferences, courses numbered 200 or greater, and for other courses which do not lend themselves to more specific grading.

Each term a sophomore, junior, or senior may select one elective course, not specifically required for graduation in his option to be graded on a pass-fail basis, subject to such requirements as may be imposed by his option. The following additional provisions apply:

(a) Any instructor may, at his discretion, specify prior to pre-registration that his course is not available on a pass-fail basis.

(b) Registration may be changed from pass-fail to regular grades and vice versa until the last day for dropping courses each term.

(c) The total number of pass-fail units in regularly scheduled courses (that is, courses other than research and reading courses) in the sophomore, junior, and senior years, which a student may offer for graduation, may not exceed 81.

To take advantage of this opportunity, each student must process a Pass-Fail Course Selection Card. As stated earlier, grades of "P" are not used in computing the grade point average, but all grades of "F" (except in the freshman year) are used in this computation.

Ineligibility for registration. Freshmen who receive no grades of "Fail" or "Condition" during the year are academically eligible to register for the sophomore year. Freshmen who have accumulated 42 or more units of "Fail" or "Condition" will automatically be evaluated by the Committee on Undergraduate Academic Standards and Honors at the end of any term. Any freshman accumulating grades of "Fail" or "Condition" in less than 42 units during the year may, at the end of the year, be referred to the Committee by the Associate Dean of Students and the student's adviser. If it is the opinion of the Committee on Undergraduate Academic Standards and Honors that any freshman referred to it is unprepared for the work of the sophomore year, he may be declared ineligible to register for academic reasons.

Freshmen whose records are to be reviewed at any meeting of the Committee will be notified in advance and invited to meet with the Committee to discuss their performance; freshmen so notified should also plan to submit a written statement to the Committee in advance of its meeting.

Any undergraduate student, except a freshman, is ineligible to register for another term:

(a) If he fails during any one term to obtain a grade-point average of at least 1.4.

(b) If he fails to obtain a grade-point average of at least 1.9 for the academic year. A student who has completed at least three full terms of residence at the Institute and has been registered for his senior year shall no longer be subject to the requirement that he make a grade-point average of at least 1.9 for the academic year. Seniors are subject to the requirement, however, that they must receive a grade-point average of at least 1.4 each term to be eligible for subsequent registration. (Special note should be made of the graduation requirement described on page 193.)

(c) Any undergraduate student, including seniors, who has been *reinstated* and who fails to make a grade-point average of at least 1.9 on a full load of at least 45 units for the following term is ineligible to register.

(d) An undergraduate student who incurs a deficiency in one term of physical education in the freshman or sophomore year must make up the deficiency in the first term of the junior year. If he fails to do so, he is ineligible to register. An undergraduate student who incurs deficiencies in any two terms of physical education in the freshman and/or sophomore year is ineligible to register.

A student ineligible for registration because of failure to meet the requirements stated in the preceding paragraphs may, if he desires, submit immediately to the Undergraduate Academic Standards and Honors Committee a petition for reinstatement, giving any reasons that may exist for his previous unsatisfactory work and stating any new conditions that may lead to better results. Each such application will be considered on its merits. If this is the first such occurrence the petition will first be referred to the appropriate Dean who can, after consultation with the student and examination of his record, reinstate him. At the Dean's discretion, such cases may be referred to the Undergraduate Academic Standards and Honors Committee for action. A reinstated student who again fails to fulfill the scholastic requirements for registration must petition the Undergraduate Academic Standards and Honors Committee, and action can only be taken by the Committee. In any case being considered by the Committee, the student may, if he wishes, appear before the committee or, on request by the Committee, he may be required to appear. A second reinstatement will be granted only under very exceptional conditions.

Deficiency. Any upperclassman whose grade-point average during a term falls between 1.4 and 1.9 shall receive the usual letter of warning that his work is below the satisfactory minimum.

Leave of Absence. Leave of absence involving non-registration for one or more terms must be sought by written petition. A petition for a *medical* leave of absence must carry the endorsement of the Director of Health Services or his representative before being acted upon. Such leave up to one year can be granted by the appropriate Dean for a student who is in good standing. Other petitions should be addressed to the Undergraduate Academic Standards and Honors Committee, and the student must indicate the length of time and the reasons for which absence is requested. In case of brief absences from any given exercise, arrangements must be made with the instructor in charge.

Departmental regulations. Any student whose grade-point average is less than 1.9 at the end of an academic year in the subjects listed under his Division* may, at the discretion of his department, be refused permission to continue the work of that option. Such disbarment, however, does not prevent the student from continuing in some other option provided permission is obtained, or from repeating courses to raise his average in his original option.

Graduation requirement. To qualify for graduation a student must complete the pre-

*The curriculum of the Institute is organized under six divisions, as follows:
Division of Biology.
Division of Chemistry and Chemical Engineering.
Division of Engineering and Applied Science.
Division of Geological Sciences.
Division of the Humanities and Social Sciences.
Division of Physics, Mathematics and Astronomy.

scribed 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 his option.

Graduation in the normally prescribed time. Any undergraduate student who fails to complete the requirements for graduation at the end of the normally prescribed time must petition the Undergraduate Academic Standards and Honors Committee for approval to register for further work.

Residence Requirement. All transfer students who are candidates for the Bachelor of Science degree must complete at least one full year of residence in the undergraduate school at the Institute immediately preceding the completion of the requirements for graduation. At least ninety of the units taken must be in subjects in professional courses. A full year of residence is interpreted as meaning the equivalent of registration for three terms of not less than 36 units each.

Honor standing. At the close of each academic year the Committee on Undergraduate Academic Standards and Honors awards Honor Standing to twenty to thirty students in the sophomore and junior classes in residence.* These awards are based on the scholastic records of the students.

Graduation with honor. With the approval of the faculty, graduation *with honor* may be granted a student who has achieved an over-all grade-point average of 3.2, including such an average in the senior year. In addition, a student may be graduated with honor under joint recommendation of his division and the Committee on Undergraduate Academic Standards and Honors, with the approval of the Faculty.

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. Permission to take a term examination at other than the scheduled time will be given only in the case of sickness or other emergency and upon the approval of the instructor in charge and of one of the Deans. When conflicts exist in a student's examination 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 to take the examination at another time.

Excess or fewer than normal units. Undergraduates who wish to register in any term for more than 58 units inclusive of Physical Education or Air Science (55 academic units for Juniors and Seniors) must obtain the recommendation of the Option Adviser and the approval of the Undergraduate Academic Standards and Honors Committee. Petitions to carry excess units will not be accepted later than the last day of preregistration.

Registration for fewer than 36 units must be approved by the Undergraduate Academic Standards and Honors Committee. See page 239 for graduate students.

Freshman honor electives. Honor Electives are available, on a voluntary basis, to all freshmen in the second and third terms of the freshman year. This Honors work is intended to maintain, or to rekindle, an interest the student brought with him to the Institute, or to develop an interest suggested by the work or the staff at the Institute; it is not intended to be used to accumulate academic credit. The Honor Electives are available campus-wide; any reasonable program of work, including critical reading, is ac-

*No honor standing will be granted for freshman class since grades in all freshman courses are only "P," indicating passed, or "F," indicating failed.

ceptable. Upon satisfactory completion of a term of Honors work, a grade of "H" will be recorded.

Sophomore Honor Sections. Individual sophomore honor sections are organized in mathematics, physics, and history. An eligible student may register for only one, any two, or all three of these sections.

To be eligible, a student must have received grades of "P" in all courses in the freshman year, be recommended by the instructor in the prior course in the field of the particular honor section and have the permission of the instructor who is to teach the honor section.

Selection of option. In the middle of the third term freshmen must notify the Registrar's Office of their selection of an option in engineering, humanities, 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 pre-registration for the following year.

An undergraduate may be allowed to major in two options for the Bachelor of Science degree. In order to do so he must obtain the approval of the Curriculum Committee prior to the beginning of his senior year. He will then be assigned an adviser in each option.

Change of option. Students wishing, or required, to change options must first obtain a Change of Option petition from the Registrar's Office. The completed petition must be signed by the Option Representative for the new option who will assign a new adviser. After final approval for the change is obtained from the Chairman of the Curriculum Committee, the petition should be returned to the Registrar's Office.

Requirement for a second Bachelor of Science degree. Students who wish to receive a second degree of Bachelor of Science in another option are required to have one additional year of residence (three terms of study involving at least 36 units per term) beyond the first Bachelor of Science degree.

Candidacy for the Bachelor's Degree

A student must file with the Registrar a declaration of his candidacy for the degree of Bachelor of Science on or before the first Monday of November preceding the date at which he expects to receive the degree. His record at the end of that term must show that he is not more than 21 units behind the requirement in the regular work of his course as of that date. All subjects required for graduation, with the exception of those for which the candidate is registered during the last term of his study, must be completed by the second Monday of May preceding commencement.

Transcripts of Records

At the request of a student, or former student, official transcripts of record bearing the seal of the Institute and signature of the Registrar will be forwarded to designated institutions or individuals. Requests should be filed at the Registrar's Office at least five days prior to the date on which the transcripts are to be mailed.

One transcript of a record will be furnished without charge. A charge of one dollar ($1.00) will be made for each transcript requested after the first.

UNDERGRADUATE OPTIONS AND COURSE SCHEDULES

FIRST YEAR, 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); Lecture (2-0-3); Recitation (2-0-2)	9	9	9
Ph 1 abc	Kinematics, Particle Mechanics, and Electric Forces (4-0-5)	9	9	9
Ch 1 abc	General and Quantitative Chemistry (3-6-3, (3-0-3), (3-0-3)	12	6	6
En 1 abc or H 1 abc or H 2 abc or PS 1 abc	Literature of the Modern World (3-0-6); An Introduction to Modern Europe (3-0-6); Modern Themes in United States History (3-0-6); Introduction to Political Science (3-0-6)	9	9	9
	Additional Electives*	0-9	6-12	6-12
PE 1 abc	Physical Education	3	3	3
		42-51	42-48	42-48

*All freshmen are required to take at least 15 units of laboratory work in experimental science including Ch 1 a laboratory—6 units. The additional 9 units of laboratory work must be chosen from Bi 1—units as arranged, Bi 9—3 units, Ch 3 ab—3 or 6 units per term, ChE 10—3 units, E 5—6 units, EE 9—6 units, Ge 1—3 units, Ph 3—6 units, Ph 4—6 units.

A partial list of other electives available to freshmen includes the following: Ay 1, Bi 2, EE 3, EE 4, EE 5, Env 1, Gr 1, IS 10 a, Ph 10 ab, and Freshman Honors (non-credit) all divisions.

INSTITUTE REQUIREMENTS — ALL OPTIONS

In addition to the requirements listed above for all freshmen, students in all options are required to complete satisfactorily Ma 2 abc, Ph 2 abc, and PE 2 abc as requirements toward the B.S. degree.

Also required in all options is a total of 108 units in Humanities and Social Sciences. 27 of these units must be taken in the freshman year and selected from the freshman courses offered. Of the 108, 27 units must be in English, En 1 abc if taken in freshman year, En 7 abc if taken later. Students who elect En 1 abc will be required to take 9 additional units at some later time.

All courses listed under Humanities and Social Sciences (English, history, economics, music, anthropology, political science, languages, philosophy, and psychology) count toward the 108 unit requirement except those specifically excluded in the course descriptions.

ASTRONOMY OPTION

(For First Year see above)

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 his division may, at the discretion of his department, be refused permission to continue the work of that option. A fuller statement of this regulation will be found on page 192.

SECOND YEAR

		Units per Term 1st	2nd	3rd
Ph 2 abc	Electricity, Fields, and Quantum Mechanics (4-0-5)	9	9	9
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ay 1	Introduction to Astronomy (3-1-5)	.	9	.
	Physics Laboratory[1]	6	or 6	and 6
	Humanities Elective, minimum	9	9	9
PE 2 abc	Physical Education (0-3-0)	3	3	3
	Electives (see below) to total	45-48	45-48	45-48

[1]Students are required to take (a) Ph 3 if not already taken, (b) Ph 5 or Ph 6, and (c) Ph 7.

Sophomore electives include at least 27 units of science and engineering courses, of which at least 18 units shall be in subjects other than mathematics, physics and astronomy. It is desirable for a student to acquire as broad as possible a background in other related fields of science and engineering. Please note the general Institute requirements for elective courses in Humanities and Social Sciences, totaling a minimum of 108 units. It is the student's responsibility to ensure satisfactory completion of this program.

THIRD YEAR

Ph 102 abc	Atomic Physics (3-0-6)	9	9	9
Ph 106 abc	Topics in Classical Physics (3-0-6)	9	9	9
Ay 112 abc	General Astronomy (3-0-3)	6	6	6
Ay 113 abc	General Astronomy Laboratory (0-4-0)	4	4	4
	Humanities elective, minimum	9	9	9
	Electives (see below) to total	46-51	46-51	46-51

FOURTH YEAR

Astronomy or Physics electives (see below)	18	18	18
Humanities electives[1]	9-18	9-18	9-18
Electives (see below) to total	44-50	44-50	44-50

Suggested Electives

The student may elect any course that is offered in any division in a given term, provided that he has the necessary prerequisites for that course. The following list contains courses useful to work in various fields of astronomy and astrophysics.

Bi 1	Introduction to Biology (3-3-3)	.	9	.
EE 5	Introductory Electronics (3-0-6)	.	.	9
Ge 1	Physical Geology (4-2-3)	9	.	.
Ge 2	Geophysics (3-0-6)	.	9	.
Ma 5 abc	Introduction to Abstract Algebra (3-0-6)	9	9	9
AM 95 abc[2]	Engineering Mathematics (4-0-8)	12	12	12

AMa 105 ab	Introduction to Numerical Analysis (3-2-6)	.	11	11
Ma 108 abc	Advanced Calculus (4-0-8)	12	12	12
Ma 112 ab	Elementary Statistics (3-0-6)	9	or 9	.
EE 13 abc	Linear Network Theory (3-0-6)	9	9	9
EE 14 abc	Electronic Circuits (3-0-6)	9	9	9
EE 20 abc	Physics of Electronic Devices (3-0-6)	9	9	9
EE 90 abc	Laboratory in Electronics (0-3-0)	3	3	3
Ge 152	Radar Astronomy (3-0-6)	9	.	.
Ge 155	Introductory Planetary Science (3-0-3)	6	.	.
Ge 166 a	Physics of the Earth's Interior (3-0-6)	.	9	.
Ge 166 b	Planetary Physics (3-0-6)	.	.	9
Ph 77 ab	Advanced Physics Laboratory	.	6	6
Ph 93 abc[2]	Topics in Contemporary Physics (3-0-6)	9	9	9
Ph 125 abc[2]	Quantum Mechanics (4-0-5)	9	9	9
Ay 131	Stellar Atmospheres (3-0-6)	9	9	.
Ay 132	Stellar Interiors (3-0-6)	9	9	.
Ay 133 abc	Radio Astronomy (3-0-6)	9	9	.
Ay 141 abc	Research Conference in Astronomy (1-0-1)	2	2	2

[1]For rules governing Humanities electives see page 196. Note special regulations on English, page 196, requiring a minimum of 27 units, at least 9 of which must be after the freshman year.
[2]Students who plan to do graduate work in astronomy or radio astronomy should elect some of these courses during their third and fourth years, on consultation with their advisers.

BIOLOGY OPTION

(For First Year see page 196)

The undergraduate option in Biology is designed to give the student an understanding of the basic facts, techniques, and concepts of biological science as well as a solid foundation in physical science. Emphasis is placed on the more general and fundamental properties of living creatures, thus unifying the traditionally separate fields of the life sciences. Involvement of undergraduates in the research programs of the division is encouraged.

Flexibility to accommodate varied individual scientific interests, within the broad scope of biology, is achieved through the provision of numerous electives courses, through the program of tutorial instruction (Bi 23) and through the Biology Scholar's Program (Bi 27 — see below).

The undergraduate option serves as a basis for graduate study in any field of biology or for admission to the study of medicine.

Biology Scholar's Program. This program permits — for a small number of Biology juniors and seniors — the formulation of individual academic programs, combining course work and independent study, adapted to each student's interests and requirements. Each program must be acceptable to and is supervised by a faculty committee; work is undertaken and evaluated on the basis of a written "contract" between the student and his committee and instructors. Students in this program continue to be bound by the normal Institute requirements outside of the biology option; however credit within the program may be, by agreement, on a pass-fail basis.

Admission into the Scholar's Program is limited and continuance is contingent upon satisfactory progress. For further details, consult the Biology Undergraduate Student Adviser.

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. Slight modifications in the curriculum may be required for admission to certain medical schools, or in cases in which the student wishes to try to complete admission requirements in three years instead of four. The student should consult with the premedical adviser about this.

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 his division may, at the discretion of his department, be refused permission to continue the work of that option. A fuller statement of this regulation will be found on page 192.

SECOND YEAR

		Units per Term 1st	2nd	3rd
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ph 2 abc	Electricity, Fields, and Quantum Mechanics (4-0-5)	9	9	9
PE 2 abc	Physical Education (0-3-0)	3	3	3
	Humanities Electives[1]	9	9	9
	Science or Engineering Electives[2]	7	.	.
Ch 41 abc	Chemistry of Covalent Compounds (3-0-6)	9	9	9
Bi 1	Introduction to Biology (3-3-3)	.	9	.
Bi 9	Cell Biology (3-3-3)	.	.	9
		46	48	48

[1]For rules governing Humanities electives, see page 196.

[2]The following Sophomore electives are recommended* for Biology majors:

Electives

Ch 46 a	Experimental Methods of Covalent Chemistry (1-6-0)	7	7	.

THIRD YEAR

	Humanities Electives[3]	9	9	9
Ch 21 abc	Physical Chemistry (3-0-6)	9	9	9
Bi 7	Organismic Biology (3-5-4)	12	.	.
Bi 110 ab	Biochemistry (3-0-7)	10	10	.
Bi 111	Biochemistry Laboratory (0-8-2)	.	10	.
Bi 122	Genetics (3-3-6)	.	.	12
	Electives	6-12	8-14	16-22
		46-52	46-52	46-52

[3]For rules governing Humanities electives, see 196.

Electives

Bi 3	Biology and Social Problems (2-0-4)	.	.	6
Bi 22	Special Problems (units to be arranged)	x or	x or	x

Bi 23	Biology Tutorial (units up to 6 maximum to be arranged)	x or	x or	x
Bi 27	Biology Scholar's Program	x or	x or	x
Bi 101	Invertebrate Biology (2-6-4)	.	12	.
Bi 102	Vertebrate Biology (2-5-5)	.	12	.
Bi 106	Introductory Developmental Biology of Animals (2-6-4)	.	12	.
Bi 114	Immunology (3-4-5)	12	.	.
Bi 119	Advanced Cell Biology (3-0-6)	.	.	9
Bi 123	Genetics Colloquium (2-0-4)	.	.	6
Bi 124	Genetics Laboratory (units to be arranged)	.	.	.
Bi 128	Advanced Microtechnique (1-4-1)	.	.	6
Bi 153	Brain Studies of Motivated Behavior (3-0-6)	.	9	.
Bi 155	Psychobiology (2-4-3)	.	.	9
Env 144	Ecology (2-1-3)	.	.	6
L 1 abc	Elementary French (3-1-6)	10	10	10
L 32 abc	Elementary German (4-0-6)	10	10	10
L 50 abc	Elementary Russian (4-0-6)	10	10	10

FOURTH YEAR

	Humanities Electives[1]	9	9	9
Bi 151	Neurophysiology (3-5-4)	12	.	.
	Electives	27-32	37-42	37-42
		46-51	46-51	46-51

Electives

In addition to those listed for the third year:

Bi 115	Virology (3-4-3)	.	.	10
Bi 152	Behavioral Biology (2-0-4)	.	6	.
Bi 129	Biophysics (2-0-4)	.	6	.
Bi 132 ab	Biophysics of Macromolecules (3-0-6)	9	9	.
Bi 133	Biophysics of Macromolecules Laboratory (0-10-4)	.	14	14
Bi 141	Selected Topics in Evolution Theory (3-0-6)	.	.	9
Bi 208	Selected Topics in Neurobiology	.	x or	x
Bi 209	Psychobiology Seminar (units to be arranged)	x or	x or	x
Bi 220 abc	Developmental Biology of Animals (2-0-4)	6	6	6
Bi 221	Developmental Biology Laboratory (units to be arranged)	x or	x or	x
Bi 241	Advanced Topics in Molecular Biology (2-0-4)	.	.	6
Bi 260	Advanced Physiology (units to be arranged)	x or	x or	x
Ch 144 ab	Advanced Organic Chemistry (3-0-6)	9	9	.
Ch 244 ab	Molecular Biochemistry (3-0-3)	6	6	.
Env 145 a	Environmental Biology (2-4-4)	.	10	.
Env 145 b	Environmental Biology (3-0-6)	.	.	9
Ge 5	Geobiology (3-0-6)	.	.	9

Any advanced course offered by another Division, subject to approval by the student's adviser.

[1]For rules governing Humanities electives see page 196.

CHEMICAL ENGINEERING OPTION

Chemical Engineering is one of the broader of the applied disciplines, since it involves intellectual development in the fundamental areas of mathematics, physics, and chemistry; in addition, it requires decision making in problem areas calling for judgment in economic and social matters. Study in this option leads, especially when followed by graduate work, to careers in teaching and research in colleges and universities or to opportunities in government and industrial concerns, including research, development and management of broad classes of problems involving chemical systems.

The first-year general chemistry course, which is taken by all freshman students, emphasizes fundamental principles and their use to systematize descriptive chemistry. The one-term required laboratory is essentially in quantitative analysis, but is designed to train the student to plan, execute, and critically interpret experiments involving quantitative measurements of various physical quantities. The laboratory in the second and third terms is optional and is designed to introduce the student to current experimental work in chemical synthesis, structure, and dynamics. Students who show themselves to be qualified by having done well in an Advanced Placement or equivalent course, and having passed a short additional departmental examination, may elect to take an advanced general chemistry course that differs chiefly from the main course by having different lectures.

In the second year of chemical engineering there is a basic course in thermodynamics and a basic course covering the properties and reactions of covalent organic and inorganic compounds. The associated laboratory course is elective in the second year and is designed to provide knowledge of the fundamental manipulative and spectroscopic techniques through studies of reactions and preparations of covalent compounds. In addition, there are elective courses which can be used by the student to enlarge his understanding of other fields of science and engineering.

In the third year, the chemical engineering option requires a basic course in physical chemistry. Chemical engineering laboratory is required in the first term, and in the second term the student may continue that laboratory or take the laboratory in physical chemistry. The chemical engineering option requires professional courses which include transport phenomena and engineering mathematics. The option provides time for some of the elective courses described on pages 202-203.

In the fourth year, chemical engineering curriculum contains courses in chemical kinetics and optimal design of chemical systems as well as electives in engineering and science and a course in advanced analytical chemistry.

Undergraduate research is emphasized in both options and students are encouraged even in the freshman year to participate in research in association with staff members. Over the past years these researches have resulted in a significant number of publications in scientific journals.

Attention is called to the fact that any student whose grade point average is less than 1.9 at the end of an academic year in the subjects listed under his division may, at the discretion of the faculty in Chemistry and Chemical Engineering, be refused permission to continue the work of that option. A fuller statement of this regulation will be found on page 192.

SECOND YEAR

		Units per Term 1st	2nd	3rd
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ph 2 abc	Sophomore Physics (4-0-5)	9	9	9
Ch 41 abc	Sophomore Chemistry (3-0-6)	9	9	9
ChE 63 abc[1]	Chemical Engineering Thermodynamics (3-0-6)	9	9	9
	Electives[2, 3, 4, 5, 6]	9	9	9
PE 2 abc	Physical Education (0-3-0)	3	3	3
		51	51	51

THIRD YEAR

ChE 126 ab[7]	Chemical Engineering Laboratory (7-0-2)	9	9	.
AM 95 abc	Engineering Mathematics (4-0-8)	12	12	12
Ch 21 abc	The Physical Description of Chemical Systems (3-0-6)	9	9	9
ChE 103 abc	Transport Phenomena (3-0-6)	9	9	9
	Electives[2, 3, 4, 5, 6]	9-12	9-12	18-21
		48-51	48-51	48-51

FOURTH YEAR

Ch 114	Quantitative Analysis (2-0-2)	4	.	.
ChE 101 ab	Applied Chemical Kinetics (2-0-7)	9	9	.
ChE 110 abc	Optimal Design of Chemical Systems (3-0-9)	9	9	9
	Electives[2, 3, 4, 5, 6]	27-30	30-33	39-42
		49-52	48-51	48-51

[1]ChE 63 abc may be taken in the junior year, but is strongly recommended for the sophomore year.

[2]A total of 15 units of elective laboratory courses, including 9 units to be taken in the first year, is required for graduation. These must include 6 units of EE 90, taken before the end of the third year.

[3]In addition to EE 90, other courses which include circuit analysis, such as EE 5, are recommended.

[4]If ChE 80 units are to be used to fulfill elective requirements in the chemical engineering option, a thesis approved by the research director must be submitted in duplicate before May 10 of the year of graduation.

[5]A total of 108 units of courses in Humanities or Social Sciences, including Ec 4 ab, must be taken by the undergraduate. Of these, a minimum of 27 units must be in English with at least 9 units of English taken after the freshman year. Elective units shown here may be used to help meet those requirements.

[6]In addition to approved elective courses listed on pages 202-203, any science and engineering course will be accepted if approved by the adviser. A student entering the chemical engineering option after the sophomore year who has not taken Ch 41 abc must take this course instead of an equal number of elective units.

[7]Students may elect Ch 26 a in place of ChE 126 b.

APPROVED ELECTIVE COURSES IN THE CHEMICAL ENGINEERING OPTION

Other courses may be taken as electives provided they are in science or engineering subjects and are approved by the adviser. The student must meet any prerequisites required for a course.

Ch 3 ab	Experimental Chemical Science (0-3-0 or 0-6-0)	.	3-6	3-6
Ch 24 c	Elements of Physical Chemistry (3-0-6)	.	.	9

Ch 46 ab	Experimental Methods of Covalent Chemistry (0-6-2)	.	8	8
Ch 113 abc	Advanced Inorganic Chemistry (3-0-6)	9	9	9
Ch 117	Introduction to Electrochemistry (2-0-2)	.	4	.
Ch 118 ab	Experimental Electrochemistry	Units to be arranged		
Ch 125 abc	Introduction to Chemical Physics (3-0-6)	9	9	9
Ch 127 ab*	Nuclear Chemistry (3-0-6)	9	9	.
Ch 129 abc*	Structure of Crystals (3-0-6)	9	9	9
Ch 130	Fundamentals of Photochemistry and Photobiology (3-0-3)	6	.	.
Ch 144 ab	Organic Chemistry (3-0-6)	9	9	.
ChE 10	Chemical Engineering Systems	.	.	9
ChE 80	Undergraduate Research	Units to be arranged		
ChE 105 abc	Applied Chemical Thermodynamics (3-0-6)	9	9	9
ChE 107 abc	Polymer Science (3-0-6)	9	9	9
ChE 172 abc	Control Systems Theory (3-0-6)	9	9	9
E 5 ab	Laboratory Research Methods in Engineering and Applied Science (1-3-2)	.	6	6
EE 3	Introduction to Solid State Electronics (2-0-2)	4	.	.
EE 5	Introductory Electronics (3-0-6)	.	.	9
EE 9	Solid State Electronics Laboratory (1-3-2)	.	6	.
EE 90 abc	Laboratory in Electronics (0-3-0)	3	3	3
ES 102 abc	Applied Modern Physics (3-0-6)	9	9	9
Ph 3	Physics Laboratory	.	6	6
Ph 4	Physics Laboratory	.	.	6
Ph 5	Physics Laboratory	6	.	.
Ph 6	Physics Laboratory	.	6	.
Ph 7	Physics Laboratory	.	.	6

*Not offered in 1970-71.

CHEMISTRY OPTION

(For first year see page 196.)

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

The first-year general chemistry course, which is taken by all freshman students, emphasizes fundamental principles and their use to systematize descriptive chemistry. The one-term required laboratory is essentially in quantitative analysis, but is designed to train the student to plan, execute, and critically interpret experiments involving quantitative measurements of various physical quantities. The laboratory in the second and third terms is optional and is designed to introduce the student to current experimental work in chemical synthesis, structure, and dynamics. Students who show themselves to be qualified by having done well in an Advanced Placement or equivalent course and having passed a short additional departmental examination may elect to take an advanced general chemistry course that differs chiefly from the main course by having different lectures.

There are no formal chemistry course requirements in the chemistry option except for 2 units of Ch 90. Each student, in consultation with his adviser, selects a suitable course of study under the supervision of the Division. Within the total period of undergraduate study there are Institute requirements for Ma 1 abc, Ph 1 abc, Ma 2 abc, Ph 2 abc, and 108 units of humanities and/or social science as well as 18 units of physical education.

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

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

SECOND YEAR

		Units per Term 1st	2nd	3rd
Ch 41 abc	Chemistry of Covalent Compounds (3-0-6) ...	9	9	9
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ph 2 abc	Electricity, Fields, and Quantum Mechanics (4-0-5)	9	9	9
Ch 46 a	Experimental Methods of Covalent Chemistry ((0-6-2)	.	8	.
	Electives	15-18	7-10	15-18
PE	Physical Education (0-3-0)	3	3	3
		45-48	45-48	45-48

THIRD YEAR

		1st	2nd	3rd
Ch 14	Chemical Equilibrium (2-6-2)	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	26-30	38-42	38-42
		47-51	47-51	47-51

FOURTH YEAR

		1st	2nd	3rd
Ch 26 a	Physical Chemistry Laboratory (0-6-4)	.	10	.
	Electives	47-51	37-41	47-51
		47-51	47-51	47-51

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

SUGGESTED REPRESENTATIVE COURSES OF STUDY FOR THOSE INTENDING TO DO GRADUATE WORK IN PARTICULAR AREAS OF CHEMISTRY

Inorganic Chemistry	*Chemical Physics*	*Organic Chemistry*	*Chemical Biology*
Sophomore year	Sophomore year	Sophomore year	Sophomore year
Ch 41 abc	Ch 41 abc	Ch 41 abc	Ch 41 abc
Ch 46 ab	Ch 46 a	Ch 46 ab	Ch 46 ab
Ph 2 abc	Ph 2 abc	Ph 2 abc	Ph 2 abc
Ma 2 abc	Ma 2 abc	Ma 2 abc	Ma 2 abc
PE 2 abc	PE 2 abc	PE 2 abc	PE 2 abc
Electives[a,b]	Electives[a,b]	Electives[c]	Electives[a]
Junior Year	Junior Year	Junior Year	Junior Year
Ch 21 abc	Ch 21 abc	Ch 21 abc	Ch 21 abc
Ch 14	Ch 14	Ch 14	Ch 14
Ch 90	Ch 26 ab	Ch 144 abc	Bi 110
Electives[a,b]	Ch 90	Ch 145 bc	Ch 132 ab
Senior Year	Am 95 ab	Ch 90	Ch 90
	Electives[a,b]	Electives[c]	Electives[a]
Ch 26 ab			
Ch 113 abc	Senior Year	Senior Year	Senior Year
Ch 125 abc	Ch 125 abc	Ch 26 ab	Ch 26 ab
Ch 135 or Ch 144 abc	Ph 106 abc or Ch 135	L 32 abc[a]	Ch 144
Electives[a,b]	Ch 226 abc	Ch 246 abc	Ch 133
	Electives[a,b]	Ch 247 ab	Bi 111
		Electives[c]	Electives[a]

[a]It should be recognized that a major fraction of the existing chemical literature, especially of organic chemistry, is in German. Russian is an important language for chemistry but the leading Russian periodicals are translated and published in English. A reading knowledge of German is important for research at the doctoral level.

[b]Experience in computer programming and use is now important to all areas of chemistry.

[c]Courses in biology and biochemistry are recommended as part of these electives.

SUGGESTED ELECTIVE COURSES FOR THE CHEMISTRY OPTION

Ch 3 ab	Experimental Chemical Science (0-3-0 or 0-6-0)	.	3-6	3-6
Ch 24 c	Elements of Physical Chemistry (3-0-6)	.	.	9
Ch 80	Chemical Research	Units to be arranged		
Ch 81	Special Topics in Chemistry	Units to be arranged		
Ch 113 abc	Advanced Inorganic Chemistry (3-0-6)	9	9	9
Ch 117	Introduction to Electrochemistry (2-0-2)	.	4	.
Ch 118 ab	Experimental Electrochemistry	Units to be arranged		
Ch 122 ab	The Structure of Molecules (2-0-4)	6	6	.
Ch 125 abc	Introduction to Chemical Physics (3-0-6)	9	9	9
Ch 127 ab*	Nuclear Chemistry (3-3-6) or (3-0-3)	12	12	.
Ch 129 abc*	Structure of Crystals (3-0-6)	9	9	9
Ch 130	Fundamentals of Photochemistry and Photobiology (3-0-3)	6	.	.
Ch 132 ab	Biophysics of Macromolecules (3-0-6)	9	9	.

Ch 133	Biophysics of Macromolecules Laboratory (0-10-4)	.	14 or	14
Ch 144 ab	Organic Chemistry (3-0-6)	9	9	.
Ch 145 bc*	Organic Chemistry Laboratory (0-3-0) second term and (0-6-0) third term	3	6	.
ChE 10	Chemical Engineering Systems (3-3-3)	.	.	9
ChE 63 abc	Chemical Engineering Thermodynamics (3-0-6)	9	9	9
ChE 80	Undergraduate Research	Units to be arranged		
ChE 101 abc	Applied Chemical Kinetics (2-0-7)	9	9	9
ChE 103 abc	Transport Phenomena (3-0-6)	9	9	9
ChE 105 abc	Applied Chemical Thermodynamics (3-0-6) ...	9	9	9
ChE 107 abc	Polymer Science (3-0-6)	9	9	9
ChE 172 abc	Control Systems Theory (3-0-6)	9	9	9
AM 95 abc	Engineering Mathematics (4-0-8)	12	12	12
Ay 1	Introduction to Astronomy (3-1-5)	.	.	9
Bi 1	Introduction to Biology (3-3-3)	.	9	.
Bi 9	Cell Biology (3-3-3)	.	.	9
Bi 110 ab	Biochemistry (3-0-7) (Prerequisite Ch 41 a) ..	10	10	.
Bi 119	Advanced Cell Biology (3-0-6)	.	.	9
Bi 122	Genetics (3-3-6)	.	.	12
E 5 ab	Laboratory Research Methods in Engineering and Applied Science (1-3-2)	.	6	6
Ec 4 ab	Economic Principles and Problems	6	6	.
		or .	6	6
EE 3	Introduction to Solid State Electronics (2-0-2)	4	.	.
EE 5	Introductory Electronics (3-0-6)	.	.	9
EE 9	Solid State Electronics Laboratory (1-3-2)	.	6	.
EE 90 abc	Laboratory in Electronics (0-3-0)	3	3	3
ES 102 abc	Applied Modern Physics (3-0-6)	9	9	9
Ge 1	Physical Geology (4-2-3)	9	.	.
Ge 130 ab	Introduction to Geochemistry (2-0-4)	6	6	.
IS 10	Introduction to Use of Computers	.	6	.
L 32	Introductory Scientific German (0-0-10)	10	10	10
Ma 108 abc	Advanced Calculus (4-0-8)	12	12	12
Ph 3	Physics Laboratory	.	6	6
Ph 4	Physics Laboratory	.	.	6
Ph 5	Physics Laboratory	6	.	.
Ph 6	Physics Laboratory	.	6	.
Ph 7	Physics Laboratory	.	.	6
Ph 106 abc	Topics in Classical Physics (3-0-6)	9	9	9
Ph 125 abc	Quantum Mechanics (4-0-5)	9	9	9
Ph 129 abc	Methods of Mathematical Physics (3-0-6)	9	9	9

*Not offered in 1970-71.

ECONOMICS OPTION

(For First Year see page 196)

SECOND YEAR

		Units per Term 1st	2nd	3rd
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ph 2 abc	Electricity, Fields, and Quantum Mechanics (4-0-5)	9	9	9
Ec 4 ab	Economic Principles and Problems (3-0-3)	6	6	.
PE 2 abc	Physical Education (0-3-0)	3	3	3
	Electives, not less than*	18	18	24
		45	45	45

THIRD YEAR

Ec 126 ab	Money, Income, and Growth (3-0-6)	9	9	.
Ec 121 a	Price Theory (3-0-6)	9	.	.
Ec 122 a	Econometrics (3-0-6)	.	9	.
Ma 112	Elementary Statistics (3-0-6)	9	.	.
	Electives, not less than*	18	27	45
		45	45	45

FOURTH YEAR

Electives, not less than*	45	45	45

*These electives are to include:

a. 54 units of natural science, mathematics or engineering beyond the sophomore level, including 9 units in mathematics in addition to Ma 112.

b. 45 units of economics, chosen from Ec 98 abc, Ec 111, Ec 112, Ec 115, Ec 116, Ec 120, Ec 121 b, Ec 122 b, Ec 123, Ec 124 ab, Ec 125 ab, Ec 127, Ec 128, IS 181 ab, or any other course approved by the adviser.

ENGINEERING AND APPLIED SCIENCE OPTION

(For First Year see page 196)

"The four-year Undergraduate Course in Engineering," as prescribed in the Educational Policies of the Institute, "shall be of general, fundamental character, with a minimum of specialization in the separate branches of engineering. It shall include an unusually thorough training in the basic sciences of physics, chemistry, and mathematics, and a large proportion of cultural studies."

The course is designed to give the greatest possible flexibility as preparation for graduate study and for professional practice. The course involves four years of study leading to the degree of Bachelor of Science. The first year is essentially common for all students at the Institute. At the end of this year a student who elects engineering is assigned an adviser in his general field of interest and together they develop a program of study for the next three years. This program includes the Institute-wide requirements in physics, mathematics, and humanities, and an additional, or third year, of advanced mathematics. Beyond these specifications the student and his adviser choose from a wide range of engineering and science electives to build a solid foundation for the kind of engineering activity toward which the student aims. For most students, graduate study in a specialized branch of engineering will be the goal. These students may wish to elect some foreign language also as graduate preparation. For others, immediate industrial work is the objective, and ultimately administration. Such students will be able to build a course of study from specialized professional courses and more general engineering science subjects suitable for more immediate engineering practice. Among such professional courses are a number which are nominally graduate subjects but which may be elected by undergraduates with adequate preparation.

The engineering curriculum is thus extremely flexible and a student will be advised to seek breadth as well as reasonable concentration in a technical area. No one rigidly prescribed curriculum can serve the needs of all students. Nor do the traditional curricula of the specialized branches of engineering properly reflect the interdisciplinary character of modern engineering. Consequently, the California Institute of Technology has adopted a single engineering curriculum strong in the sciences and humanities, with great flexibility of choice among the engineering sciences. This four-year bachelor's program leads logically toward graduate study in some specialized engineering field. It recognizes the increasing national growth in graduate engineering education and through good counseling and elective freedom builds an adequate preparation.

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 his division may, at the discretion of the faculty in Engineering and Applied Science, be refused permission to continue the work of that option. A fuller statement of this regulation will be found on page 192.

SECOND YEAR

		Units per Term 1st	2nd	3rd
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ph 2 abc	Electricity, Fields, and Quantum Mechanics (4-0-5)	9	9	9
PE 2 abc	Physical Education (0-3-0)	3	3	3
	Science or Engineering Electives	9	9	9
	Electives[1,2]	12-18	12-18	12-18
		42-48	42-48	42-48

THIRD YEAR

	Humanities Elective[2] (3-0-6)	9	9	9
AM 95 abc	Engineering Mathematics or	12	12	12
Ma 108 abc	Introduction to Real & Complex Analysis (4-0-8)			
	Electives[1]	25-31	25-31	25-31
		46-52	46-52	46-52

FOURTH YEAR

	Humanities Elective[2] (3-0-6)	9	9	9

E 10 ab	Technical Presentations (1-0-1)	2	2	.
	Electives[1]	34-40	34-40	34-40
		45-51	45-51	45-51

[1]The electives must include at least 99 units of courses in the Division of Engineering and Applied Science (Ae, AMa, AM, E, EE, ES, Env, Gr, Hy, IS, JP, MS, ME) in which a passing grade is obtained. None of the courses included in the 99 units shall be elected by the student to be taken on a pass-fail basis. Of these 99 units, at least 9 units must be chosen from among the laboratory courses listed below. In addition, the student shall take at least 9 units of another laboratory course offered in any option beyond the freshman year; if this course is in Engineering and Applied Science, it may be included in the 99 unit requirement. Electives must be approved by the student's adviser. A passing grade must be obtained in courses aggregating at least 399 units beyond the freshman year for graduation in the Engineering and Applied Science option.

Courses that may be used to satisfy the laboratory requirement are as follows:

Ae 105 b	6 units	Fluid Mechanics Laboratory
Ae 105 c	6 units	Fluid Mechanics Laboratory
Ae 106 b	6 units	Solid Mechanics Laboratory
Ae 106 c	6 units	Solid Mechanics Laboratory
AM 155	9 units	Dynamics Measurements Laboratory
AM 160	6 units	Vibrations Laboratory
EE 90 a	3 units	Laboratory in Electronics
EE 90 b	3 units	Laboratory in Electronics 6 units maximum
EE 90 c	3 units	Laboratory in Electronics
EE 91 a	5 units	Experimental Projects in Electrical Engineering and Applied Physics
EE 91 b	5 units	Experimental Projects in Electrical Engineering and Applied Physics
EE 91 c	5 units	Experimental Projects in Electrical Engineering and Applied Physics
ES 103	9 units	Nuclear Radiation Measurements Laboratory
ES 104	9 units	Nuclear Energy Laboratory
Hy 111	6-9 units	Fluid Mechanics Laboratory
Hy 121	6 + units	Advanced Hydraulics Laboratory
JP 170	9 units	Jet Propulsion Laboratory
ME 126	9 units	Fluid Mechanics and Heat Transfer Laboratory
MS 11	9 units	Metallography Laboratory
MS 102	9 units	Pyrometry
MS 103 a	9 units	Physical Metallurgy Laboratory
MS 103 b	6 units	Physical Metallurgy Laboratory
MS 104 a	9 units	Materials Science Laboratory
MS 104 b	9 units	Materials Science Laboratory
MS 104 c	9 units	Materials Science Laboratory

[2]For rules governing Humanities electives, see page 196.

Note: A student who plans to apply for graduate study at the Institute in some field of Engineering and Applied Science should, before choosing his electives, consult Section IV of this catalog for specific requirements for admission to graduate study in this field.

ENGLISH OPTION

(For First Year see page 196)

Attention is called to the requirement that all students in the English option must demonstrate competence in one foreign language. This means the satisfactory completion (grade of C or better) of the first year of an Institute language course, or the equivalent.

SECOND YEAR

Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ph 2 abc	Electricity, Fields, and Quantum Mechanics (4-0-5)	9	9	9
PE 2 abc	Physical Education (0-3-0)	3	3	3
	Electives, not less than*	24	24	24
		45	45	45

*Students in the English option must complete successfully:

a. At least 54 units of natural science, mathematics, or engineering taken beyond the sophomore year.

b. 108 units of English beyond the freshman year.

THIRD YEAR

	Electives, not less than *	45	45	45

FOURTH YEAR

En 122 abc	Senior Seminar (2-0-7)	9	9	9
	Electives, not less than *	36	36	36
		45	45	45

*Students in the English option must complete successfully:
a. At least 54 units of natural science, mathematics, or engineering taken beyond the sophomore year.
b. 108 units of English beyond the freshman year.

GEOLOGICAL SCIENCES OPTION

(For First Year see page 196)

The aim of the undergraduate program in the geological sciences is to provide thorough training in basic geological disciplines and, wherever possible, to integrate the geological studies with and build upon the courses in mathematics, physics, chemistry, and biology taken during the earlier years at the Institute. Special emphasis is also placed on field work because it provides first-hand experience with geological phenomena that can never be satisfactorily grasped or understood solely from classroom or laboratory treatment. Options are offered in geology (including paleontology and paleoecology), geophysics, and geochemistry. Sufficient flexibility in electives is provided to permit a student to follow lines of special interest in related scientific and engineering fields. Research in pertinent aspects of planetary science is increasing. Men who do well in the basic sciences and at the same time have a compelling curiosity about the earth and its natural features are likely to find their niche in the geological sciences, especially if they possess a flexible mind that enables them to grapple with complex problems involving many variables. Most students majoring in the earth sciences now find further training at the graduate level necessary.

Men trained in the earth sciences find employment in research and teaching in colleges and universities, and in research in a wide variety of other professional endeavors. Many work for the petroleum industry, both in the field and in the laboratory, on theoretical as well as applied problems. Some eventually become administrators and executives. Mining companies, railroads, large utilities, and other organizations engaged in development of natural resources employ men trained in the geological sciences, as do a number of government agencies such as the U. S. Geological Survey and the Bureau of Reclamation.

Attention is called to the fact that any student whose grade-point average in freshman and sophomore physics, chemistry, and mathematics is less than 1.9 at the end of an academic year may, at the discretion of the Division of Geological Sciences, be refused permission to register in the Geological Sciences Option. Furthermore, any student whose grade-point average is less than 1.9 in the subjects in the Division of Geological Sciences for the academic year, may, at the discretion of the Division, be refused permission to continue in the Geological Sciences Option.

SECOND YEAR

(All options in the Division)

		Units per Term 1st	2nd	3rd
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ph 2 abc	Electricity, Fields, and Quantum Mechanics (4-0-5)	9	9	9
PE 2 abc	Physical Education (0-3-0)	3	3	3
	Electives (see suggested Electives listed below)*	**	**	**

*The following courses are suggested as being especially suitable for a balanced program of study: Ch 14, Ch 41 abc, Ch 46 abc, Bi 1, Bi 7, Ge 1, Ge 2, Ge 4, Ge 5. Different courses may be elected with the advice and consent of the student's adviser, but at least 18 units of electives must be taken outside of the Division.

**In choosing electives note:

1) The Institute requires 108 units of Humanities for graduation, including En 7 (or 27 units of English). See page 196.

2) The Division requires L 32 abc (German) or L 50 abc (Russian) for graduation. Election of these in the second or third year permits a student to take L 33 abc or L 51 abc in the following year as part of the Humanities requirement and gives him the command of a language required for graduate study.

3) The Division requires that 24 units of Physics and/or Chemistry Laboratory courses be completed by the end of the third year. Transfer students with irregular programs must consult with their advisers concerning exceptions to the time of completion of these requirements.

4) The Division requires that at least 405 units of required courses plus electives be taken after the first year, based on an average of 45 units per quarter.

5) Electives should be chosen with the advice and consent of the student's adviser.

THIRD YEAR

Geology Option

Ge 104 abc	Advanced General Geology (4-2-3)	9	9	9
Ge 105 abc	Geological Field Training and Problems (0-6-0)	6	6	6
Ch 24 ab	Elements of Physical Chemistry (3-0-6)*	9	9	.
Ge 114	Mineralogy II (Optical Mineralogy) (3-6-1)	.	10	.
Ge 115 a	Igneous Petrology and Petrography (3-6-1)	.	.	10
	Electives (select from Electives listed below under Geochemistry Option)	**	**	**

*Paleontologists may substitute Ch 41 abc and Ch 46 abc for Ch 24 ab.
**Note Second year comments on choice of electives.
Summer Field Geology, Ge 123, 30 to 40 units, required after third year in Geology Option.

Geochemistry Option

Ge 104 abc	Advanced General Geology (4-2-3)	9	9	9
Ge 105 abc	Geological Field Training and Problems (0-6-0)	6	6	6
Ch 21 abc	Physical Chemistry (3-0-6)	9	9	9
Ge 114	Mineralogy II (Optical Mineralogy) (3-6-1)	.	10	.

Ge 115 a	Igneous Petrology and Petrography (3-6-1) ...	.	.	10
	Electives (select from Electives listed below)	**	**	**

**Note Second Year comments on choice of electives.
Summer Field Geology, Ge 123, 30 to 40 units, required after third year in Geochemistry Option.
Ge 130 and Ge 132 are strongly recommended for geochemists. Other elective subjects include Ay 1, Ma 112, Ch 14, Ch 41 abc, Ch 46 abc, ChE 10, Hy 210 ab, AM 95 abc, AM 97 abc, Ph 102 abc among others, provided student has proper prerequisites.

Geophysics Option

Ge 104 abc	Advanced General Geology (4-2-3)	9	9	9
Ge 105 abc	Geological Field Training and Problems (0-6-0)	6	6	6
Ph 106 abc	Topics in Classical Physics (3-0-6)	9	9	9
AM 95 abc	Engineering Mathematics (4-0-8)	12	12	12
	Electives*	**	**	**

*Any Ge course, Ay 1, ES 130 abc, Ph 102, MS 5, Ma 108, Ma 109, Ma 112 ab, AMa 105, Ch 21 abc, EE 5.
**Note Second Year comments on choice of electives.

FOURTH YEAR

Common to All Options in the Division

L 32 abc	Elementary German (4-0-6)	10**	10**	10**
or				
L 50 abc	Elementary Russian			
Ge 102	Oral Presentation (1-0-1)	2	.	.
Ge 100	Geology Club (1-0-0)	1	1	1

**Note Second Year comments on choice of electives.

Geology Option

Ge 121 abc	Advanced Field Geology (0-8-2)	10	10	10
	Electives*	**	**	**

*These electives are to include a minimum of 30 units of Ge 111 ab, Ge 115 bc, Ge 126, Ge 130, Ge 132, Ge 135. AM 95 abc is strongly recommended.
**Note Second Year comments on choice of electives.

Geochemistry Option

Ge 115 c	Metamorphic Petrology and Petrography (3-4-3)	10	.	.
Ch 14	Quantitative Analysis (2-6-2)	10	.	.
Ch 26 ab	Physical Chemistry Laboratory (0-6-2)	.	8	8
	Electives*	**	**	**

*Suggested electives: Ch 113, Ch 127 ab, Ch 129, Ge 212, Ge 215, Ph 102 abc, AM 95 abc.
**Note Second Year comments on choice of electives.

Geophysics Option

Physics or Mathematics Electives*	18	18	18
Geology or Geophysics Electives	**	**	**

*Suggested physics or math electives: Ph 102, Ph 129, Ph 205, AMa 101, AMa 104, AMa 152, Ma 205, AM 125.
**Note Second Year comments on choice of electives.

HISTORY OPTION

(For First Year see page 196)

Attention is called to the requirement that all students in the History option must demonstrate competence in one foreign language. This means the satisfactory completion (grade of C or better) of the first year of an Institute language course, or the equivalent.

SECOND YEAR

		Units per Term 1st	2nd	3rd
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ph 2 abc	Electricity, Fields, and Quantum Mechanics (4-0-5)	9	9	9
PE 2 abc	Physical Education (0-3-0)	3	3	3
	Electives, not less than*	24	24	24
		45	45	45

THIRD YEAR

		1st	2nd	3rd
H 97 bc	Junior Tutorial (2-0-7)	.	9	9
	Electives, not less than*	45	36	36
		45	45	45

FOURTH YEAR

		1st	2nd	3rd
H 98 ab	Senior Tutorial (2-0-7)	9	9	.
H 99 abc	Research Tutorial (1-0-8)	9	9	9
	Electives, not less than*	27	27	36
		45	45	45

*Students in the History option must complete successfully:
a. At least 54 units of natural science, mathematics, or engineering beyond the sophomore year.
b. At least 90 units of history, comprised of H 97 bc, H 98 ab, H 99 abc, and 27 units of courses chosen from among those listed as "Advanced Subjects." Students are expected to use H 97 and H 98 to prepare themselves in two of the following fields: Medieval and Early Modern European; Modern European; American; and non-Western history. They are also expected to take the required 27 units of advanced courses outside the two fields which they may select. Students may substitute appropriate advanced courses for H 98 a or b with their adviser's approval.

MATHEMATICS OPTION

(For First Year see page 196)

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

Since the more interesting academic and industrial positions open to mathematicians require training beyond a bachelor's degree, the student who expects to make mathematics his profession must normally plan to continue, either here or elsewhere, with graduate work leading to the degree of Doctor of Philosophy. The undergraduate should bear this in mind in choosing his course of study. In particular he is urged to include at least one year, and preferably two years, of language study in his program. Overloads in course work are strongly discouraged; students are advised instead to deepen and supplement their course work by independent reading. The excellent mathematics library with its large collection of journals is housed on the seventh floor of the Robert A. Millikan Memorial Library. In addition, there is a reference library of duplicate books and periodicals located on the third floor of the Sloan Laboratory of Mathematics and Physics. Books that are not on reserve for special courses may be borrowed from the Millikan Library. Current periodicals may be consulted in either library.

Normally the undergraduate will have joined the option by the beginning of his sophomore year. He is required to take course Ma 5 abc during his second year. Students transferring from another option at the end of the sophomore year who have not yet taken this course will take it as their selected course in mathematics during their junior year concurrently with Ma 108, and will also take two selected courses in mathematics during their senior year.

The schedule of courses in the undergraduate mathematics option is flexible. It enables the student to adapt his program to his needs and mathematical interests and gives him the opportunity of becoming familiar with creative mathematics early in his career. Each term during his junior and his senior year the student will normally take 18 units of courses in mathematics, including the required course Ma 108. These courses are chosen from the subjects of instruction listed under A on page 362 of this catalog. The courses Ma 102, 103, 104, 109, 112, 116 and AMa 105 are recommended to juniors and seniors. The other courses demand more maturity and prerequisites. They are recommended to seniors only.

Attention is called to the fact that any student whose grade-point average is less than 1.9 at the end of the academic year in the subjects listed under the division may, at the option of his department, be refused permission to continue the work of that option. A fuller statement of this regulation will be found on page 192.

SECOND YEAR

		Units per term		
		1st	2nd	3rd
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ph 2 abc	Electricity, Fields, and Quantum Mechanics (4-0-5)	9	9	9
Ma 5 abc	Introduction to Abstract Algebra (3-0-6)	9	9	9
	Electives outside of Mathematics	9	9	9
	Humanities Electives,[1] Minimum for first two years: 45 units	0-9	0-9	0-9
PE 2 abc	Physical Education (0-3-0)	3	3	3
		42-51	42-51	42-51

THIRD YEAR

Ma 108 abc	Advanced Calculus (4-0-8)	12	12	12
	Selected courses in Mathematics .... Minimum	9	9	9

Humanities Electives,[1] Minimum for first three years: 81 units	9-18	9-18	9-18
Non-Mathematics Electives ....Minimum	9	9	9
For each term the total number of units is required to fall within range	39-48	39-48	39-48

FOURTH YEAR

Selected course in Mathematics	9	9	9
Humanities Electives,[1] Minimum for Graduation: 108 units	9-18	9-18	9-18
Electives (Mathematics or Non-Mathematics) Minimum	18	18	18
For each term the total number of units is required to fall within range	36-45	36-45	36-45

Normally a junior will elect 9 units each term, and a senior 18 units each term, in Mathematics. Sophomores who have not taken Ma 5 must take this course as juniors, postponing the selected course in Mathematics to the senior year. They are strongly advised to take one or preferably two full-year courses in languages.

[1]For rules governing Humanities electives, see page 196.

PHYSICS OPTION

(For First Year see page 196)

The distinctive feature of the undergraduate work in physics at the California Institute is the creative atmosphere in which the student at once finds himself. This results from the combination of a large and very productive graduate school with a small and carefully selected undergraduate body.

In order to provide the thorough training in physics required by those who are going into scientific or engineering work, two full years of general physics are required of all students. This first course in physics introduces modern ideas at the beginning of the first year and develops these along with the principles of classical mechanics and electricity as they apply to the dynamics of particles. More complex problems including the mechanics of continuous media, electromagnetic fields, and atomic structure will be treated in the second year. Those who want to major in physics take intensive courses during their junior and senior years that provide an unusually thorough preparation for graduate work. The curriculum provides for the teaching of classical and modern physics from the first year through the entire undergraduate course of study. Elective courses during the junior and senior years provide flexibility which enables the student to select a program to fit his individual requirements. Many of the undergraduate students who elect physics are also given an opportunity to participate in some of the thirty to sixty research projects which are always under way and the graduate seminars which are open to undergraduates at all times.

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 his division may, at the discretion of his department, be refused permission to continue the work of that option. A more complete statement of this regulation will be found on page 192.

SECOND YEAR

		Units per term 1st	2nd	3rd
Ph 2 abc	Electricity, Fields, and Quantum Mechanics (4-0-5)	9	9	9
Ma 2 abc	Sophomore Mathematics (4-0-5)	9	9	9
Ph 3,5,6,7	Physics Laboratory (See below for requirements)	0-6	0-6	6
	Electives[1,2] not less than	21	21	21
PE 2 abc	Physical Education (0-3-0)	3	3	3
		45-51	45-51	51

Physics Laboratory Requirements

Students choosing a major in physics must complete the following laboratory requirements by the end of the second year:

Ph 3 or Ph 4	6 units
Ph 5 or Ph 6	6 units
Ph 7	6 units
	18 units

Ph 3	Physics Laboratory (sophomores only)	6	.	.
	(freshmen only)	.	6	6
Ph 4[3]	Physics Laboratory	.	.	6
Ph 5	Physics Laboratory	6	.	.
Ph 6	Physics Laboratory	.	6	.
Ph 7	Physics Laboratory	.	.	6

Suggested Electives

The student may elect any course that is offered in any term, provided only that he has the necessary prerequisites for that course. The following subjects are suggested as being especially suitable for a well-rounded course of study.

Ma 5 abc	Introduction to Abstract Algebra (3-0-6)	9	9	9
Ge 1	Physical Geology (3-3-3)	9	.	.
Bi 1	Introduction to Biology (3-3-3)	.	9	.
Ay 1	Introduction to Astronomy (3-1-5)	.	.	9
ME 1 ab	Introduction to Design (2-6-1)	.	9	9
ME 3	Materials and Processes (3-0-6)	.	9	.
ME 17 abc	Thermodynamics (3-0-6)	9	9	9
EE 5	Introductory Electronics (3-0-6)	.	9	.
EE 13 abc	Linear System Theory (3-0-6)	9	9	9
EE 14 abc	Electronic Circuits (3-0-6)	9	9	9
Ch 41 abc	Chemistry of Covalent Compounds (3-0-6)	9	9	9
Ch 46 ab	Experimental Methods of Covalent Chemistry (0-6-2)	.	8	8
L 32 abc	Elementary Scientific German (3-1-6) (3-1-6) (4-0-6)	10	10	10

[1]At least 27 units of sophomore electives shall be chosen from science and engineering courses of which at least 18 units shall be in science and engineering courses other than mathematics or physics.

[2]For rules governing Humanities electives, see page 196.

[3]Students who have failed two or more terms of Ph 1 laboratory must pass Ph 4.

THIRD YEAR

Ph 102 abc	Modern Physics[1] (3-0-6)	9	9	9
Ph 106 abc	Topics in Classical Physics (3-0-6)	9	9	9
	Electives not less than	23	23	23
		41	41	41

Suggested Electives

Ph 77 ab	Advanced Physics Laboratory[2]	.	6	6
Ph 125 abc	Quantum Mechanics[3] (3-0-6)	9	9	9
Ph 171	Reading and Independent Study[4]	x	x	x
Ph 172	Experimental Research in Physics[4]	x	x	x
AM 95 abc	Engineering Mathematics (4-0-8)	12	12	12
Ma 108 abc	Advanced Calculus (4-0-8)	12	12	12
Ge 166 a	Physics of the Earth's Interior (3-0-6)	.	9	.
Ge 166 b	Planetary Physics (3-0-6)	.	.	9
Bi 9	Cell Biology (3-3-3)	.	.	9
Ay 112 abc	General Astronomy (3-0-3)	6	6	6
Ay 113 abc	General Astronomy Laboratory (0-4-0)	4	4	4
Ay 10	Introduction to Astrophysics (2-2-4)	.	8	.
Ay 15	Introduction to Radio Astronomy (3-0-6)	.	.	9
EE 13 abc	Linear System Theory (3-0-6)	9	9	9
EE 14 abc	Electronic Circuits (3-0-6)	9	9	9
EE 20 abc	Physics of Electronic Devices (3-0-6)	9	9	9
EE 90 abc	Laboratory in Electronics (0-3-0)	3	3	3
Ch 21 abc	Physical Chemistry (3-0-6)	9	9	9
Ch 26 ab	Physical Chemistry Laboratory (0-6-2)	.	8	8
L 50 abc	Elementary Russian (4-0-6)	10	10	10
L 1 abc	Elementary French (3-1-6)	10	10	10

[1]This requirement may also be satisfied by Ph 125 or Ph 112.
[2]Offered during all three terms.
[3]To be taken by juniors with permission of the instructor only.
[4]Up to a maximum of 9 units per term.

FOURTH YEAR

Ph 77 ab	Advanced Physics Laboratory[1,2]	6	6	.
	Physics Electives	18	18	18
	Humanities Elective[3]	9	9	9
	Electives	17	17	17
		50	50	44

Physics Electives

Ph 78 abc	Senior Thesis Experimental	9	9	9
Ph 79 abc	Senior Thesis Theoretical	9	9	9
Ph 87 ab	Experimental Projects in Applied Physics[2]	6	6	.
Ph 93 abc	Topics in Contemporary Physics (3-0-6)	9	9	9
Ph 112 abc	Modern Physics[4] (3-0-6)	9	9	9
Ph 113 abc	Introduction to Solid State Physics (3-0-6)	9	9	9
Ph 125 abc	Quantum Mechanics (3-0-6)	9	9	9
Ph 129 abc	Methods of Mathematical Physics (3-0-6)	9	9	9

Any graduate physics course (with number 200 or greater) for which the student has adequate prerequisites.

[1]This requirement may also be satisfied by 18 units of Ph 78 or two terms of Ph 87.
[2]Offered during all three terms.
[3]For rules governing Humanities electives, see page 196.
[4]Not open to students who have taken Ph 102.

STUDENT HEALTH AND PHYSICAL EDUCATION

Physical Education

Starting with the freshman year, all undergraduate students are required to enroll in and successfully complete six terms of physical education. This requirement may be satisfied by participation at the Intercollegiate or Intramural levels of athletics or by successfully completing a physical education class.

Men may be excused from the requirement of physical education by petitioning the Athletics and Physical Education Committee for such excuse (1) because of physical disability, or (2) can show credit for six terms of physical education at the college level. It is the responsibility of students who wish to be excused and who are eligible under this ruling to make application for excuse at the Athletic Office. A transfer student accepted with junior standing will not be required to take Physical Education regardless of Physical Education credit from his previous institution or the lack of it.

For graduate students there is no required work in physical education, but opportunities are provided for both recreational and competitive athletics. Graduate students should consult the Department of Athletics and Physical Education for further information.

Student Health

PRE-ADMISSION MEDICAL EXAMINATION AND VACCINATION

All admissions, whether graduate or undergraduate, are conditional until the Medical History and Physical Examination report is received and approved by the Director of Student Health (see page 183). Required are: smallpox vaccination, tetanus immunization, and tuberculosis testing, all within six months of matriculation.

STUDENT HEALTH SERVICES

The Archibald Young Health Center is located at 1239 Arden Road, south of California Boulevard. Facilities include a Dispensary and a ten-bed Infirmary, with provision for expanding this to sixteen beds in an emergency. The Health Center provides general office medical care, minor emergency surgery, and certain psychological and psychiatric services. Complete laboratory facilities are available through the Pasadena Clinical Laboratory.

The services of the Health Center are available to undergraduate and graduate students. They are available for faculty on a limited basis, covering emergency care, on-the-job injuries, inoculations, and annual physical examinations under certain conditions. They are available for employees of the Institute for on-the-job injuries and inoculations.

The staff of the Health Center consists of attending physicians, retained consultants, a psychologist, nurses, and a receptionist. A medical consultant in radiological safety is on the consulting staff. Close cooperation is maintained with leading specialists in all fields within the Pasadena area. The services of these doctors are used freely in maintaining high standards of modern medical care.

The Dispensary is open for all regular service from 9:00 a.m. to 5:00 p.m., Monday through Friday, and 9:00 a.m. to noon on Saturday, except during the summer months, when a slightly restricted schedule is observed. The Infirmary is operated (with a registered nurse available for emergency care, and a physician on call for emergencies) twenty-four hours a day, seven days a week, except during holidays and the summer period.

The Health Center is financed by the Institute and a Health Fee. During the summer, a special health fee of $10.00 is charged to student trainees and to students who have not been enrolled during the preceding three school terms, except that those graduate students who pay regular tuition during the summer months are exempt from this special fee.

STUDENT HEALTH PLAN

In addition to services available at the Health Center, year around coverage under California Physicians Service is provided. This integrated two-part plan includes basic hospital and surgical and major medical coverage for 80% of costs up to $10,000 after a $100 deductible. Details of coverage are contained in booklets available at the Personnel Office. All students are included, and benefits continue for twelve months, on campus and off campus, provided students remain enrolled through the school year. Students have available the following services:

1. Office consultations and treatment with a staff physician at prescribed hours.
2. Laboratory tests, consultations, and radiographs as prescribed or ordered by the staff physician.
3. Inoculations and treatments administered by nurses.
4. Routine drugs and medicine which may be dispensed at the Health Center.
5. Infirmary and hospital care.
6. Emergency care, hospital benefits, physician visits while in the hospital, and surgical benefits outlined in the Student Health Plan brochure available at the Personnel Office and also distributed upon registration.
7. In hardship cases funds are available to the Faculty Health Committee to assist students with the first $100 of expenses under the major medical coverage.
8. Psychological counseling and psychiatric service to the extent that these can be provided on a short-term basis. A staff psychiatrist and a staff psychologist are available at the Health Center. Cases requiring intensive or long-time care will be referred to outside physicians at the discretion of the Health Center staff and with the concurrence of the student or his family.
9. The Department of Physical Education maintains an insurance plan covering accidents in intercollegiate athletic participation.

COVERAGE OF DEPENDENTS

Besides the student coverage outlined above, a student's spouse and all unmarried dependent children over 14 days and under 19 years of age are eligible under the California Physicians Service contract. Dependent care is not administered at the Health Center except in case of severe emergency.

Application for dependent's insurance must be made at the time of registration or within 31 days of registration for any one school term. Rates applicable to dependent coverage are contained in the Student Health Plan brochure.

SERVICES NOT PROVIDED BY STUDENT HEALTH PLAN

1. Services provided to the student not authorized or requested by the Health Center staff (except during vacations or emergencies when the student is unable to utilize services of the Student Health Center).
2. Services for pregnancy or conditions arising therefrom, except for ectopic pregnancies.

3. Workman's Compensation cases.
4. Services provided by federal or state governmental agencies or without cost to the student by any other governmental agency.
5. Services provided by any other medical or hospital service organization.
6. Eye refractions.
7. Hospitalization for tuberculosis after diagnosis, except when required for surgery.
8. Dental services, including oral surgery and hospitalization for such, except that up to $300 is provided for care of injury to the permanent teeth.

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 Dispensary and Infirmary, as described above, 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 specified above. To secure payment 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 major medical claim is made through the Personnel Office.

UNDERGRADUATE EXPENSES

For freshmen applying for admission, there is a $10.00 Application Fee, not refundable, but applicable upon registration to the Tuition Fee.

For freshman and transfer students, there is a $10.00 Registration Fee payable upon notification of admission, not refundable if admission is cancelled by applicant. Housing contracts, accompanied by a $50.00 deposit, must be returned to Master's Office by August 1. The deposit will be applied to the first term room charge.

EXPENSE SUMMARY

	1970-71	1971-72
General:		
General Deposit[1]	$ 25.00	$ 25.00
Tuition	2,385.00	2,565.00
Health Fee	40.00	55.00
Student Body Dues, including *California Tech*	22.00	22.00[4]
Assessment for *Big T*	8.00	8.00[4]
	$2,480.00	$2,675.00
Other:[2]		
Books and Supplies (approx.)	$ 130.00	
Student House Living Expenses (20 meals per week) (Rates for room and board are subject to revision prior to August 1st of any year)		
Board	695.00	
Room[3]	465.00	
Dues	30.00	
	$1,320.00	

The following is a list of undergraduate student expenses at the California Institute of Technology for the Academic Year 1970-71, together with the dates on which the various fees are due. Charges are subject to change at the discretion of the Institute.

	First Term	*Fee*
September 24, 1970	General Deposit	$ 25.00
Freshmen	Tuition	795.00
September 28, 1970	Health Fee	40.00
All Others	Associated Student Body Dues	7.00
	Assessment for *Big T*	3.00
	Board and Room	420.00
	Student House Dues	10.00
	Second Term	
January 4, 1971	Tuition	795.00
	Associated Student Body Dues	7.50
	Assessment for *Big T*	2.50
	Board and Room	379.00
	Student House Dues	10.00
	Third Term	
March 29, 1971	Tuition	795.00
	Associated Student Body Dues	7.50
	Assessment for *Big T*	2.50
	Board and Room	361.00
	Student House Dues	10.00
Tuition Fees for fewer than	normal number of units:	
	Over 35 Units	Full Tuition
	Per unit per term	22.00
	Minimum per term	220.00
	Auditor's Fee (p. 189)	$30.00 per term, per lecture hour

1This charge is made only once during residence at the Institute (see page 222).
2Other annual expenses for the Academic Year 1971-72 are not available at this time.
3There are a few single rooms available which will rent for an additional $65.00 per year. Room contracts are on a term basis for all students.
4Fees subject to change by action of the Board of Directors of the Associated Students of the California Institute of Technology.

Withdrawals. Students withdrawing from the Institute during the first three weeks of a term, for reasons deemed satisfactory to the Institute, are entitled to a refund of tuition fees paid, less a reduction of 20 percent and a pro rata charge for time of attendance.[1] Adjustment of tuition charges may be arranged for changes in units if reported during the first three weeks of a term. No portion of the Student Body Dues, or subscription to *California Tech,* is refundable upon withdrawal at any time. Room contracts are on a term basis for all students. Premature termination of the room contract will be permitted only upon petition approved by the Faculty Committee on Undergraduate Student Houses.

Associated Student Body Dues. Associated Student Body dues of $22 are payable by

1Pro rata refunds are allowed students who are drafted (not volunteers) at any time in the term provided the period in attendance is insufficient to entitle student to receive final grades.

all undergraduate students. The dues are used for the support of athletics and any other student activity that the Board of Directors of the Associated Students of the California Institute of Technology may deem necessary. The subscription to the student newspaper, *California Tech,* $3.00 per year, is included in the A.S.B. dues. In addition, each undergraduate student is assessed $8.00 per year for the college annual, the *BIG T.*

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

Winnett Student Center. Winnett Student Center facilities are reserved for the use of Caltech students and their guests. A contribution of fifty cents a year is made by each member of the Associated Student Body ($1.00 by other students wishing to use the facilities) to help defray the expenses of the game room.

Student Houses. Students in the Houses must supply their own blankets, but bed linens and towels are furnished and laundered by the Institute.

Application for rooms in the Student Houses may be made by addressing the Master of Student Houses (see page 169).

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

Unpaid Bills. All bills owed the Institute must be paid when due. Any student whose bills are delinquent may be refused registration for the term following that in which the delinquency occurs. Students who have not made satisfactory arrangements regarding bills due and other indebtedness to the Institute by the date of graduation will be refused graduation. Transcripts cannot be released until all bills due have been paid or satisfactory arrangements are made with the business office for payment.

Loans. Loans are available to members of all undergraduate classes including entering freshmen, who need such aid to continue their education. They are made upon application, subject to the approval of the Scholarships and Financial Aid Committee and the extent of the available funds. There are three sources of loan funds and the conditions governing each are described below.

1. California Institute loan funds are available in amounts not to exceed $1,000 in any one year and a maximum of $4,000 during undergraduate residence. No interest is charged and no repayment of principal is required during undergraduate residence as long as residence is continuous (The term "residence" includes the usual vacation periods). For those who do not go on to graduate school, repayment commences after graduation of their class and is at the rate of $65 per month including simple interest at 4 percent per annum on the unpaid balance. For those who go on to graduate school at Caltech or elsewhere not later than the fall following their class graduation, interest is charged at the rate of 3 percent per annum, but no principal is required until the final advanced degree is earned provided that the borrower remains in continuous residence. After the final degree has been earned, repayment commences at the rate of $65 per month including interest at 4 percent on the unpaid balance. The interest rate increases to 5 percent starting three years after the final degree and to 6 percent starting five years after the final degree and continues at 6 percent until the loan has been repaid in full. If the borrower withdraws from undergraduate or graduate registration at any time before receiving the last degree for which he has been working, the total amount owed the Institute becomes due and payable at once, unless the Scholarships and Financial Aid Committee agrees to some exception to this rule.

It is inadvisable for foreign students from countries with seriously adverse rates of exchange to borrow more than they can repay from savings (after taxes) out of salaries earned in the United States. The federal government grants a maximum extension of only 18 months on students' visas for holders who engage in full-time commercial employment after they take their degrees. For practical purposes, this means that total indebtedness may not exceed $2,000.

To the extent of available funds, students who wish to borrow and who meet the stipulated requirements will be given their choice of loan sources as stated on page 231.

2. Federal loans under the National Defense Education Act are available to undergraduate students in amounts not to exceed $1,000 for any individual in a single year up to a total of $5,000. The borrower must demonstrate financial need. A further requirement is that he must be willing to sign a loyalty oath. No interest is charged on these loans nor is any repayment of principal required until nine months after the final degree has been earned. At that time repayment commences and interest is charged at the rate of 3 percent per annum on the unpaid balance.

For loans to graduate students under the National Defense Education Act see page 295.

3. The Higher Education Act of 1965 also contains provisions for student assistance through loans insured by the Federal Government (Title IV, Part B). The maximum loan amount is $1,500 per academic year with an aggregate maximum of $7,500.

Deferred Payment Plan. In addition to loans there is available a plan under which any student in good standing may defer up to $1,500 of his college bills each year to a total of $6,000 and may pay the deferred portion in installments after his graduation. The sum of $58.50 ($3.90 per hundred of amount borrowed) a year is added to the deferred portion and represents the premiums on a life insurance policy in the amount of any balance due the Institute under this plan. The insurance policy covers the life of the student for the duration of the obligation, and during the four undergraduate years it also covers the life of the parent or guardian responsible for the student's support. Interest on the amount deferred is charged at the bank prime rate plus 1 percent payable quarterly. The interest is the only payment made on this plan during the undergraduate years. On November 1 following his class graduation the student commences repayment on the deferred portion at the rate of $85.00 a month including interest on the unpaid balance. For those who go on to graduate school more favorable repayment arrangements may be made for the duration of graduate work. As in the case of loans, the total of any balance owed the Institute under this plan becomes due and payable at once if continuous residence is not maintained unless in the opinion of the Scholarships and Financial Aid Committee some exception to this rule should be made.

Loans and the Deferred Payment Plan may be used in combination, but the total that may be borrowed or deferred may not exceed $1,500 in any one year (maximum of $7,500).

Entirely aside from loans and Deferred Payment Plan there is a twelve months payment program offered by Education Funds, Inc., Fund Management Corporation, 36 South Wabash, Chicago, Illinois 60603. The total charge for this program is a $20 participation fee per year to cover the cost of administration.

A student may also arrange with the business office to pay his college bills monthly rather than at the beginning of each term as is customary. No interest is charged on such monthly payments, but arrangements with the business office must be made in advance.

SCHOLARSHIPS, STUDENT AID AND PRIZES

1. Freshman Scholarship Grants

The recipients of freshman scholarship grants are selected by the Freshman Admission Committee from the candidates who have satisfied the entrance requirements of the Institute, and have submitted a *Parents' Confidential Statement* (see below).

Scholarship grants are awarded to the extent of available funds where financial need is demonstrated. Awards are made on the basis of all information available in regard to the applicants — the results of their examinations, their high school records and recommendations, the statements submitted as to their student activities and outside interests, and the result of personal interviews where these are possible. A list of scholarship funds will be found on pages 225-231.

The California Institute uses the uniform scholarship grant application that has been adopted by many colleges in the United States. All applications for scholarship grants where financial need exists must be made on this form. This form, called a *Parents' Confidential Statement,* may be obtained in nearly all cases at the school the applicant is attending. If his school does not have a supply, he should write to the College Scholarship Service at one of the College Entrance Examination Board offices, the addresses of which are given on page 181. The form is put out by the College Scholarship Service of the College Board and is to be returned directly to the appropriate office of the College Board (see page 181) and not to the California Institute. Space is provided on the form for the applicant to indicate that he wishes a copy sent to the California Institute and to such other colleges as he may desire. A small fee is charged by the service for sending a copy of the form to one college, and an additional amount for each copy sent to an additional college. This fee must accompany the form when it is returned to the College Board Office.

Parent's Confidential Statement forms must be sent to the appropriate College Board office not later than February 1 of the year in which admission is desired. All applicants who have submitted this form by the above date are considered for scholarship grants. *It is not necessary to apply for any particular scholarship by name.*

STATE AND NATIONAL SCHOLARSHIP AWARDS

Candidates for freshman scholarships are urged to make exhaustive inquiry of their school advisers and to watch their school bulletin boards for announcements of scholarship contests the winners of which may use the awards at the college of their choice. The State of California, for example, awards such scholarships annually to residents of the state who wish to attend a college within the state. Residents of the State of California who request financial aid will be penalized in consideration for scholarship grants if they do not apply for California State scholarships, provided their test scores indicate that they would have won a State award had they applied. Among the nationwide awards are the National Merit Scholarships, and the Westinghouse Talent Search Awards. Applicants in need of financial assistance should enter any such contest for which they are eligible, in addition to applying for California Institute Scholarship grants. While duplicate awards will not be given beyond the actual extent of need, the more sources to which a candidate applies the greater are his chances of receiving scholarship assistance.

REGULATIONS AND RENEWALS

Recipients of scholarship grants are expected to maintain a satisfactory standing in their academic work during the year for which the scholarship is granted. If the recipient fails to maintain such an academic standing, or if, in the opinion of the Scholarships and Financial Aid Committee, the recipient in any way fails to justify the confidence placed in him, the Committee may cancel the scholarship for the balance of the academic year. Recipients of scholarships which run for more than one year are expected to pass all courses in their freshman year and thereafter to maintain at least a 2.5 grade-point average. The amount of the award carried by these scholarships may be increased or decreased at the beginning of any year if the financial need has changed. Freshmen who receive scholarship awards for the freshman year only will be considered for scholarship aid in subsequent years on the basis of need according to the regulations in the following paragraph.

2. Upperclass Scholarship Grants

Sophomores, juniors, and seniors are considered for scholarships if need is demonstrated and if throughout the preceding year they have carried at least the normal number of units required in their respective options, and if they have completed the preceding academic year with a satisfactory academic record. Students with good academic records receive priority in the awarding of scholarships. Awards are generally at or below the level of full tuition. When individual scholarships carry amounts in excess of full tuition and other expenses exclusive of room and board, the excess is given in the form of a credit against board and room in the Student Houses. A student who expects to finish the academic year satisfactorily and who wishes to apply for a scholarship grant for the next year should obtain a scholarship form from the Admissions Office in March. This form is to be filled out by the student and his parents (or guardian) and returned to the Admissions Office by May 1. No one will be considered for a scholarship grant unless a scholarship form completely filled out and signed by parents (or guardian) is submitted by the proper date. If a scholarship applicant feels that his parents should no longer be responsible for his support, he may attach an explanatory note to the form, but the form must be filled out.

It is expected that students to whom awards are made will maintain a high standard of scholarship and conduct. Failure to do so at any time during the school year may result in the termination of the award. The amount of a scholarship will be reduced if a student pays less than full tuition because of registration for less than a full academic load.

3. Scholarship Funds

Funds for freshman and upperclass scholarships are provided in large part from the special scholarship funds named below. Where the amount of a grant is not specified, there is a certain total sum available each year to be distributed among several scholarship holders in any proportion. It is not necessary to apply for any particular scholarship by name. Applicants for admission who have a *Parents' Confidential Statement* on file will be considered for the best award to which their relative need and academic standing entitle them.

Alcoa Scholarships: The Alcoa Foundation of the Aluminum Company of America has given funds for two undergraduate scholarships.

Alumni Scholarships: The Alumni Association of the California Institute provides scholarships covering full tuition to be awarded to entering freshmen. The recipients of these scholarships can expect to receive this amount for four years provided their conduct and grades continue to be satisfactory.

ARCS Foundation (Achievement Rewards for College Scientists) of Los Angeles: The ARCS Foundation has established a fund for the award of several undergraduate and graduate scholarships.

R. C. Baker Foundation Scholarship: The R. C. Baker Foundation of Los Angeles has established a fund for undergraduate engineering scholarships.

Edward C. Barrett Scholarship: Friends of Edward C. Barrett, who for forty-one years was Secretary of the California Institute, established in his name a scholarship to be awarded annually to an undergraduate student.

Meridan Hunt Bennett Scholarships and Fellowships: Mrs. Russell M. Bennett of Minneapolis in January 1946 made a gift to the Institute to constitute the Meridan Hunt Bennett Fund as a memorial to her son, Meridan Hunt Bennett, a former student at the Institute. The income of this fund is to be used to maintain scholarships which shall be awarded to undergraduate and graduate students of the Institute, the holders of such scholarships to be known as Meridan Hunt Bennett Scholars.

Blacker Scholarships: Mr. and Mrs. Robert Roe Blacker of Pasadena, in 1923, established the Robert Roe Blacker and Nellie Canfield Blacker Scholarship and Research Endowment Fund. A portion of the income of this fund, as determined by the Board of Trustees, may be used for undergraduate scholarships.

C. F. Braun and Company Scholarships: C. F. Braun and Company of Alhambra, California, established three scholarships of $1000 each to be awarded to entering freshmen. In selecting candidates preference will be given to those who indicate that they wish to pursue a course in engineering.

California Scholarship Federation Scholarship: The California Institute each year awards a scholarship to a C.S.F. member who is also a sealbearer provided that such a candidate is available who has met the Institute's requirements for a freshman scholarship grant. Sealbearer status must be verified by the C.S.F. adviser at the time of submitting the regular application for a scholarship grant.

Chisholm Scholarship: Mr. William Duncan Chisholm made provision for an annual scholarship to be awarded to an undergraduate.

Class of 1927 Scholarship: The Class of 1927 established the Class of 1927 Scholarship Endowment Fund. The income from this fund is to be used for an undergraduate scholarship.

Crellin Scholarships: Mrs. Amy H. Crellin made provision for annual scholarships to be awarded to undergraduates.

Cyprus Mines Corporation Scholarship: The Cyprus Mines Corporation of Los Angeles gives $1000 annually to be used for undergraduate scholarships.

Dabney Scholarships: Mrs. Joseph B. Dabney made provision for annual scholarships to be awarded at the discretion of the Institute to members of the undergraduate student body. The recipients are designated Dabney Scholars.

Drake Scholarship: Mr. and Mrs. A. M. Drake of Pasadena made provisions for an annual scholarship available for a graduate of the high schools of St. Paul, Minnesota, and a similar annual scholarship available for a graduate of the high school of Bend, Oregon. If there are no such candidates, the Institute may award the scholarships elsewhere. Mr. and Mrs. Drake, by a Trust Agreement of July 23, 1927, also established the Alexander McClurg Drake and Florence W. Drake Fellowship and Scholarship Fund, the income of which may be used for fellowships and scholarships as determined by the Board of Trustees of the Institute.

Robert S. and Nellie V. H. Dutton: Mrs. Robert S. Dutton established a fund, the interest from which is used for undergraduate scholarships.

Educational Opportunity Grant: Students with exceptional financial need may qualify for an Educational Opportunity Grant, authorized by the Higher Education Act of 1965. Freshmen and upperclassmen are both eligible, provided they are United States citizens or permanent residents. They must also have financial need large enough so that they cannot attend without an EOG. Grants depend upon the resources of the family and range from \$200 to \$1,000 per year. The grants, which are ordinarily renewed in following years can represent no more than half the total scholarship and loan assistance a student receives.

General Motors Corporation Scholarships: The General Motors Corporation established two scholarships at the California Institute to be awarded to entering freshmen. The award may range from a prize scholarship of \$200 for a student not in need of financial assistance to an amount as high as \$2000 a year depending on need. A holder of this scholarship may expect it to be renewed in each of the three upperclass years provided his grades and conduct remain satisfactory. Preference is given to engineering students who hope to enter business. An attempt is also made to award General Motors Scholarships to minority students.

The Gnome Club Scholarship: The alumni of the Gnome Club established a scholarship usually awarded to a student in the senior class.

Goodyear Scholarship: The Goodyear Foundation, Inc., of Akron, Ohio, established a scholarship of \$1500 to be awarded to a junior or senior in engineering who may be interested in a career in business or industry.

Graham Scholarships: Mrs. John D. Graham of Santa Barbara has made possible the award of several undergraduate scholarships.

Grant Foundation Scholarship: The Grant Foundation of Anaheim, California, has given a scholarship of \$1000 to be awarded to an undergraduate majoring in engineering.

Robert E. Gross — Lockheed Aircraft Corporation: These scholarships are part of an award program to perpetuate the memory of Robert E. Gross, who founded Lockheed and served as its principal officer until his death in 1961.

Harriet Harvey and Walter Humphry Scholarships: Miss Harriet Harvey and Mrs. Emily A. Humphry made provisions for two scholarships. The first of these, the Harriet Harvey Scholarship, is to be awarded preferably to a well-qualified candidate from the state of Wisconsin. If there is no such candidate the Institute may award the scholarship elsewhere. The second, the Walter Humphry Scholarship, is to be awarded preferably to a well-qualified candidate from the state of Iowa. If there is no such candidate, the Institute may award the scholarship elsewhere.

Robert Haufe Memorial Scholarship: This scholarship is supported by a fund established in 1950 by Mr. and Mrs. J. H. Haufe as a memorial to their son, Robert Haufe.

The Holly Scholarship: The Holly Manufacturing Company has established a scholarship fund to be awarded to an undergraduate student.

The International Nickel Company Scholarship: The International Nickel Company of New York established a four-year scholarship covering tuition, fees, plus $300 for a student entering the freshman year in 1962. A new scholarship is awarded every four years.

Earle M. Jorgensen Scholarship: Mr. Earle M. Jorgensen has made possible the award of two full tuition scholarships.

J. B. Keating Scholarships: Mr. John B. Keating has made possible the award of two scholarships for undergraduate juniors or seniors.

Kennecott Copper Corporation Scholarship: The Kennecott Copper Corporation has given a $1000 scholarship for a junior or senior student majoring in chemical engineering.

Clarence F. Kiech Scholarship: The family and friends of the late Clarence F. Kiech, Class of 1926, have established a memorial fund to provide undergraduate scholarships.

Fannie Kirshner Scholarship: This scholarship in the amount of $500 a year is given by Henry Kirshner, who loved his fellow man. It was the donor's wish that this scholarship be considered as a loan; however, there is no legal obligation upon the recipient to repay such a loan, it being the belief of the donor that the recipients will do so when they have become established in their professions and are financially able to make such repayment.

Lockheed Leadership Scholarship: The Lockheed Aircraft Corporation of Burbank, California, established a scholarship covering tuition and certain other expenses. This scholarship is to be awarded to an entering freshman who indicates that he intends to pursue a course in engineering or physics. The recipient of this scholarship may expect to continue to receive this award during each of the three upperclass years, provided that his grades and conduct remain satisfactory.

Management Club of California Institute of Technology Scholarship: The Management Club at the Institute gives two tuition scholarships to be awarded to undergraduate students in any of the three upper classes.

Mayr Foundation Scholarships: The George H. Mayr Foundation of Beverly Hills granted funds for a number of undergraduate scholarships to students resident in California.

William C. McDuffie Scholarship: Friends of Mr. William C. McDuffie, for many years a Trustee of the California Institute, have given a fund, the income from which is used for undergraduate scholarships.

Clark S. Millikan Scholarships: Provided by gifts from the family and friends of the late Clark S. Millikan, for 37 years a member of the Caltech faculty, former director of the Guggenheim Aeronautical Laboratory and the Graduate Aeronautical Laboratory.

Robert L. Minckler Scholarships: Provided by gifts from the family and friends of the late Robert L. Minckler, at the time of his death Chairman of the California Institute Board of Trustees.

Seeley Mudd Scholarships: The Seeley W. Mudd Foundation of Los Angeles provided funds for scholarships to cover non-tuition expenses of a student, or students, in the geology option.

David Lindley Murray Educational Fund: Mrs. Katherine Murray of Los Angeles, by her will, established the David Lindley Murray Educational Fund, the income to be expended in assisting worthy and deserving students to obtain an education, particularly in engineering.

Frances W. Noble Scholarship: This scholarship has been established from funds given to the Institute by Mrs. Frances W. Noble.

La Verne Noyes Scholarship: Under the will of La Verne Noyes of Chicago, funds are provided for paying the tuition, in part or in full, for deserving students needing this assistance to enable them to procure a university or college training. This is to be done without regard to difference of race, religion or political party, but only for those who shall be citizens of the United States of America and either: first, shall themselves have served in the army or navy of the United States of America in the war into which our country entered on the 6th of April, 1917, and were honorably discharged from such service, or second, shall be descended by blood from someone who has served in the army or navy of the United States in said war, and who either is still in said service or whose said service in the army or navy was terminated by death or an honorable discharge. The recipients are designated La Verne Noyes Scholars.

Pasadena Optimists Club Scholarship Endowment Fund: The Pasadena Optimists Club gave a fund the interest from which is to be used for undergraduate scholarships.

Edgar H. Pflager Scholarship Fund: Mr. Edgar H. Pflager established, by gift and bequest, a fund the income from which is to be used for undergraduate scholarships.

Phillips Foundation Scholarship: The Charlotte Palmer Phillips Foundation of New York established a four-year scholarship to be awarded to an entering freshman, with no restriction as to major field of study.

Radio Corporation of America Scholarship: The Radio Corporation of America provided funds for an $800 undergraduate scholarship.

Rotary Club of Los Angeles Scholarship: The Rotary Club of Los Angeles, through its Foundation, is awarding a $1,700 scholarship to a junior student in engineering. This scholarship is renewable for the senior year.

Standard Oil Company of California Scholarships: The Standard Oil Company of California provided two scholarships for undergraduates majoring in engineering and geology.

Elizabeth Thompson Stone Scholarship: Miss Elizabeth Thompson Stone of Pasadena established, in her will, a scholarship known as the Elizabeth Thompson Stone Scholarship.

William W. Stout Scholarship Endowment Fund: Mr. William W. Stout established a scholarship fund the interest from which is to be used for undergraduate scholarships.

Superior Oil Company Scholarship: The Superior Oil Company of Los Angeles established a four-year scholarship covering tuition and certain other expenses. Preference is given to a student interested in geology, chemical engineering, or physics.

Texaco Scholarships: Texaco Inc. is providing for one or more scholarships to be awarded to juniors or seniors majoring in a field of engineering or science that would prepare them for a career in the petroleum industry.

The Waltmar Foundation of Garden Grove, California, has given $3,000 for the award of undergraduate scholarships. Preference is given to residents of Orange County.

Brayton Wilbur-Thomas G. Franck Scholarship: Mr. Brayton Wilbur and Mr. Thomas G. Franck of Los Angeles established the Brayton Wilbur- Thomas G. Franck Scholarship Fund, the income to be used for a scholarship for a deserving student at the Institute.

In addition to the foregoing named scholarships, there is a Scholarship Endowment Fund made up of gifts from various donors.

Of the scholarship donors listed above the following include with their scholarship gifts an unrestricted grant to the Institute's general funds to help defray educational costs in excess of that portion covered by tuition.

Alcoa Foundation
The R. C. Baker Foundation
Cyprus Mines Corporation
General Motors Corporation
Goodyear Foundation, Inc.
International Nickel Co., Inc.
Kennecott Copper Corporation
Lockheed Leadership Fund
Radio Corporation of America
Texaco Inc.

4. Student Aid Loan Funds

(See also page 222)

INSTITUTE LOAN FUNDS

Thanks to funds presented by a number of generous donors, the Institute is enabled to lend money to many students who, without aid, could not complete their education. Each fund is administered according to the wishes of the donor, but in general, as outlined on pages 222-223. Borrowers must be making satisfactory progress toward their degrees. The Institute Loan Funds are named as follows:

The Gustavus A. Axelson Loan Fund
The Olive Cleveland Fund
George W. and Beatrice W. Downs Loan Fund
The Hosea Lewis Dudey Loan Fund
The Dudley Foundation Loan Fund
The Claire Dunlap Loan Fund
Ford Foundation Loan Fund
Susan Baker Geddes Loan Fund
Thomas Lain Gordon Memorial Loan Fund
The Roy W. Gray Fund
The Raphael Herman Loan Fund
The Vaino A. Hoover Student Aid Fund
The Howard R. Hughes Student Loan Fund
The Thomas Jackson Memorial Fund
The Ruth Wydman Jarmie Loan Fund
Walter and Margaretta Kendall Loan Fund
Eugene Kirkeby Loan Fund
The Gustav D. Koehler Loan Fund
The Frank W. Lehan Loan Fund
The John McMorris Memorial Loan Fund
The James K. Nason Memorial Loan Fund
The Noble Loan and Scholarship Fund
The James R. Page Loan Fund
Richard W. Shoemaker Loan Fund

The Sloan Foundation Loan Fund
The Albert H. Stone Educational Fund
Scholarship and Loan Fund—Sundry Donors
Neal Wilson Student Emergency Loan Fund

NATIONAL DEFENSE STUDENT LOAN PROGRAM

All students are eligible to apply for loans from these limited funds provided they are: citizens or permanent residents of the United States; meeting the Institute's academic standards and standards of conduct; and are recommended by the Scholarships and Financial Aid Committee.

A student may apply for a maximum of $1000 a year for five years. Beginning one year after he has completed his education, he pays 3 percent interest per year on the unpaid balance of his loan. He pays no interest as long as he is a full-time student, nor if he is serving in the armed forces (maximum three years).

Applicants must show evidence of need (statement of family income and resources, personal resources, and an estimated annual budget); sign an oath of allegiance; and (if applicant is under 21) obtain signature of parent or guardian to the effect that he has read the application.

DEFERRED PAYMENT PLANS FOR TUITION

See detailed information on page 223.

STUDENT EMPLOYMENT

Students who desire part-time or summer employment will receive assistance from the Placement Office. New students who desire employment are advised to write to the Director of Placements prior to coming to the Institute. The requirements of the courses at the Institute are so exacting, however, that under ordinary circumstances, students who are entirely or largely self-supporting through employment should not expect to complete a regular course program in the usual time. It is highly inadvisable for freshmen students to attempt to earn their expenses.

PLACEMENT SERVICE

The Institute maintains a placement service to provide information about colleges and universities throughout the world and opportunities for employment. The service is under the direction of a member of the faculty, with a full-time staff.

The Placement Office provides assistance to undergraduate students, graduate students, research fellows, and alumni for the procurement of employment. It arranges for interviews by prospective employers for candidates for degrees and research fellows. Students, both graduate and undergraduate, desiring part-time employment during the school year or during vacations, should register with the Placement Office. Assistance will be given whenever possible in securing employment for summer vacations. Alumni who are unemployed, or desire a change in position, should register with the Placement Office.

The Placement Service maintains a Student Information Center which provides information in the form of brochures, catalogs, and announcements concerned with employment opportunities, admissions to colleges and universities, and fellowships and scholarships offered by universities, foundations, and industry. The brochures show employment opportunities offered by all types of organizations. The Director of Placements is always available for consultation and guidance on placement problems.

The Institute assumes no responsibility in obtaining employment for its graduates, although the Placement Office will make every effort to provide suggestions for employment for those who wish to make use of this service.

5. Prizes

THE 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 twenty 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, in the judgment of the undergraduate Deans, throughout his undergraduate years at the Institute has made the greatest contribution to the student body and whose qualities of character, leadership, and responsibility have been outstanding. At the discretion of the Deans, more than one award or none may be made in any year. The award, presented at commencement without prior notification, consists of $100 in cash, a certificate, and a suitable memento.

THE CONGER PEACE PRIZE

The Conger Peace Prize was established in 1912 by the Reverend Everett L. Conger, D.D., for the promotion of interest in the movement toward universal peace, and for the furtherance of public speaking. The annual income from $1000 provides for a first and second prize to be awarded at the public contest. The contest is under the direction of representatives of the Division of the Humanities and Social Sciences.

THE MARY A. EARLE MCKINNEY PRIZE IN ENGLISH

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

THE DON SHEPARD AWARD

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

THE DAVID JOSEPH MACPHERSON PRIZE IN ENGINEERING

The David Joseph Macpherson Prize in Engineering was established in 1957 by Margaret V. Macpherson in memory of her father, a graduate of Cornell University in civil engineering, class of 1878. A prize of $100 is awarded annually to the graduating senior in engineering who best exemplifies excellence in scholarship. The winning student is selected by a faculty committee of three, appointed annually by the chairman of the Division of Engineering.

THE 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 the California Institute and elsewhere. A prize of $150 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.

THE GEORGE W. GREEN MEMORIAL PRIZE

The George W. Green Memorial Prize was established in 1963 based on contributions given in memory of George W. Green, who for fifteen years served on the staff of the Caltech business office and was from 1956-1962 Vice President for Business Affairs. The prize of $400 is awarded annually to an undergraduate student, in any class, selected by the division chairmen and the deans on the basis of original research, an original paper or essay in any field, or other evidence of creative scholarship beyond the normal requirements of specific courses.

THE DONALD S. CLARK ALUMNI AWARDS

From funds contributed by the Caltech Alumni Association annual awards may be made to two sophomores and two juniors in recognition of demonstrated potential leadership and good academic performance. Each award of $250 has been made since 1967 by a Faculty committee headed by the Chairman of the Division of Engineering and Applied Science. Preference is given to students in that Division and to those in Chemical Engineering. The awards honor the work of Professor Clark, class of 1929, both in the field of engineering and in the Association.

THE HAREN LEE FISHER MEMORIAL AWARD IN JUNIOR PHYSICS

Mr. and Mrs. Colman Fisher have established the Haren Lee Fisher Memorial Award in Junior Physics in memory of their son, who was killed in an automobile accident in May of 1967, in his junior year at Caltech. The General Electric Foundation also contributed to the fund under the matching plan of their Corporate Alumnus Program. A prize of $150 will be awarded annually to a junior physics major, to be selected by a physics faculty committee as demonstrating the greatest promise of future contributions to physics.

THE SCAAPT PRIZE

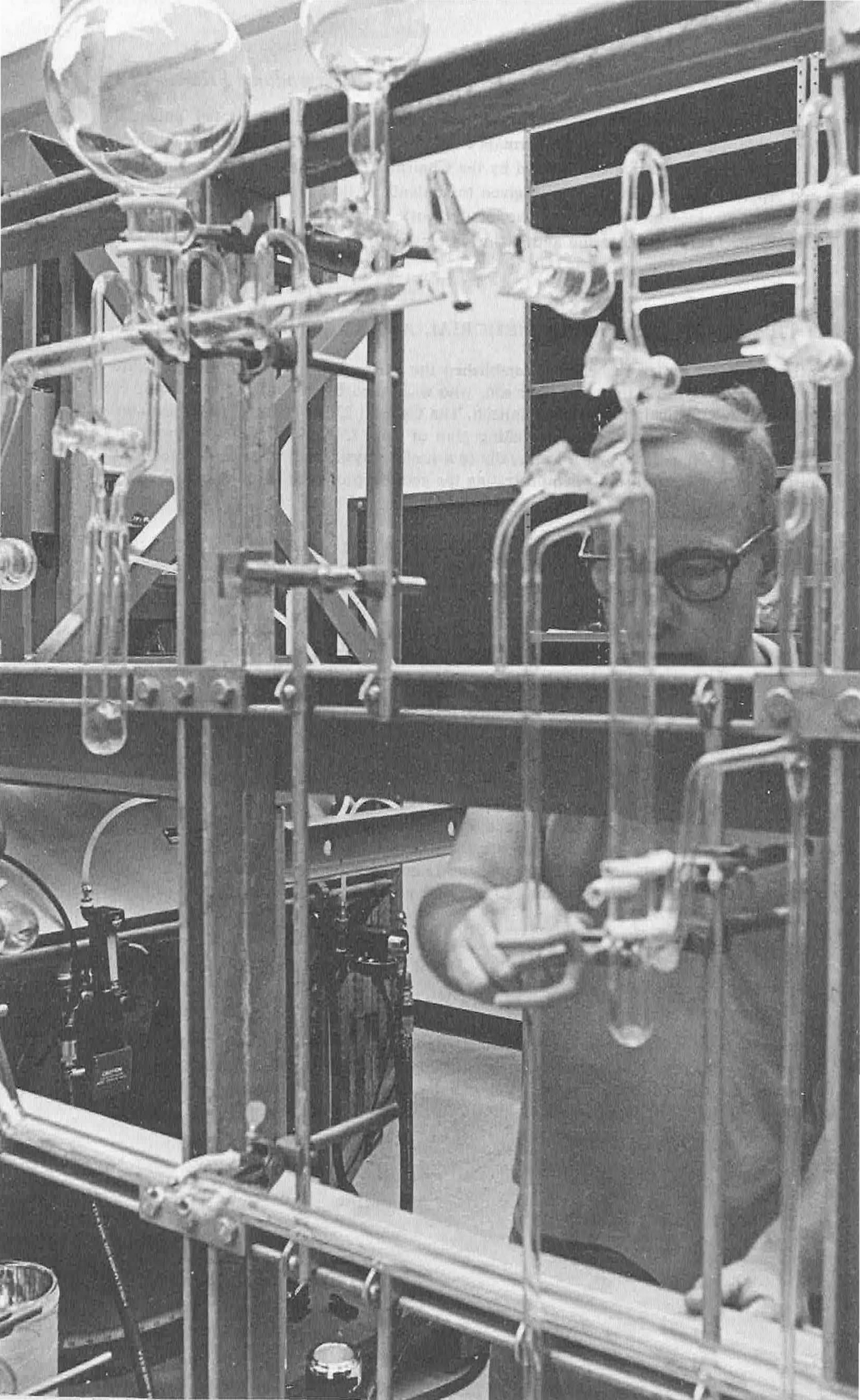
A prize of $250 is awarded each year in connection with the annual high school contest of the Southern California Section of the American Association of Physics Teachers. The prize goes to the highest ranking man in the contest who is admitted and registers at the California Institute in the fall following his senior year.

THE JACK E. FROELICH MEMORIAL AWARD

The family and friends of the late Jack E. Froelich, who took his undergraduate and graduate work at the California Institute and was later of great importance in the space efforts of the Institute and the Jet Propulsion Laboratory, have established a prize fund which will provide a gift of money to the student in the junior class with the highest cumulative rank.

THE SIGMA XI AWARD

In accordance with the aim of The Society of the Sigma Xi to encourage original investigation in pure and applied science, the Institute Chapter of the Society annually awards a prize of $400, funded from membership dues, to a senior undergraduate student selected for an outstanding piece of original scientific research.



Section IV

INFORMATION AND REGULATIONS FOR THE GUIDANCE OF GRADUATE STUDENTS

The Graduate Program

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, Geological Engineer, Geophysical Engineer, and Mechanical Engineer.

The academic work of the Institute is organized in six divisions:

- Biology
- Chemistry and Chemical Engineering
- Engineering and Applied Science
- Geological Sciences
- The Humanities and Social Sciences
- Physics, Mathematics and Astronomy

Graduate work at the Institute is further organized into graduate options. Each option is 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 who is 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 from each area of graduate study is available for consultation on problems concerning academic programs, degree requirements, financial aid, etc. The representatives for 1970-71 are as follows:

Aeronautics:	Prof. E. E. Sechler
Applied Mathematics:	Prof. G. B. Whitham
Applied Mechanics:	Prof. F. S. Buffington
Applied Physics:	(to be appointed)
Astronomy:	Prof. J. E. Gunn
Biology:	Prof. J. F. Bonner
Chemistry:	Prof. R. E. Dickerson
Chemical Engineering:	Prof. J. F. Seinfeld
Civil Engineering:	Prof. F. S. Buffington
Electrical Engineering:	Prof. R. W. Middlebrook
Engineering Science:	Prof. F. S. Buffington
Environmental Engineering Science:	Prof. F. S. Buffington
Geological and Planetary Science:	Prof. A. L. Albee
Materials Science:	Prof. F. S. Buffington
Mathematics:	Prof. R. P. Dilworth
Mechanical Engineering:	Prof. F. S. Buffington
Physics:	Prof. W. Whaling

General Regulations

Admission to Graduate Standing

Application for admission to graduate standing should be made to the Dean of Graduate Studies, on a form obtained from his office. Admission to graduate standing will be granted *only to a limited number of students of superior ability,* and application should be made as early as possible. No application fee is required. In general, admission to graduate standing is effective for enrollment only at the beginning of the next academic year. The California Institute of Technology accepts applications from ɔth men and women. Students applying for assistantships or fellowships need not make separate application for admission to graduate standing, but should submit their applications before February 15.

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 substantially equivalent to one of the options offered by the Institute. He must, moreover, have attained such a scholastic record and, if from another institution, must present such recommendations as to indicate that he is fitted to pursue, with distinction, advanced study and research. In some cases examinations may be required. If the applicant's preliminary training has not been substantially that given by the four-year undergraduate options at the Institute, he may be admitted subject to satisfactory completion of such undergraduate subjects as may be assigned. Admission sometimes may have to be refused solely on the basis of limited facilities in the department concerned.

Prior to final acceptance for admission, each applicant is required to submit a report of Medical History and Physical Examination on a form which will be sent him at the time he is notified of admission. It is the applicant's responsibility to have this form filled out by a Doctor of Medicine (M.D.) of his own choosing. Admission is tentative pending such examination, and is subject to cancellation if the report indicates the existence of a condition that the Director of Health Services deems unsatisfactory. Vaccination and a standard two-injection tetanus inoculation (or booster shot if appropriate) and tuberculosis testing are required at the time of the examination. Students who have been on leave of absence for three terms or more must submit Medical History and Physical Examination reports under the same conditions as for new students.

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

Students from non-English speaking countries are expected to read, write, and speak English and comprehend the spoken language. It is recommended that such students take the Test of English as a Foreign Language (TOEFL). They are urged to take it at the time they receive their application forms and have the scores sent to us. For information, applicants should write to the Educational Testing Service, Princeton, New Jersey, 08540. Special no-credit classes in English are available for those students who need to improve their command of the language or who wish to perfect it. Information regarding these classes can be obtained from the Chairman of the Faculty Committee on Foreign Students and Scholars or from the International Desk. It is strongly recommended, however, that students who achieve a low TOEFL score make arrangements for remedial work during the summer preceding their registration.

Special students, not working for degrees, are admitted only under exceptional circumstances.

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. If fewer than 36 units are successfully carried, the residence will be regarded as shortened in the same ratio; but the completion of a large number of units in any one term will not be regarded as increasing the residence. The residency requirement for each degree will be found under the degree regulation. In general, the degree requirements are: Master of Science, after a minimum of one year of graduate work; Aeronautical Engineer, Electrical Engineer, Geological Engineer, Geophysical Engineer, and Mechanical Engineer, after a minimum of two years of graduate work; and Doctor of Philosophy after a minimum of three years of graduate work.

Advanced work is defined as study or research in courses whose number is greater than or equal to 100.

Registration

Students are required to register and file a program card in the Registrar's Office at the beginning of each term of residence, whether they are attending a regular course of study, carrying on research or independent reading only, writing a thesis or other dissertation, or utilizing any other academic service.

Before registering, the student should consult with members of the department in which he is taking his major work to determine the studies which he can pursue to the best advantage.

The number of units allowed for a course is so chosen that one unit corresponds roughly to one hour a week of work throughout the term for a student of superior ability.

A student will not receive credit for a course unless he is properly registered. At the first meeting of each class he should furnish the instructor with a class admission card for the course, obtained on registration. *The student himself is charged with the reponsibility of making certain that all grades to which he is entitled have been recorded.*

Graduate students who cannot devote full time to their studies are allowed to register only under special circumstances. Except by specific action of the Committee on Graduate Study, graduate students will be required to register for at least 36 units during each of their first three terms of attendance at the Institute. A graduate student who is registered for 36 or more units is classed as a full-time student.

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

Graduate students are encouraged to continue their research during the whole or a part of the summer, but in order that such work may count in fulfillment of the residence requirements, the student must file a registration card for such summer work in the office of the Registrar on May 17. A minimum of 10 units must be taken. Students who are registered for summer research must pay the Summer Insurance Accident fee. They will not in general be required to pay tuition for the research units, but will be required to pay minimum tuition of $220 if Ph.D. or engineer's degree thesis requirements are completed during the summer.

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, in addition to his department's consent, the approval of the Dean of Graduate Studies. M.S. candidates must obtain the signature of the Dean of Graduate Studies on all drop or add cards.

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

A graduate student who undertakes activities related to the Institute (studies, research, and assisting or other employment) aggregating more than 62 hours per week must receive approval from the Dean of Graduate Studies. Petition forms for this purpose may be obtained from the Graduate Office and must carry the recommendation of the student's major department before submission to the Graduate Office.

Registration, with at least minimum tuition (see page 288), is required for the term or summer period in which the requirements for an advanced degree are completed, including either the final examination or submission of a thesis. Registration with minimum tuition will be allowed for, at most, one term, except for summer registration.

With the approval of the Committee on Graduate Study, any graduate student whose work is not satisfactory may be refused registration at the beginning of any term by the department in which the student is doing his major work.

The registration of a graduate student is not complete unless his photograph for the Registrar's record card is affixed thereto, or a certification from the photographer is obtained to show that such photograph is in course of preparation on the date of registration. The Registrar provides the opportunity to have these photographs made, without cost to the student, on the registration days of the first and second terms of each year. Photographs taken for this purpose at other times are provided by the student at his own expense.

Grades in Graduate Courses

Term examinations are held in all graduate courses unless the instructor, after consultation with the Chairman of the Division, shall arrange otherwise. No student taking a course for credit shall be exempt from these examinations when they are held.

Grades for all graduate work are reported to the Registrar's office at the close of each term.

The following system of grades is used to indicate class standing in graduate courses: "A" excellent, "B" good, "C" satisfactory, "D" poor "E" conditioned, "F" failed, "Inc" incomplete. In addition to these grades, which are to be interpreted as having the same significance as for undergraduate courses (see page 190), the grade of "P," which denotes passed, may be used at the discretion of the instructor, for all or some of the students, in the case of seminar or other work which does not lend itself to more specific grading. In graduate research, only the grades of "P" and "F" are given.

Degree Regulations

Degree of Master of Science

The Master of Science degree is a professional degree intended 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, but students from other schools who do not have completely adequate preparation may require longer.

Special regulations for the Master's Degree in each graduate option are on pages 246 through 287.

Residence and Units of Graduate Work Required

At least one academic year of residence at the Institute (as defined on page 239) and 135 units of graduate work subsequent to the baccalaureate degree are required for the master's degree. Included in these 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 option with a grade-point average of at least 1.90, considering the grade of P as being equivalent to C, and excluding grades for research.

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

Admission to Candidacy. Before mid-term of the first term of the academic year in which the student expects to receive the degree, he must 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 will submit his proposed plan of study, which must have the approval of his department. This plan of study, if approved, shall then constitute the requirements for the degree, and changes in the schedule will not be recognized unless initialed by the proper authority. Not later than mid-term of the third term, the student is required to review his candidacy form and then submit it for final department approval. The approved form must then be returned to the Graduate Office at least two weeks before Commencement.

All changes in registration must be reported on drop or add cards to the Registrar's Office. M.S. candidates must obtain the signature of the Dean of Graduate Studies on all drop or add cards.

Engineer's Degree

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 the degree desired and should be planned in consultation with the members of the faculty concerned. Advanced studies are defined on page 237. Regulations governing registration will be found on page 239. 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 application 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 (as defined on page 239) subsequent to a baccalaureate degree equivalent to that given by the California Institute are required for an engineer's degree. Of these, at least the last three terms must be at the California Institute. It must be understood that these are minimum requirements, and students must often count on spending a somewhat longer time in graduate work.

To qualify for an engineer's degree a student must complete the work prescribed by his supervising committee with a gradepoint average of at least 1.90, considering the grade of P as being equivalent to C and excluding grades for research. Work upon research and the preparation of a thesis must constitute no fewer than 55 units. More than 55 units may be required by certain departments and the student should determine the particular requirements of his department when establishing his program.

In the case of a student registered for work toward an engineer's degree, and holding a position as graduate assistant or other Institute employee, the actual number of hours per week required by his teaching or research services shall be deducted from the total number of units for which he might otherwise register. This number of units shall be determined by his department.

Admission to Candidacy. Before mid-term of the first term of the academic year in which the student expects to receive the degree he 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, in consultation with the chairman of the appropriate division, will appoint a committee of three members of the faculty to supervise the student's work and to certify to its satisfactory completion. One of the members of the committee must be in a field outside the student's major field of study. The student should then consult with this committee in planning the details of this work. The schedule of his 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 which 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 his supervising committee certifies: (a) that all the special requirements for the desired degree have been met, with the exception that certain courses of not more than two terms in length may be taken after admission to candidacy; (b) that the thesis research has been satisfactorily started and probably can be finished at the expected time.

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

Thesis. At least two weeks before the degree is to be conferred, each student is required to submit to the Dean of Graduate Studies two copies of his thesis in accordance with the regulations governing the preparation of doctoral dissertations, obtained from the Graduate Office.

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.

Before submitting his thesis, the candidate must obtain written approval of it by the chairman of the division and the members of his supervising committee, on a form obtained from the office of the Dean of Graduate Studies.

Examination. At the option of the department representing the field in which the degree is desired, a final examination may be required. This examination would be conducted by a board to be 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 scientific attainment and of power to investigate scientific 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 scientific 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 expressing himself clearly and forcefully both orally and in written language.

Subject to the general supervision of the Committee on Graduate Study, the student's work for the degree of Doctor of Philosophy is specifically directed by the department in which he has chosen his major subject. Each student should consult his department concerning special divisional and departmental requirements. See pages 246-287.

Admission. With the approval of the Committee on Graduate Study, students are admitted to graduate standing by the department 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. These degrees, however, 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 new application 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.

During the second or third term of work toward the engineer's degree, a student may apply for admission to work toward the doctor's degree. If this admission is granted, his admission for the engineer's degree will be cancelled.

Major and Minor Program of Study. The work for the doctor's degree must consist of scientific research and advanced studies in some branch of science or engineering, called the major program of study. The minor program of study will be at the option of the student, either a general minor or a subject minor.

Advanced studies include courses with numbers of 100 or over. However, only in approved cases is graduate residence credit given for such courses when they are required in the undergraduate option corresponding to the student's major field. No residence credit is given for courses with numbers under 100 when they constitute prerequisites to the student's minor subject courses. Credit in the amount to be determined by the Committee on Graduate Study may be allowed for other courses with numbers under 100 when they are outside the student's major field.

(a) *General Minor.* The work will consist of at least 36 units of advanced work and of 18 units of either advanced or undergraduate work (including introductory language courses) taken after admission to graduate standing. The requirement for these 18 units will be waived for graduate students who, in the opinion of the staff in languages, have an adequate knowledge of at least one foreign language. The waiver will be granted on the basis of an examination, or of an adequate past score of a GSFLT test, or appropriate course work taken previously.

The work in the minor must be in one or more disciplines in the humanities, sciences or engineering, other than that of the major subject. The choice and scope of this work must be approved by the Division in charge of the major subject, on a form obtainable from the Graduate Office.

(b) *Subject Minor.* The work is concentrated in one discipline, including at least 45 units of advanced work in this discipline, and must be comprehensive enough to give the student a fundamental knowledge of it. The minor subject may be in the humanities or languages or in any discipline listed on pages 246-287, under special requirements adopted by the various divisions of the Institute. The program must be approved by both major and minor divisions on a form obtainable from the Graduate Office. The candidate will be examined on this work (see page 245). A student who has satisfied the requirements for such a minor program of study will be given recognition for this work by explicit mention on his Ph.D. diploma of the minor subject or minor subjects if the requirements have been satisfied in more than one discipline.

Residence. At least 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. However, no student will be allowed to continue work toward the doctor's degree for more than 15 terms of graduate residence, nor more than 18 registrations for full- or part-time academic work except by special action of the Committee on Graduate Study. In either case graduate study taken elsewhere will be counted when residence credit at the Institute has been allowed. (See page 240 regarding summer registration for research.)

Graduate students will be permitted only by special arrangement made in advance to conduct all or a portion of their research in the field, in government laboratories, or elsewhere off the campus. In order that such research be counted in fulfillment of residence requirements, the graduate student must file in advance a registration card for this work. The work must be carried out under the direct supervision of a member of the Institute staff. The number of units to be credited for such work shall be determined by the Dean of Graduate Studies in consultation with the chairman of the division in which the student is carrying his major work; and a recommendation as to the proportion of the full tuition to be paid for such work shall be made by the Dean to the Vice President for Business Affairs.

A student whose undergraduate work has been insufficient in amount or too narrowly specialized, or whose preparation in his special field is inadequate, must count upon spending increased time in work for the degree.

Admission to Candidacy. On recommendation of the chairman of the division concerned, the Committee on Graduate Study will admit a student to candidacy for the degree of Doctor of Philosophy after he 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 his major department and, if needed, by his minor department; has satisfied the several departments concerned by written or oral examination or otherwise that he has a comprehensive grasp of his major and minor subjects as well as of subjects fundamental to them; has fulfilled any necessary language requirements; has shown ability in carrying on research with a research subject approved by the chairman of the division concerned. For special departmental regulations concerning admissions to candidacy, see pages 246-287. Members of the Institute staff of rank higher than that of assistant professor are not admitted to candidacy for a higher degree.

A standard form, to be 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 himself 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 division to the Dean of Graduate Studies for permission to register for further work.

Foreign languages. The Institute believes in the importance of the knowledge of foreign languages and encourages their study as early as possible and 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 smaller academic unit.

To encourage the study of foreign languages, the Institute recognizes previous work (see general minor, page 243) and offers the possibility of further study as a graduate student. Course work in languages is recognized for part of a general minor. The Institute offers also a two-year intensive program in French, German, and Russian. In addition, successful completion of this program, together with 27 additional course work units in the literature of the language, entitles the student to a subject minor in that language. The latter is not open to foreign students in their native language.

Examination. During his course of study every doctoral candidate shall be examined broadly and orally on his major subject, the scope of his thesis and its significance in relation to his major subject. The examination, subject to the approval of the Committee on Graduate Study, may be taken at such time after admission to candidacy as the candidate is prepared, except that it must take place at least two weeks before the degree is to be conferred.

The examination may be written in part, and may be subdivided into parts or given all at one time at the discretion of the departments concerned. The student must petition for this examination on a form obtained from the Dean of Graduate Studies in time for the examination to be announced in the Institute's weekly calendar. For special departmental regulations concerning candidacy and final examination, see pages 246-287.

If the candidate has a subject minor, he must also be examined broadly and orally on the subject of that program. This examination may, but need not be included in the final examination. It may be given at a time to be determined by agreement between the major and minor departments.

Thesis. Two weeks before the degree is to be conferred, the candidate is required to submit to the Dean of Graduate Studies two copies of his thesis in accordance with the regulations governing the preparation of doctoral dissertations obtainable from the Graduate Office. For special departmental regulations concerning theses, see pages 246-287.

With the approval of the department 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. In any case, however, a substantial portion of the thesis must be the candidate's own exposition of his work.

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.

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.

Before submitting his thesis to the Dean of Graduate Studies, the candidate must obtain approval of it by the chairman of his division and the members of his examining committee. This approval must be obtained in writing on a form which will be furnished at the office of the Dean. The candidate himself is responsible for allowing sufficient time for the members of his committee to examine his thesis.

Special Regulations of the Graduate Options

AERONAUTICS

Admission

The field of aeronautics is so many-sided that a student who has completed the undergraduate course either in engineering or in applied science will be admitted to the first-year graduate course. However, programs for the more advanced degrees may be taken only by students who have completed the first graduate year course at Caltech or who have had substantially the same preparation elsewhere.

Master's Degree in Aeronautics

The following courses are required for the degree of Master of Science in Aeronautics:

Ae 101abc	Basic Fluid and and Gasdynamics
or	
Hy 101 abc	FluidMechanics
Ae 102 abc	Basic Solid Mechanics
Ae 104	Experimental Techniques
Ae 105 bc	Fluid Mechanics Laboratory
or	
Ae 106 bc	Solid Mechanics Laboratory
Ae 150 abc	Aeronautical Seminar

plus electives to complete the required number of units.

Degree of Aeronautical Engineer

The prerequisite is one year of graduate study covering the equivalent of the above Master of Science degree program. In addition, not less than 60 units of either

Ae 200 abc	Research in Aeronautics
or	
JP 280 abc	Research in Jet Propulsion

are required, as well as an advanced seminar such as:

Ae 208 abc	Fluid Mechanics Seminar
Ae 209 abc	Solid Mechanics Seminar
JP 290 abc	Advanced Seminar in Jet Propulsion

plus at least one of the following courses:

Ae 201 abc	Advanced Fluid Mechanics
Ae 203 abc	Applied Aerodynamics and Flight Mechanics II
Ae 210 abc	Advanced Solid Mechanics

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.

Degree of Doctor of Philosophy in Aeronautics

In general, a graduate student is not admitted to work for the doctor's degree in aeronautics until he has completed at least 40 units of research in his chosen field. Thus, upon completion of his first year of graduate work he will be admitted to work towards the engineer's degree. If he wishes to continue toward the doctorate, a qualifying examination for admission to work toward the doctor's degree must be taken. Upon satisfactorily passing this examination, he will be admitted to work towards the doctor's degree and his admission to work towards the engineer's degree will be canceled.

To be recommended for candidacy for the doctor's degree in aeronautics the applicant must pass (with a grade of C or better) one of the following, or its equivalent:

AMa 101 abc	Methods of Applied Mathematics
AM 125 abc	Engineering Mathematical Principles
Ma 108 abc	Advanced Calculus
Ph 129 abc	Methods of Mathematical Physics

plus at least one of the following:

Ae 201 abc	Advanced Fluid Mechanics
Ae 203 abc	Applied Aerodynamics and Flight Mechanics
Ae 210 abc	Advanced Solid Mechanics

If any of the above subjects were taken elsewhere than at the Institute, the candidate may be required to pass special examinations indicating an equivalent knowledge of the subject.

To be admitted to candidacy, the applicant must pass a candidacy examination at least one year before the degree is to be conferred. By the beginning of the third term of the year in which the degree is to be conferred, a candidate for the degree of Doctor of Philosophy must deliver rough drafts of the thesis to his supervising committee. Not less than two weeks after the submission of the thesis rough draft, the candidate is expected to give a seminar covering the results of his research, and this seminar will be followed by a thesis examination by his supervising committee. The seminar should be given as early as possible, but not later than two months before the degree is to be conferred.

APPLIED MATHEMATICS

Aims and Scope of Graduate Study in Applied Mathematics

A program for graduate study in applied mathematics is organized jointly by the Division of Physics, Mathematics and Astronomy and the Division of Engineering and Applied Science. The course of study leads to the Ph.D. degree and requires three or four 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. Students will be admitted to one of the two divisions according to background and interests. A special committee coordinates the program and provides over-all guidance to students.

As the joint sponsorship by the two divisions indicates, several different groups in the Institute contribute to the teaching and supervision of research. Conversely, students in applied mathematics should 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 interests from the courses offered under Mathematics, and from the whole range of Institute courses in specific areas of physics, engineering, etc. Further advanced courses will be added as this new program develops. There is also an applied mathematics colloquium in which visitors, faculty, and students discuss current research.

Placement Examinations

Each new graduate student admitted to work for the Ph.D. in Applied Mathematics will be 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 in mapping out a course of study. The work of the student during the first year will include some independent reading and/or research.

Categories of Courses

Courses which are expected to form a large part of the student's program are divided into three categories as follows:

Group A. Courses in mathematics and mathematical methods. Examples of these would include:

AMa 101	Methods of Applied Mathematics I
AMa 201	Methods of Applied Mathematics II
AMa 104	Matrix Theory
AMa 105	Introduction to Numerical Analysis
Ma 109	Delta Functions and Generalized Functions
Ma 125	Analysis of Algorithms
Ma 137	Real Variable Theory
Ma 141	Ordinary Differential Equations
Ma 143	Introduction to Functional Analysis
Ma 144	Probability

Group B. Courses of a general nature in which common mathematical concepts and techniques are applied to problems occurring in various scientific disciplines. Examples of these include:

AMa 110	Introduction to the Calculus of Variations
AMa 152	Linear and Non-Linear Wave Propagation
AMa 153	Stochastic Processes
AMa 251	Applications of Group Theory
AMa 181	Linear Programming
AMa 260	Special Topics in Continuum Mechanics

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, etc.

Master's Degree in Applied Mathematics

Entering graduate students are 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. This examination will normally be given during the first term of the second graduate year. It will be 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 the independent study carried out by the student during his first graduate year.

Further Requirements. In order to be recommended for the Ph.D. in Applied Mathematics, the student must do satisfactory work in a program containing at least 45 units of work in courses of the type indicated in Group A, and at least 45 units of courses chosen from Groups B and C. This is intended to prevent undue specialization in either the more mathematical or the more engineering type of courses.

The Minor. Students majoring in Applied Mathematics must satisfy the minor requirements of the Institute. A proposal for a General Minor must involve fields of study sufficiently far removed from the student's major field and is subject to approval by the Committee on Applied Mathematics. In accordance with Institute requirements, candidates who elect a Subject Minor must pass a special examination in this subject. It is the responsibility of the candidate to arrange for this examination, which should be taken as soon as possible after completion of course work in the minor field.

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 his completed thesis to his research supervisor.

Final examination. The final oral examination will be held as nearly as possible four weeks after the submission of the thesis. The examination will cover the thesis and related areas.

Subject Minor in Applied Mathematics

Students majoring in other fields may take a subject minor in Applied Mathematics provided the program consists of 45 units sufficiently far removed from their major program of study and is approved by the Applied Mathematics Committee.

APPLIED MECHANICS

Master's Degree in Applied Mechanics

Study for the degree of Master of Science in Applied Mechanics ordinarily will consist of three terms of course work totaling at least 135 units. AM 125 abc: Engineering Mathematical Principles, and E 150 abc: Engineering Seminar, are required. With faculty approval, AM 125 abc may be replaced by Ma 108 abc: Advanced Calculus, AMa 101 abc: Methods of Applied Mathematics, or other satisfactory substitute. A minimum of 54 units must be selected from the Elective Course List below; however substitution for electives from this list may be made with the approval of the student's adviser and the faculty in Applied Mechanics. Students are encouraged to consider a Humanities elective as part of their free electives.

Degree of Doctor of Philosophy in Applied Mechanics

The degree of Doctor of Philosophy in Applied Mechanics will ordinarily involve a second year of graduate work in advanced courses and research, plus at least one additional year on a comprehensive thesis research project. Such study and research programs are individually planned to fit the interests and background of the student.

Course Requirements. To be recommended for candidacy for the Ph.D. degree in Applied Mechanics, the student must, in addition to the general Institute requirements:

a. Complete 12 units of research.
b. Complete at least 50 units of advanced courses arranged by the student in conference with his adviser and approved by the faculty in Applied Mechanics.
c. Pass with a grade of at least C an advanced course in mathematics or applied mathematics such as AM 125 abc, Ph 129 abc, or AMa 101 abc, acceptable to the faculty in Applied Mechanics. The requirement in mathematics shall be in addition to requirement (b) above, and shall not be counted toward the minor requirements.

Language Requirements. The student is encouraged to discuss with his adviser the desirability of taking foreign languages, which may be included in a general minor or as a subject minor with the proper approvals. Foreign languages are not required.

Thesis and Final Examination. A final oral examination will be given after the thesis has been formally completed. This thesis examination will be a defense of the doctoral thesis and a test of the candidate's knowledge in his specialized field of research.

Subject Minor in Applied Mechanics

A student majoring in another branch of engineering, or another division of the Institute, may, with the approval of the faculty in Applied Mechanics, elect Applied Mechanics as a subject minor.

Elective Course List

AMa 104	Matrix Algebra	9		
AMa 105 ab	Introduction to Numerical Analysis		11	11
AMa 151 abc	Perturbation Methods	9	9	9
AMa 153 abc	Stochastic Processes	9	9	9
AM 112 abc	Structural Mechanics	9	9	9
AM 135 abc	Mathematical Elasticity Theory	9	9	9
AM 136 abc	Advanced Mathematical Elasticity Theory	9	9	9
AM 140 abc	Plasticity	9	9	9
AM 141 abc	Wave Propagation in Solids	9	9	9
AM 151 abc	Dynamics and Vibrations	9	9	9
AM 175 abc	Advanced Dynamics	9	9	9

Ae 101 abc	Basic Fluid and Gas Dynamics	9	9	9
Ae 102 abc	Basic Solid Mechanics	9	9	9
Ae 210 abc	Advanced Solid Mechanics	9	9	9
EE 172 abc	Feedback Control Systems	9	9	9
ES 130 abc	Introduction to Classical Theoretical Physics I	9	9	9
Hy 101 abc	Fluid Mechanics	9	9	9
JP 121 abc	Jet Propulsion Systems and Trajectories	9	9	9
Ph 106 abc	Topics in Classical Physics	9	9	9

ASTRONOMY

Admission

It is strongly recommended that applicants, including those from foreign countries, for admission to graduate study in astronomy submit Graduate Record Examination Test scores for verbal and quantitative aptitude tests and the advanced test in physics.

Placement Examinations

Each student admitted to work for an advanced degree in astronomy is required to take the Placement Examinations in physics, (see Placement Examinations, page 285) covering material equivalent to Ph 102, Ph 106, and Ph 125. An oral examination by the staff covering the material in Ay 112 is given on the Friday preceding the beginning of instruction for the first term. These examinations will test whether the student's background of atomic and nuclear physics, mathematics, physics, and astronomy is sufficiently strong to permit advanced study in these subjects. If 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 131, Ay 132, Ay 133, Ay 134, Ay 136, Ay 138, Ay 139, Ay 201. The courses Ay 112, Ay 113, Ph 102, Ph 106, and Ph 125 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 Humanities and Social Sciences are required.

Degree of Doctor of Philosophy

Astronomy Program: The student's proposed over-all program of study must be planned and approved by the department during the first year. Required courses for candidacy are Ay 131, Ay 132, Ay 133 ab, Ay 138, and Ay 139. The student should take these courses as soon as they are offered. Also required are research and reading projects, starting in the second term of the first academic year. Credit for this work will be given under courses Ay 142 and Ay 143. Written term papers dealing with the research or reading done will be required at the end of each term.

Physics Program: The student's program during the first two years of graduate study should include at least 36 units of physics courses, exclusive of Ph 102, Ph 106, and Ph 125. This requirement may be reduced on written approval of the department for students who take substantial numbers of units in Ph 102, Ph 106, and Ph 125. Students in radio astronomy should include Ph 209 in the required 36 units of physics; they may take the remaining units in an advanced course in electrical engineering or applied mechanics. Students in planetary physics may substitute appropriate advanced courses in geophysics and geochemistry.

The Minor: Fields in which subject minors are usually taken include physics, geology, or engineering, dependent on the student's field of specialization.

Language Requirement: To be admitted to candidacy for the Ph.D. degree in astronomy, the student must demonstrate a knowledge of Russian, German, or French sufficient for the reading of technical material in his field. Students will be required to take a special examination administered by the staff in fulfillment of this requirement.

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

(1) complete satisfactorily 36 units of research Ay 142 or reading Ay 143,

(2) pass with a grade of C or better, or by special examination, Ay 131, Ay 132, Ay 133 ab, Ay 138, and Ay 139,

(3) pass an oral examination (see below),

(4) fulfill the language requirement (see above), and

(5) be accepted for thesis research by a staff member.

Students in planetary physics may omit Ay 138 and Ay 139, substituting a corresponding number of units from Ay 134, Ay 136, Ge 166, or Ge 220, after consultation with their advisers and the instructors.

The oral examination must be taken before the end of the second term of the second year. The candidacy examination will cover material from (1) the required astronomy courses, (2) the basic physics courses Ph 102, Ph 106, and Ph 125, and (3) the material submitted as term papers for courses Ay 142 (research) and Ay 143 (reading). Special permission will be required for further registration if the candidacy course requirements and the oral examination are not satisfactorily completed by the end of the second 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 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 during the first year of graduate work. In addition to general Institute requirements, the student must (a) complete satisfactorily, with an average grade of C or better, 45 units in advanced courses in astronomy, and (b) pass a short oral examination given by the department. Students who have not had the equivalent of Ay 112 and Ay 113 will be required to take these courses, but at a reduced credit toward the minor of 6 units per term for the combined courses.

BIOLOGY

Aims and Scope of Graduate Study in Biology

Graduate students in biology come with very diverse undergraduate preparation — majors in physics, chemistry, and 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 his particular chosen major specialty; perception of the nature and logic of biology as a whole; sufficient strength in basic science to allow him to continue self-education after his formal training has been completed and thus to keep in the forefront of his changing field; and the motivation to serve his 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 discipline of biology of his own choice, supplemented with advanced course work and independent study in this discipline; (b) the minor program, usually designed to provide him with professional insight into a discipline outside his major one and consisting of specialized course work, or course work and a special research program; and as a rule (c) a program of course work in advanced subjects, designed to provide him with a well-rounded and integrated training in biology and the appropriate basic sciences, and adjusted to his special interests and needs. (b) and (c) may include supervised, independent study. An individual program will be recommended to each student when he meets with his advisory committee (see section 4). A student majoring in psychobiology or experimental psychology may arrange to do one or more terms on another campus to obtain relevant course work in psychology and medicine not offered at the Institute.

Admission

Applicants are expected to meet the following minimal requirements: mathematics through calculus, general physics, organic chemistry, physical chemistry, and elementary biology. Students with deficient preparation in one or more of these categories may be admitted but required to remedy their deficiencies in the first years of graduate training, no graduate credit being granted for such remedial study. This will usually involve taking the 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 such as neurophysiology-electrical engineering, other kinds of undergraduate preparation may be substituted for the general requirements listed above. Graduate Record Examinations are required of applicants for graduate admission intending to major in biology.

Placement Examinations

All students admitted to graduate work in Biology are required either to take placement examinations in cell biology and in organismic biology, or to take the equivalent courses (Bi 9 and Bi 7). The examination in organismic biology is so constructed as to test basic knowledge of either animal or plant biology. The examinations or courses must be passed with a grade of B– or better before the end of the first year of graduate study.

Advisory Committee

During the week preceding registration for the first term, each entering student confers with the divisional Graduate Advisory Committee. The committee consists of a chairman and three other members of the faculty representing diverse fields of biology. The committee will advise the student of deficiencies in his training; will design a remedial study program where necessary; and will recommend an individual study program of advanced course work in accordance with item (c), section 1. The committee will also be available for consultation and advice throughout his graduate study until the student is admitted to candidacy (see below).

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 and the student has received a passing grade on each of two placement examinations. 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 doctor's degree in Biology in any of the following disciplines:

Biochemistry	Genetics
Biophysics	Immunology
Cell Biology	Neurophysiology
Developmental Biology	Psychobiology
Experimental Psychology	Virology

Minor subjects. A student majoring in one of the above disciplines may elect to take a minor in either of the following ways, subject to the approval of the graduate advisory committee: a) A general minor consisting of not less than 54 units of advanced course work in one or more disciplines in biology (if not closely related to the major discipline), other sciences, engineering or the humanities, or b) a subject minor in another division of the Institute. When a student takes a subject minor, his degree designates the disciplines of his major or minor (e.g. Biophysics and Chemistry). When he takes a general minor, his degree designates only his major discipline, (e.g. Biochemistry or Neurophysiology). Courses listed jointly by the Biology Division and another Division are not credited toward a general minor for majors in a closely related discipline of biology, even if the student registers for the course under the other division's course number.

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 his ability to carry out original research and have passed, with a grade of B or better, the candidacy examination in his major. With regard to his minor: (a) a student who elects to take a general minor is required to complete the course requirements of the minor with grades of B or better; (b) in case the minor is taken outside the Biology Division, the student is required to fulfill the minor requirements of the outside division and of the Institute.

Thesis committee. After admission to candidacy, a thesis committee is appointed for each student by the Chairman of the Division upon consultation with the student and his professor. This committee will consist of the student's major professor as chairman and four other appropriate members of the faculty including a member of the faculty of the subject minor (if any). The thesis committee will meet with the student soon after his admission to candidacy and at intervals thereafter to review the progress of his thesis program. This committee will, with the approval of the Dean of Graduate Studies, also serve as the thesis examination committee (see below).

Thesis and final examination. Two weeks after copies of the thesis are provided to the examination committee, the candidate collects the copies and comments for correction. At this time, the date for the final examination is set at the discretion of the major professor and the division chairman, to allow as necessary for such matters as publication of the examination in the Institute calendar, thesis correction, preparation of publications, and checking out and ordering of the student's laboratory space. The final oral examination covers principally the work of the thesis, and according to Institute regulation must be held at least two weeks before the degree is conferred. Two copies of the thesis are required of the graduate and are deposited in the Institute library. A third copy is retained in the division library.

Subject 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 disciplines listed above under major subjects of specialization. Requirement for such a minor consists of (a) passing the placement examination in cell biology *or* organismic biology, and (b) passing the qualifying examination in the discipline elected. A minor program in Biology is also available to students of other divisions. Such a program shall consist of 45 units of upper division course work in the Biology Division, each course passed with a grade of "C" or better. Approval of each program must be obtained from the Biology Graduate Advisory Committee. Advanced courses in the Biology Division can of course be included in a General Minor under the supervision of the student's major division. A student majoring in another division who elects a subject minor in one of the disciplines of biology may if desired arrange to have his minor designated as Biology, rather than with the name of his specific minor discipline.

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.

As a new graduate student, soon after you arrive in the laboratories, you will attend a series of orienting seminars that introduce you to the active research interests of the staff. You should then talk in detail with each of several staff members whose fields attract you, eventually settle upon the outlines of a problem that interests you, and begin research upon it early in the first year. You can elect to do research which crosses the boundaries of areas that are commonly distinguished by schismatic names; for in this relatively compact Division, a man is encouraged to go where his scientific curiosity drives him; he is not confined to a biochemical or physical or organic laboratory. A thesis that involves more than one adviser is common, and interdisciplinary programs with biology, physics, and geology are open and encouraged.

An extensive program of seminars will enable you to hear of and discuss notable work in your own and other areas. In the Divisional Research Conferences, members of the staff and distinguished visitors present accounts of research of broad interest. More specialized seminars are devoted to such subjects as theoretical chemistry, physical organic chemistry, electrochemistry, crystal-structure analysis, and biological chemistry. Graduate students are encouraged also to attend seminars in other divisions.

Placement Examinations

During the week preceding General Registration for the first term of graduate study, graduate students admitted to work for advanced degrees will be required to take written placement examinations in the fields of inorganic chemistry and organic chemistry (on Monday) and physical chemistry (on Tuesday). These examinations will cover their respective subjects to the extent that these subjects are treated in the undergraduate chemistry option offered at this Institute. In general, they will be designed to test whether you possess an understanding of general principles and a power to apply these to specific problems, rather than a detailed informational knowledge. You will be expected to demonstrate a proficiency in the above subjects not less than that acquired by abler undergraduates. Students who have demonstrated this proficiency in earlier residence at this Institute may be excused from these examinations.

On Tuesday of the week preceding General Registration, but at a different time than the physical chemistry examination, there will be a placement examination in chemical physics. It will be designed specifically to test the preparation of students who wish to carry on research in this area, and will require a knowledge of physics and mathematics beyond the corresponding courses normally required for the undergraduate chemistry option at this Institute. Students taking and passing the chemical physics examination with sufficiently high marks may, with permission, use this performance to satisfy a placement examination deficiency in one other field.

In the event that you fail to show satisfactory performance in any of the placement examinations, you will be required to register for a prescribed course, or courses, in order to correct the deficiency promptly. In general no graduate credit is given for these courses. If your performance in the required course or courses is not satisfactory, you will not be allowed to continue graduate studies except by special action of the Division of Chemistry and Chemical Engineering on receipt of a petition to be allowed to continue.

Course Program

For an advanced degree, no graduate courses in chemistry are specifically required. You should plan a program of advanced courses in consultation, at first with a representative of the Divisional Committee on Graduate Study and later with your research adviser.

Master's Degree in Chemistry

Students are not ordinarily admitted to graduate work leading to an M.S. degree, but the master's program is available. All masters' programs for the degree in chemistry must include at least 40 units of chemical research and at least 30 units of advanced courses in science. The remaining electives may be satisfied by advanced work in any area of mathematics, science, engineering, or humanities, or by chemical research.

Two copies of a satisfactory thesis describing this research, including a one-page digest or summary of the main results obtained, must be submitted to the Divisional Graduate Secretary at least ten days before the degree is to be conferred. The copies of the thesis should be prepared according to the directions formulated by the Dean of Graduate Studies and should be accompanied by a statement approving the thesis, signed by the staff member directing the research and by the Chairman of the Committee on Graduate Study of the Division.

Candidates must satisfy the department of languages that they are able to read scientific articles in at least one of the following languages: German, French or Russian.

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, you must give satisfactory evidence of proficiency at a high level in your primary field of interest, as approved by the Division. This is accomplished by an oral candidacy examination which is normally held during or before your fifth term of graduate residence. At this examination you will be asked to demonstrate scientific and professional competence and promise by discussing a research report and propositions as described below.

The research report should describe your progress and accomplishments to date and plans for future research. Three propositions, or brief scientific theses, must accompany the report. These should reflect your breadth of reading, originality, and ability to see valid scientific problems. They should *not* all be in your own field of research. The research report and propositions must be in the hands of your examining committee one week prior to the examination.

If you fail to pass the oral examination or if any of your propositions are judged inadequate, then you will have to correct the deficiencies or in some cases schedule a new examination the following term. You must be admitted to candidacy at least three terms before your final oral examination. You cannot continue in graduate work in chemistry past the end of the sixth term of residence without being admitted to candidacy, except by petitioning the Division for special permission. This permision, to be requested by a petition submitted to the Divisional Graduate Committee in advance of registration day stating a proposed timetable for correction of deficiencies, must be obtained prior to registration for each subsequent term until admission to candidacy is achieved.

Language Requirements and Candidacy. Satisfactory completion of the language requirement and removal of placement examination requirements are also necessary before you can be admitted to candidacy. Ph.D. chemists must demonstrate proficiency in *one* language: French, German, or Russian. This demonstration can be by test, good performance in a course at Caltech, or by sufficient undergraduate course work in the language.

The Minor. The units of study offered to satisfy a minor requirement are to consist in general of graduate courses other than research; however, the Division of Chemistry and Chemical Engineering may, by special action, permit up to one-half of these units to consist of appropriate research. The general minor must represent an integrated program approved by the Division; it must consist of courses other than chemistry. A grade of C or better is required in these courses.

Thesis and Final Examination. The final examination will consist in part of oral presentation and defense of a brief resume of your research and in part of the defense of a set of propositions prepared by you. Five propositions are required. In order to obtain diversity with respect to subject matter not more than two shall be related to the immediate area of your thesis research. Each proposition shall be stated explicitly and the argument presented in writing with adequate documentation. Propositions of exceptional quality presented at the time of the candidacy examination may be included among the five submitted at the time of the final examination.

The propositions should display originality, breadth of interest, and soundness of training; you will be judged on your selection and formulation of the propositions as well as on your defense of them. You should begin formulating a set of propositions early in the course of graduate study.

You must submit a copy of the thesis and propositions in final form to the chairman and to each member of the examining committee, and a copy of the propositions and an abstract of the propositions to the Divisional Graduate Secretary, *not less than* two weeks prior to your final examination. One reproduced copy of the thesis, corrected after proofreading by the Graduate Office, is to be submitted to the Divisional Graduate Secretary for the Divisional library.

Subject Minor in Chemistry

Graduate students taking chemistry as a subject minor shall complete a program of study which in general shall include Ch 125 or Ch 144 and one or more graduate courses in chemistry so selected as to provide an understanding of at least one area of chemistry. The total number of units shall not be less than 45, and a grade of C or better in each course included in the program will be required.

CHEMICAL ENGINEERING

Aims and Scope of Graduate Study in Chemical Engineering

The Institute was one of the earliest schools to use the engineering science approach to chemical engineering. The emphasis in both instruction and research is on basic subjects rather than on specialized material relating primarily to particular industries or processes. It is believed that the basic subjects essential to constructive thinking in engineering are most easily mastered with sympathetic and continuous instruction, whereas the material of applied nature is more properly learned in the industrial environment.

The general objective of the graduate work in chemical engineering is to produce men who are exceptionally well trained to apply the principles of mathematics, the physical sciences, and engineering to new situations involving chemical reactions and the transport of momentum, energy, and material.

Admission

It is expected that each applicant for graduate study in the Division of Chemistry and Chemical Engineering will have studied mathematics and physics substantially to the extent that these subjects are covered in the required undergraduate courses at Caltech. In case the applicant's training is not equivalent to this, the Division may prescribe additional work in these subjects before recommending him as a candidate.

Master's Degree in Chemical Engineering

The master's degree is intended for students who plan to pursue careers in design, process engineering, development, or management. The degree is normally obtained in one academic year.

Course Requirements. The requirements include ChE 126 abc, Chemical Engineering Laboratory. ChE 126bc represents two terms of research under the supervision of a chemical engineering faculty member. The student who has taken ChE 126a or its equivalent as an undergraduate may substitute an equal amount of research, ChE 280. A student originally admitted to work toward the Ph.D. degree can substitute an equal amount of research, ChE 280, for all or part of this requirement but must also submit a research report in thesis form and have it accepted by the faculty in chemical engineering. A research report is required for the master's degree. In addition, there are electives, which may include humanities as well as graduate courses from other branches of science and engineering. A minimum of 18 units of these electives must be in advanced chemical engineering subjects; the remainder are to be chosen from other approved advanced subjects but may also include up to 30 units of freely elected graduate courses, which may be in humanities as well as in engineering and science subjects. In addition to 81 units of advanced professional subjects, AM 113abc must be taken if the equivalent has not been studied previously.

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 in the minor program. The research program is also started during this period. During the second year the student is expected to spend at least half time on his research, and to complete his minor and the candidacy examination. Some time is available for elective courses. It is expected that the research project will occupy full time during the third year. Thus, if summers are spent on research and other academic pursuits, the Ph.D. requirements may be completed in three calendar years.

Admission. During the Friday preceding General Registration for the first term of graduate study, students admitted to work for the Ph.D. degree are required to consult with the professor in charge of the courses of engineering and chemical thermodynamics, transport phenomena, and applied chemical kinetics. This informal consultation is aimed at planning course work for each student. A student whose background in a given subject is not sufficiently strong will be advised to take the appropriate 100-series course or do some remedial work. Students with adequate background in a given area will be encouraged to take advanced courses.

Minor. The units of study offered to satisfy a minor requirement are in general to be in graduate courses other than research; however, the Division of Chemistry and Chemical Engineering may, by special action, permit up to one-half of these units to be in appropriate research. The general minor must represent an integrated program approved by the Division; for students in chemical engineering it must consist of courses other than chemical engineering. A grade of C or better is required in these courses.

Candidacy Examination. To be recommended for candidacy the student must demonstrate proficiency at a graduate level in chemical engineering. This will be done by way of chemical engineering courses and the Divisional oral candidacy examination which is to be taken before the end of the second term of the student's second year of graduate residence at the Institute. At least one week before the examination the student will submit one proposition and a written progress report on his research to his examining committee. The examination will cover the progress report and proposition. Questions on applied physical chemistry, thermodynamics, applied chemical kinetics, transport phenomena, and the joint application of these and related subjects to practical problems will also be included, with emphasis at the discretion of the committee. A student who fails to satisfy the Division's candidacy requirements by the end of the third term of his second year of graduate residence at the Institute will not be allowed to register in a subsequent academic year except by special permission of the Division of Chemistry and Chemical Engineering.

Thesis and Final Examination. The final examination will be concerned with the candidate's oral presentation and defense of a brief resume of his research and in part of the defense of a set of propositions prepared by the candidate.

Three propositions are required. In order to obtain diversity with respect to subject matter none shall be related to the immediate area of the candidate's thesis research. Each proposition shall be stated explicitly and the argument presented in writing with adequate documentation. At least one proposition is required at the time of the candidacy examination. If the proposition is acceptable, it may be included among the three submitted at the time of the final examination.

The propositions, prepared by the candidate himself, should display his originality, breadth of interest, and soundness of training; the candidate will be judged on his selection and formulation of the propositions as well as on his defense of them. It is recommended that the candidate begin the formulation of his set of propositions early in his course of graduate study.

The candidate must submit a copy of his thesis and propositions in final form to the chairman and to each member of his examining committee, and a copy of the propositions and an abstract of the propositions to the Divisional graduate secretary *not less than* two weeks prior to his final examination, which according to the Institute regulation must be held at least two weeks before the degree is conferred. After his examination two copies of the thesis are to be submitted to the office of the Dean of Graduate Studies to be proof-read. In addition, one copy, corrected after proof-reading by the Graduate Office, is to be submitted to the Divisional Graduate Secretary for the Divisional library. All reproduced copies may be either electrostatic bound copy (Xerox or similar) or electrostatic vellum (Xerox or similar).

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 program in consultation with a member of the faculty. In some cases, the student may be required to make up deficiencies in engineering science courses at the undergraduate level. However, in every case the student will be urged to take some courses which will broaden his understanding of the overall field of civil engineering, as well as courses in his specialty. Most graduate students are also required to take further work in applied mathematics.

Master's Degree in Civil Engineering

Although the first year of graduate study involves specialized engineering subjects, the student working for the Master of Science degree is encouraged not to overspecialize in one particular field of civil engineering. For the M.S. degree a minimum of 138 units of academic credit is required. The program must include 3 units of CE 130 abc; 27 units of courses in humanities or social sciences; and 108 units (minimum) of courses from the five groups of electives listed below. Each student's program should include selections from at least three of the five groups that are approved by his adviser. Students who have not had AM 95 abc or its equivalent will be required to include AM 113 abc as part of their elective units. Other courses not listed here may be elected if approved by the Civil Engineering faculty.

Elective Course Lists:

Electives in Structures

		Units per Term 1st	2nd	3rd
Ae 102 abc	Basic Solid Mechanics (3-0-6)	9	9	9
AM 112 abc	Structural Mechanics (3-0-6)	9	9	9
AM 135 abc	Mathematical Elasticity Theory (3-0-6)	9	9	9
AM 151 abc	Dynamics and Vibrations (3-0-6)	9	9	9
AM 155	Dynamic Measurements Laboratory (1-6-2)	9	.	.
AM 160	Vibrations Laboratory (0-3-3)	.	6	.
CE 121	Analysis and Design of Structural Systems (0-9-0)	.	.	9
CE 124	Special Problems in Structures	9 or	9 or	9
CE 180	Experimental Methods in Earthquake Engineering (1-5-3)	9	.	.
CE 181	Principles of Earthquake Engineering (3-0-6)	.	9	.
CE 182	Structural Dynamics of Earthquake Engineering (3-0-6)	.	.	9
CE 212 abc	Advanced Structural Mechanics (3-0-6)	9	9	9

Electives in Soil Mechanics

		1st	2nd	3rd
CE 105	Introduction to Soil Mechanics (2-3-4)	9	.	.
CE 115 ab	Soil Mechanics (3-0-6; 2-3-4)	9	9	.
CE 150	Foundation Engineering (3-0-6)	.	.	9

Electives in Hydraulics and Water Resources

		1st	2nd	3rd
Env 112 abc	Hydrologic Transport Processes (3-0-6)	.	9	9
Hy 101 abc	Fluid Mechanics (3-0-6)	9	9	9
Hy 103 ab	Advanced Hydraulics and Hydraulic Structures (3-0-6)	9	9	.
Hy 105	Analysis and Design of Hydraulic Projects[2]	.	.	.
Hy 106	Experimental Hydraulics and Similitude (3-1-5)	9	.	.
Hy 111	Fluid Mechanics Laboratory[1]	.		
Hy 113	Coastal Engineering (3-0-6)	.	.	9
Hy 121	Advanced Hydraulics Laboratory[2]			

[1]Six to nine units as arranged, second or third term.
[2]Six or more units as arranged, any term.

Electives in Environmental Health Engineering

Env 141	Applied Aqueous Solution Chemistry (3-3-3)	9	.	.
Env 142 ab	Applied Chemistry of Natural Water Systems (2-3-4)	.	9	9
Env 144	Ecology (2-1-3)	.	6	.
Env 145 ab	Environmental Health Biology (2-4-4; 2-3-4)	.	10	9
Env 146 abc	Analysis and Design of Water and Wastewater Systems (3-0-6)	9	9	9
Env 155	Special Problems in Waste Management (2-3-4)	.	9	.
Env 156	Industrial Wastes (3-0-6)	.	.	9
Env 170 ab	Behavior of Disperse Systems in Fluids (3-0-6)	9	9	.
Ch 124 abc	Elements of Physical Chemistry (4-0-2)	6	6	6

Electives in Mathematics

AMa 101 abc	Methods of Applied Mathematics I (3-0-6)	9	9	9
AMa 104	Matrix Algebra (3-0-6)	9	.	.
AMa 105 ab	Introduction to Numerical Analysis (3-2-6)	.	11	11
AM 113 abc	Engineering Mathematics (4-0-8)	12	12	12
AM 125 abc	Engineering Mathematical Principles (3-0-6)	9	9	9
Ma 112 ab	Elementary Statistics (3-0-6)	9	or 9	9

Degree of Civil Engineer

Greater specialization is provided by work for the Engineer's than for the Master's degree. The candidate for this degree is allowed wide latitude in selecting his 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

Major subjects of specialization. A student may pursue major work leading to the Doctor's degree in Civil Engineering in any of the following disciplines: structural engineering and applied mechanics, earthquake engineering, soil mechanics, hydraulics, coastal engineering, and environmental health engineering. Other disciplines may be selected with approval of the Civil Engineering faculty.

Minor Requirements. A student may elect to take a minor in either of the following ways subject to the approval of his adviser: (a) a subject minor in a discipline sufficiently removed from the field of his major work, or (b) a general minor consisting of at least 54 units of work of which at least 36 units must be in advanced subjects in one or more disciplines in the humanities, sciences or engineering. The purpose of the minor program of study is to broaden the student's outlook by acquainting him with subject matter outside his major field. The minor requirement is the completion of advanced courses arranged by the student in conference with his adviser, and approved by the faculty. A portion of the general minor should be taken outside the Division of Engineering and Applied Science. Furthermore, the minor program (subject or general) may not include (a) the courses used to satisfy the mathematics requirement (including prerequisites); nor (b) any course in the specialized field of the student's thesis research.

Admission to candidacy. Before the end of the second year of graduate residence the student must pass a Ph.D. qualifying oral examination. The examination will include, but will not be limited to, presentation and defense of one or more propositions which should be controversial or unresolved topics for which there is more than one point of view. At least eight weeks before the examination the student must submit his propositions for approval. Furthermore, ten days before the examination the student must present: (a) a brief exposition of the arguments for each of his propositions, and (b) a brief statement of his proposed thesis research.

To be recommended for admission to candidacy for the Ph.D. degree, the student must have demonstrated his ability to carry out original research. In addition to general Institute requirements, he must:

a. Pass the qualifying examination described above.

b. Pass a candidacy oral examination on the major subject.

c. Submit a satisfactory written progress report on his thesis research.

d. Complete a program of advanced courses as arranged by the student in consultation with his adviser, and approved by the faculty.

e. Pass at least 27 units of course work in advanced mathematics, such as AM 125, Ph 129, or satisfactory substitution. For a student whose program is more closely related to the sciences of biology or chemistry than physics, AMa 104 and AMa 105 ab (or AMa 104 and IS 18 lab) will be an acceptable substitution for the mathematics requirement.

Thesis and Final Examination. Copies of the completed thesis must be provided to the examining committee two weeks prior to the examination. The date for the final oral examination is decided at the discretion of the major professor and the Division Chairman to allow as necessary for such matters as publication of the examination in the Institute Calendar. The oral examination covers principally the work of the thesis, and according to Institute regulations, must be held at least two weeks before the degree is conferred. Two copies of the thesis are required of the graduate, one of which is deposited in the Institute Library and the other is deposited with University Microfilms. The examining committee will consist of such individuals as may be recommended by the Chairman of the Division and approved by the Dean of Graduate Studies.

ELECTRICAL ENGINEERING

Aims and Scope of Graduate Study in Electrical Engineering

The Bachelor of Science degree is followed by additional graduate work for the Master of Science degree in Electrical Engineering, usually completed in one year. For exceptional students, instruction is offered leading to the degrees of Electrical Engineer and Doctor of Philosophy. The graduate curriculum is sufficiently flexible to allow the student to select courses closely aligned with his particular field of interest. Students are encouraged to participate in graduate seminars and in research projects with the electrical engineering faculty.

Placement Examination

Students admitted to work toward the degree of Master of Science in Electrical Engineering are required to take a placement examination in mathematics. This examination is given on the Friday of the week preceding registration, and will be concerned primarily with subject matter of the undergraduate course, AM 95 abc. The result of this examination has no bearing on a student's admission to graduate study, but in the event that preparation in this subject area is judged to be inadequate, the student will be required to enroll in AM 113 ab, for which graduate credit may be received. In cases where there is a clear basis for ascertaining the student's preparation, the examination may be waived. Notices of the placement examination are sent well in advance of the examination date.

Master's Degree in Electrical Engineering

A minimum of 102 units are required from the following list of courses.

		Units per term		
		1st	2nd	3rd
EE 113 abc	Modern Optics (3-0-6)	9	9	9
EE 114 abc	Electronic Circuit Design (3-0-6)	9	9	9
EE 131 abc	Physics of Semiconductors and Semiconductor Devices (3-0-6)	9	9	9
EE 133 abc	Interaction of Radiation and Matter (3-0-6)	9	9	9
EE 135 abc	Ferromagnetism (3-0-6)	9	9	9
EE 155 abc	Electromagnetic Fields (3-0-6)	9	9	9
EE 194	Microwave Laboratory (1-4-4)	.	.	9
EE 291	Advanced Work in Electrical Engineering	.	.	.
Ph 113 abc	Solid State Physics (3-0-6)	9	9	9
Ph 125 abc	Quantum Mechanics (3-0-6)	9	9	9
Ph 129 abc	Methods of Mathematical Physics (3-0-6)	9	9	9
Ph 204 abc	Low Temperature Physics (3-0-6)	9	9	9
Ph 209 abc	Electromagnetism and Electron Theory (3-0-6)	9	9	9
Ph 214 ab	Solid State Physics (3-0-6)	9	9	.
Ph 216 abc	Introduction to Plasma Physics (3-0-6)	9	9	9
Ph 221	Topics in Solid State Physics (3-0-6)	.	.	9
Ph 227 abc	Thermodynamics, Statistical Mechanics, and Kinetic Theory (3-0-6)	9	9	9
AM 125 abc	Engineering Mathematical Principles (3-0-6)	9	9	9
IS 110 abc	Principles of Digital Information Processing (3-3-3)	9	9	9
IS 129 abc	Formal Languages and Programming Systems (3-0-6)	9	9	9
AMa 101 abc	Methods of Applied Mathematics (3-0-6)	9	9	9
AMa 104	Matrix Algebra (3-0-6)	9	.	.
AMa 105 ab	Introduction to Numerical Analysis (3-2-6)	.	11	11
AMa 153 abc	Stochastic Processes (3-0-6)	9	9	9
AMa 181 ab	Linear Programming (3-0-6)	.	9	9
Ma 108 abc	Advanced Calculus (4-0-8)	12	12	12

Other electives may be substituted upon approval of the Electrical Engineering faculty. E 150 abc: Engineering Seminar, is also required. If, as a result of the placement examinations, a student is required to take AM 113, or EE 151, no more than 30 units from these courses may be offered for the M.S. degree. Students are urged to consider including a humanities course in the 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

Admission. In general, a graduate student is not admitted to work for the doctor's degree in Electrical Engineering until he has received a degree of Master of Science or equivalent.

Admission to graduate work beyond the M.S. degree is by recommendation of the EE faculty, based upon three factors: (1) the student's academic record, (2) performance in a preliminary oral examination normally taken the January before he obtains his M.S. degree, and (3) future research potential as evaluated by his proposed thesis adviser.

Candidacy. To be recommended for candidacy for the doctor's degree the applicant must satisfy the requirements listed below.

a. Complete 18 units of research in his field of interest.

b. Obtain approval of a minor course of study. Courses for either a subject or a general minor may be offered only if their content is primarily in a field other than that of the student's thesis research. Preferably some of the courses in a general minor should be outside the Division of Engineering.

c. Pass one of the following subjects with no grade lower than C:

AMa 101 abc	Methods of Applied Mathematics
AM 125 abc	Engineering Mathematical Principles
Ma 108 abc	Advanced Calculus
Ph 129 abc	Methods of Mathematical Physics

An applicant may also satisfy any of the above course requirements by taking an examination in the subject with the instructor in charge. Every examination of this type will cover the whole of the course specified, and the student will not be permitted to take it either in parts (e.g. term by term) or more than twice.

d. Pass a qualifying oral examination covering broadly his major field and minor program of study. This examination is normally taken in the third term of the student's first post-M.S. year.

Thesis and Final Examination. The candidate is required to take a final oral examination covering his doctoral thesis and its significance in and its relation to his 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.

ENGINEERING SCIENCE

Aims and Scope of Graduate Study in Engineering Science

The Engineering Science option at Caltech is designed for students of subjects which might be called classical, and semi-classical, physics, and mathematics, or the subjects which form the core of the new "interdisciplinary" sciences. These branches of science provide the basis for modern technology. Students tend to choose physics and applied mathematics as their minor subjects and to choose a thesis adviser within the Division of Engineering and Applied Science. The possibilities of choice of research subject may be seen in the following thesis titles: "Multiple Scattering of Acoustic Waves," "Studies of Cyclotron Echoes in Plasmas," "Problems of Palladium-Silicon Alloys," and "Mechanical Properties of the Red Blood Cell."

Students wishing to pursue graduate studies in nuclear engineering should apply for admission in this option. Such applicants are encouraged to apply for AEC Special Fellowships in nuclear science and engineering, details of which may be obtained from Oak Ridge Associated Universities, Oak Ridge, Tennessee.

Students who wish to follow a program in the Biological Engineering Sciences or in Information Science may do so in Engineering Science.

Master's Degree in Engineering Science

One of the following courses in mathematics is required:

AMa 101 abc	Methods in Applied Mathematics I
AM 125 abc	Engineering Mathematical Principles
Ph 129 abc	Methods of Mathematical Physics

Students in Information Science may substitute Ma 108 or AMa 153 abc for the above requirement in applied mathematics.

A minimum of 54 units must be selected from the Elective Course List below; however, substitutions for electives in this list may be made with the approval of the student's adviser and the faculty in Engineering Science.

Degree of Doctor of Philosophy in Engineering Science

Course Requirements. To be recommended for candidacy for the Ph.D. degree in Engineering Science, the student must, in addition to the general Institute requirements:

a. Complete 12 units of research.
b. Complete at least 50 units of advanced courses arranged by the student in conference with his adviser and approved by the faculty in Engineering Science.
c. Pass with a grade of at least C an advanced course in mathematics or applied mathematics such as AM 125 abc, Ph 129 abc, or AMa 101 abc, acceptable to the faculty in Engineering Science.

   In place of AM 125 abc, Ph 129 abc, or AMa 101 abc, students in Information Science are required to take Ma 108 abc and at least 27 units of advanced mathematics such as Ma 116 abc, EE 162a, or AM 153 abc.

   The requirement in mathematics shall be in addition to requirement (b) above, and shall not be counted toward the minor requirements.

Language requirements. The student is encouraged to discuss with his adviser the desirability of taking foreign languages, which may be included in a general minor or as a subject minor with the proper approvals. Foreign languages are not required.

Thesis and Final Examination. A final oral examination will be given after the thesis has been formally completed. This thesis examination will be a defense of the doctoral thesis and a test of the candidate's knowledge in his specialized field of research.

Subject Minor in Engineering Science

A student majoring in another branch of engineering, or another division of the Institute, may, with the approval of the faculty in Engineering Science, elect Engineering Science as a subject minor.

Elective Course list

		Units per Term 1st	2nd	3rd
AMa 104	Matrix Algebra	9	.	.
AMa 105 ab	Introduction to Numerical Analysis	.	11	11
AM 135 abc	Mathematical Elasticity Theory	9	9	9
ChE 103 abc	Transport Phenomena	9	9	9
EE 133 abc	Interaction of Radiation and Matter	9	9	9
EE 135 abc	Ferromagnetism	9	9	9
EE 172 abc	Feedback Control System	9	9	9
Env 141	Applied Aqueous Solution Chemistry	9	.	.
Env 142 ab	Applied Chemistry Natural Water System	.	9	9
ES 101 abc	Nuclear Reactor Theory	9	9	9
ES 102 abc	Applied Modern Physics	9	9	9
ES 103	Nuclear Radiation Measurements Laboratory	.	9	.
ES 104	Nuclear Energy Laboratory	.	.	9
ES 130 abc	Introduction to Classical Theoretical Physics I	9	9	9
ES 131 abc	Introduction to Classical Theoretical Physics II	9	9	9
Hy 101 abc	Fluid Mechanics	9	9	9
IS 110 abc	Principles of Digital Information Processing	9	9	9
IS 129 abc	Formal Languages and Programming Systems	9	9	9
Ma 108 abc	Advanced Calculus	12	12	12
Ma 125 abc	Analysis of Algorithms	9	9	9
Ph 106 abc	Topics in Classical Physics	9	9	9
Ph 113 abc	Introduction to Solid State Physics	9	9	9
Ph 125 abc	Quantum Mechanics	9	9	9
Ph 216 abc	Introduction to Plasma Physics	9	9	9

ENVIRONMENTAL ENGINEERING SCIENCE

Aims and Scope of Graduate Study in Environmental Engineering Science

By their nature, environmental problems cut across many diverse disciplines. The graduate program in environmental engineering science attempts to emphasize the problem areas and to draw together work from whatever traditional disciplines are relevant. Close interactions among engineers, scientists and social scientists are considered essential.

In selecting courses and research topics each student is expected to plan for both breadth of study of the environment and depth of research on a particular subject. There are no set requirements, and not all students are expected to study all subjects. The seminars (Env 150 and 250) offer an opportunity for all students to become acquainted with the full range of environmental research and engineering control procedures.

The curriculum has been planned primarily for the students pursuing the Ph.D. degree, although the M.S. degree is also offered. The purpose of the Ph.D. program is to prepare students for careers of specialized research, or advanced engineering and planning in various aspects of the environment. Although students are expected and encouraged to develop a broad awareness of the full range of environmental problems, the program is not designed to train environmental generalists.

Admission

Students with Bachelor's degrees in engineering, any of the sciences, mathematics, or economics 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 his adviser. In some instances students may need to take some additional undergraduate subjects in preparation for the graduate courses in this field.

Master's Degree in Environmental Engineering Science

For the M.S. degree a minimum of 135 units of academic credit in advanced courses is required. Each student's program should be well balanced with courses in several sub-disciplines to avoid over-specialization.

The program must have at least 105 units of electives from the list below, including 3 units of Env 150 abc. The remaining units are for free electives of any advanced courses at the Institute. Students are encouraged to include social science or humanities courses among their free electives. Students who have not had AM 95 abc or its equivalent are required to include AM 113 abc as part of their elective units.

List of Electives

		Units per Term		
		1st	2nd	3rd
AMa 101 abc	Methods of Applied Mathematics I (3-0-6)	9	9	9
AMa 104	Matrix Algebra (3-0-6)	9	.	.
AMa 105 ab	Introduction to Numerical Analysis (3-6-0)	.	11	11
AM 113 abc	Engineering Mathematics (4-0-8)	12	12	12
AM 125 abc	Engineering Mathematical Principles (3-0-6)	9	9	9
Env 100	Special Topics in Environmental Engineering Science[1]	.	.	.
Env 112 ab	Hydrologic Transport Processes (3-0-6)	.	9	9
Env 118	Environmental Economics (3-0-6)	9	.	.
Env 141	Applied Aqueous Solution Chemistry (3-3-3)	9	.	.
Env 142 ab	Applied Chemistry of Natural Water Systems (2-3-4)	.	9	9
Env 144	Ecology (2-1-3)	.	6	.
Env 145 ab	Environmental Biology (2-4-4; 3-0-6)	.	10	9
Env 146 abc	Analysis and Design of Water and Wastewater Systems (3-0-6)	9	9	9
Env 150 abc	Seminar in Environmental Engineering Science	1	1	1
Env 155	Special Problems in Waste Management (2-3-4)	.	9	.
Env 156	Industrial Wastes (3-0-6)	.	.	9
Env 160	Biological Fluid Flows: Hemorheology (2-0-4)	.	6	.
Env 170 ab	Behavior of Disperse Systems in Fluids	9	9	.
Env 203	Advanced Topics in Environmental Engineering Science[2]	.	.	.
Env 206 abc	Special Problems in Biological Engineering Science[2]	.	.	.

[1]Six or more units as arranged, any term.
[2]Units by arrangement, any term.

Env 214 abc	Advanced Environmental Fluid Mechanics (3-0-6)	9	9	9
Env 250	Advanced Environmental Seminar (2-0-2)	4	4	4
Env 300	Thesis Research[2]	.	.	.
Bi 110	Biochemistry (4-0-8)	.	12	.
Bi 111	Biochemistry Laboratory (0-8-2)	.	10	.
Ch 114	Quantitative Analysis (2-0-2)	4	.	.
Ch 124 abc	Elements of Physical Chemistry (4-0-2)	6	6	6
ChE 101 abc	Applied Chemical Kinetics (2-0-7)	9	9	9
ChE 103 abc	Transport Phenomena (3-0-6)	9	9	9
ChE 105 abc	Applied Chemical Thermodynamics (3-0-6)	9	9	9
ChE 172 abc	Control Systems Theory (3-0-6)	9	9	9
Ae 101 abc	Basic Fluid and Gas Dynamics (3-0-6)	9	9	9
Ae 104	Experimental Techniques (3-0-3)	6	.	.
Ae 105 bc	Fluid Mechanics Laboratory (1-3-2)	.	6	6
Hy 101 abc	Fluid Mechanics (3-0-6)	9	9	9
Hy 103 ab	Advanced Hydraulics and Hydraulic Structures (3-0-6)	9	9	.
Hy 106	Experimental Hydraulics and Similitude (3-1-5)	9	.	.
Hy 111	Fluid Mechanics Laboratory[3]	.		
Hy 113	Coastal Engineering (3-0-6)	.	.	9
Hy 121	Advanced Hydraulics Laboratory			

Degree of Doctor of Philosophy in Environmental Engineering Science

Major subjects of specialization. Students may do major study including the doctoral thesis in any of the following general areas: environmental chemistry, marine ecology, air and water quality control, environmental health engineering, bioengineering, hydraulics and hydrology, environmental economics and systems analysis. Other subjects may be selected with approval of the Faculty in Environmental Engineering Science.

Minor Requirements. A student may elect to take a minor in either of the following ways subject to the approval of his adviser: (a) a subject minor in a discipline sufficiently removed from the field of his major work, or (b) a general minor consisting of at least 54 units of work of which at least 36 units must be in advanced subjects in one or more disciplines in the humanities, sciences or engineering. The purpose of the minor program of study is to broaden the student's outlook by acquainting him with subject matter outside his major field. The minor requirement is the completion of advanced courses arranged by the student in conference with his adviser, and approved by the faculty. A portion of the general minor should be taken outside the Division of Engineering and Applied Science. Furthermore, the minor program (subject or general) may not include (a) the courses used to satisfy the mathematics requirement (including prerequisites); nor (b) any course in the specialized field of the student's thesis research.

Admission to candidacy. Before the end of the second year of graduate residence the student must pass a Ph.D. qualifying oral examination. The examination will include, but will not be limited to, presentation and defense of one or more propositions which should be controversial or unresolved topics for which there is more than one point of view. At least eight weeks before the examination the student must submit his propositions for approval. Furthermore, ten days before the examination the student

[2]Units by arrangement, any term.
[3]Six or nine units as arranged, second or third term.

must present: (a) a brief exposition of the arguments for each of his propositions, and (b) a brief statement of his proposed thesis research.

To be recommended for admission to candidacy for the Ph.D. degree, the student must have demonstrated his ability to carry out original research. In addition to general Institute requirements, he must:

a. Pass the qualifying examination described above.
b. Pass a candidacy oral examination on the major subject.
c. Submit a satisfactory written progress report on his thesis research.
d. Complete a program of advanced courses as arranged by the student in consultation with his adviser, and approved by the faculty.
e. Pass at least 27 units of course work in advanced mathematics, such as AM 125, Ph 129, or satisfactory substitution. For a student whose program is more closely related to the sciences of biology or chemistry than physics, AMa 104 and AMa 105 ab (or AMa 104 and IS 181 ab) will be acceptable for the mathematics requirement.

Thesis and Final Examination. Copies of the completed thesis must be provided to the examining committee two weeks prior to the examination. The date for the final oral examination is decided at the discretion of the major professor to allow as necessary for such matters as publication of the examination in the Institute Calendar. The oral examination covers principally the work of the thesis, and according to Institute regulations, must be held at least two weeks before the degree is conferred. Two copies of the thesis are required of the graduate, one of which is deposited in the Institute Library and the other is deposited with University Microfilms. The examining committee will consist of such individuals as may be recommended by the Chairman of the Division of Engineering and Applied Science and approved by the Dean of Graduate Studies.

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 his proposed minor program to the departmental representative for approval.

GEOLOGICAL AND PLANETARY SCIENCES

Aims and Scope of Graduate Study

Graduate students in the Division of Geological Sciences enter with very diverse undergraduate preparation — majors in physics, astronomy, chemistry, and mathematics, as well as in geology, geophysics, and geochemistry. Graduate study and research within the Division is equally diverse and the graduate program aims to provide for each student a depth of competence and experience in his major field, sufficient strength in the basic sciences as to allow him to continue self-education after his formal training has been completed, and the motivation and training to keep him in the forefront of his field through a long and productive career.

Graduate Record Examination Test Scores

All North American applicants for admission to graduate study in the Division of the Geological Sciences are required to submit Graduate Record Examination test scores for verbal and quantitative aptitude tests and the advanced test in geology, or their field of undergraduate specialty if other than geology. Non-North American applicants are strongly urged to submit Graduate Record Examination scores and TOEFL (Test of English as a Foreign Language) scores to assist in proper evaluation of the applications.

Placement Examinations

On Wednesday, Thursday, and Friday of the week preceding registration for his first term of graduate work, the student will be required to map a small field area and to take written placement examinations covering basic aspects of the earth sciences and including elementary physics, mathematics, chemistry, and biology. These examinations will be used to determine the student's understanding of basic scientific principles and his ability to apply these principles to specific problems. It is not expected that he possess detailed informational knowledge, but it is expected that he demonstrate a degree of proficiency not less than that attained by undergraduate students at the California Institute. A student who has demonstrated proficiency in earlier residence at the Institute may be excused from these examinations.

The student's past record and his performance in the placement examinations will be used to determine whether he should register for certain undergraduate courses. Any deficiencies must be corrected at the earliest possible date.

Adviser

Each member of the Division faculty serves as an academic adviser to a small number of graduate students intending to major in his field. Each graduate student will be notified, prior to his arrival, who his adviser will be, and prior to registration day the student should seek the counsel of his adviser in planning his program for each term. A student can and should consult with other staff members concerning his program of study and research. It is the responsibility of the adviser to see that the student registers at the earliest possible time for the proper courses to provide background, fulfill requirements, and to constitute a sensible, integrated program. It is the responsibility of the student to seek and consider his adviser's advice. If a student elects to do a Ph.D. thesis under his academic adviser, another staff member will then be appointed as his academic adviser, as distinct from his thesis adviser.

Registration for Early Research

It is the wish of the Division that its graduate students become productively research-minded as early as possible. To that end it is strongly recommended that each student register for not less than 8 units of research in two out of the first three terms of residence. Each of these terms of research should be under the direction of *different* staff members. Guidance in arranging for research should be sought from the student's adviser and from individual members of the staff. The primary objective is to communicate to the students the excitement of discovery based on original investigations. An important by-product can be the formulation of propositions for the Ph.D. oral examination or an orientation toward Ph.D. thesis research.

Basic Geology Requirement

The solution of many problems in all subdisciplines within the earth sciences requires an understanding of earth materials and geological and field relationships. Therefore, all graduate students who have not had training equivalent to that provided in the courses Ge 104 abc and Ge 105 abc will be required to take those courses during their first year of graduate work. Graduate students majoring in geology, as distinct from other major subjects within the division will be required to fulfill the equivalent of the Institute's undergraduate field geology program consisting of Ge 105, Ge 121, and Ge 123.

Students who exhibit exceptional ability in physics and mathematics and whose program of study and research is devoted strictly to problems unrelated to surface or subsurface geology or to the characteristics of rocks and geological relations as they can be observed in the field may be excused from the minimal program of study in geology. Individual decisions on these matters are made by a special committee appointed by the Division Chairman upon request of the student's adviser.

Master's Degree in the Geological and Planetary Sciences

Master's Degree students in Geology, Geochemistry, Geophysics, or Planetary Science will be expected to have satisfied, either before arrival or in their initial work at the Institute, the basic requirements of the undergraduate Geology, Geochemistry, or Geophysics curriculum (pages 210-213). Particular attention is called to requirements in petrology, field geology, chemistry, physics, and mathematics; competence in these subjects will be evaluated during the placement examination. Twenty-seven units of such course work may be counted toward the Institute requirement of 135 graduate units. In addition, students must satisfy the Institute requirement of 81 units of advanced graduate work by taking, in consultation with the student's adviser, courses numbered over 100 in geology or other science and engineering options that are not required in the Geology, Geochemistry, and Geophysics undergraduate curriculum. Humanities work may be included in the 27 units of free electives. For most students, two years will be required to meet the Master's Degree requirements.

Students with limited experience in geological field work may be required to take all or a portion of Ge 104-105 abc as a prerequisite to Ge 121 abc or Ge 123. By approval of the Committee on Field Geology, the field geology requirement may be satisfied by evidence of equivalent training obtained elsewhere.

Degree of Doctor of Philosophy

Major Subject. The work for the doctorate in the Division of the Geological Sciences shall consist of advanced studies and of research in some discipline in the geological sciences which will be termed the "major subject" of the candidate. The Division will accept as major subjects any of the disciplines listed herewith, provided that the number of students working under the staff members in that discipline does not exceed the limit of efficient supervision.

Geology		Geochemistry
Geobiology	Planetary Science	Geophysics

Admission to Candidacy. A student may be admitted to candidacy for the Ph.D. degree by vote of the Division staff upon meeting the following requirements:

a. He must pass the qualifying examination.
b. He must satisfy minimum course requirements in his major and minor subjects.
c. He must satisfy the language requirement.
d. He must satisfy his academic and thesis advisers that his course work has prepared him to undertake research in his major subject.
e. He must be accepted for thesis research by a Division staff member.

A student admitted to work for the Ph.D. degree must file with the Division before the end of the ninth term of residence the regular form for admission to candidacy with evidence of having met these requirements. If the requirements are not met by that time, the student must petition the Division for continued registration. After the third year of graduate work a student can only register with the approval of his thesis adviser.

Qualifying Examination. This examination will consist of: the oral defense of 4 propositions prepared by the student, each supported by a succinct one-paragraph statement of the problem and of the candidate's specific approach to it. The propositions offered must represent a knowledge and breadth of interest judged acceptable by the Division in terms of the student's maturity. The student has the privilege of consultation and discussion with various staff members concerning his ideas on propositions but the material submitted must represent the work of the student and not a distillation of comments and suggestions from the staff. Candidates should realize that propositions based on field investigations are just as acceptable as those arising from laboratory or theoretical work. In general, the examination is designed to evaluate a student's background in the earth sciences and allied fields and to determine his capabilities in applying scientific principles to the solution of specific problems. The ideal candidate will display originality and imagination as well as scholarship.

Propositions must be submitted to the Division office at least one week before registration day of the 4th term of residence, and the examination will be taken within the ensuing two-week period at a time and before a committee arranged by the Division.

Graduate students are encouraged to register for as many as 15 units per term of research, or advanced study under appropriate staff members to gain experience and background for preparation of their propositions.

Minimum Course Requirements for Ph.D.

In Geology and Geobiology: In addition to the general Institute requirements the candidate for the Ph.D. in Geology or Geobiology must successfully complete a minimum of 135 units of 100-200 level courses, including the 200-level courses most pertinent to his major field, but excluding languages, research and reading courses, and certain courses constituting basic preparation in his field as follows: Ma 1, Ma 2, Ph 1, Ph 2, Ch 1, Ge 104-105, Ge 114, Ge 115, Ge 123, Ge 121, Ch 124 ab. At least 36 of the 135 units must be taken outside the Geology Division (with a grade of C or better) and may be used as part of the minor. For good work in most modern earth-science fields a proficiency in mathematics equivalent to that represented by AM 113 (Engineering Mathematics) is essential. Summer study and research at a marine biology laboratory is required of most candidates in Geobiology. Throughout his graduate work a student is expected to participate in departmental seminars and in seminar courses led by distinguished visitors.

In Geochemistry: In addition to the general Institute and Division requirements, the Ph.D. candidate in Geochemistry must demonstrate a knowledge of both geology and chemistry equivalent to the average attained in the Caltech undergraduate curriculum in Geochemistry. This can be done by either (a) adequate performance on *both* the Geological Sciences and division placement examinations, or (b) appropriate supplemental course work. The typical student should be able to perform well on one of the placement examinations, although not necessarily on both. Beyond this, the candidate will be expected to take a minimum of 90 units of 100- and 200-level courses, at least 54 units of which should be outside the Geology Division. The same courses can be presented to satisfy the requirements for a minor. A proficiency in mathematics equivalent to AM 113 (Engineering Mathematics) is desirable.

In Geophysics: Students beginning work for a Ph.D. in Geophysics should have completed Ph 106 abc and AM 113 abc or their equivalents. Students lacking this background may have to spend extra time in residence. In addition, Ph.D. candidates in Geophysics are required to complete a minimum of 90 units of courses chosen from the following three categories. At least 20 units must be completed in each group.

Group A — Courses in mathematics and mathematical methods: Ph 129, AMa 101, AMa 110, AMa 151, AMa 201, AMa 204, Ma 142, Ma 143, Ma 205, AM 141, EE 163, EE 255, Ae 210. A minimum proficiency in basic mathematical methods at the level of Ph 129 or AMa 101 and AMa 201 is therefore strongly recommended. AMa 104 and AMa 105 will prove useful to the student in his further training but are not required and cannot be used to satisfy the Group A requirements.

Group B — Courses in physics and chemical physics: Ph 113, Ph 125, Ph 205, Ph 214, Ph 227, Ph 236, MS 205, EE 133, Ch 125, Ch 225, Ch 226. Geophysics courses cannot be substituted for courses in this group.

Group C — Courses in geology: Ge 104, Ge 105, Ge 121, Ge 135, Ge 212, Ge 247, Ge 214, Ge 114, Ge 115, Ge 215, Ge 216. A minimum proficiency in basic geology equivalent to that of Ge 104 and 105 is required of Geophysics majors. The student's competence in these areas will be evaluated on the basis of his previous course work and on the basis of the placement examination.

The recommended courses in these three categories are representative of the required level, but the list is not exhaustive. Substitutions can be made upon consultation with the student's adviser.

In addition, Ph.D. candidates in Geophysics are required to take 45 units of Geophysics courses at the 100 or higher level. Ge 166 ab, Ge 261, Ge 260, Ge 155, and Ge 160 are suitable for part of this requirement and are particularly recommended for the first year. Research and reading courses cannot be used to satisfy this requirement, but registration in reading and research courses is recommended in preparation for the oral qualifying examination.

In Planetary Science: In addition to general Institute and Divisional requirements the candidate for a Ph.D. degree in Planetary Science shall acquire at least a minimum graduate background in each of three categories of course work: (1) The Earth Sciences, (2) Physics, Mathematics, Chemistry, and Astronomy, and (3) Planetary Science.

These requirements may be met by successful completion of at least 45 hours of suitable course work at the 100 or higher level in each category. Ph 106 abc and AM 113 abc, or equivalents, are considered as necessary prerequisites, and may not be used to satisfy part of this requirement. Reading and research courses may not be used, although students are expected to take such courses.

Students should be aware of current research in planetary science within the Division. This involves taking the Planetary Science Seminar (Ge 225) for credit at least once and participating in it each year. In addition students should participate in the brief trips to the Mount Wilson Observatory, the Owens Valley Radio Observatory, and the radar facility. Students should expect to devote their time each summer to research in planetary science.

The minor requirement can be satisfied in the usual manner, and courses used for this purpose also fulfill (2) above.

The intention is to provide flexibility in the Ph.D. program in Planetary Science. Should further flexibility appear desirable, the student should formally petition the Division accordingly.

Minor Requirement. The purpose of the minor requirement is to give diversification of training and a broadening of outlook. It should involve basic approaches, techniques, and knowledge distinct from those of the major field. The Division prefers that students take a subject minor in other divisions of the Institute, but the student may take a general minor or a subject minor in the Division in a different field from his major. A subject minor must be comprehensive enough to give the student a fundamental knowledge of the field and his diploma and degree will indicate both the major and minor fields. A general minor may consist of courses from a variety of fields constituting a broad base to the major field, but it is not indicated on the diploma or degree. A general minor consists of at least 36 units of advanced work distributed in courses not specifically required by the major field and 18 units of either advanced or undergraduate work (including language courses) taken after admission to graduate standing.

If the student takes a subject minor in the Division, then he must demonstrate a competency in the minor field markedly exceeding that normally expected by his major field and markedly exceeding the undergraduate requirements in the field. Such a subject minor will normally include at least 45 units, including one or more 200-level courses as well as the 100-level supporting courses. The oral examination requirement may be met through the choice of propositions (if the major field is within the Division) or a special examination may be held.

A proposed minor program should be discussed with the adviser and the option representative and submitted to the staff for preliminary evaluation before the end of the 6th term of residence. Final approval will be given only after completion of all courses.

Language Requirement. To be admitted to candidacy for the Ph.D. degree in the Division of Geological Sciences a student must demonstrate a useful knowledge of a foreign language. This may be demonstrated in one of four ways:

a. Take a subject minor in German, Russian, or French (such a minor cannot be in the student's mother tongue).
b. Demonstrate a superior knowledge of German, Russian, or French by passing the appropriate two-year graduate course (L 102 abc, L 103 abc, L 130 abc, L 152 abc, L 153 abc). L 103, L 131, and L 153 may be used as part of a minor.
c. Demonstrate a superior knowledge of German, Russian, or French by passing the final examination of the appropriate two-year course or by other methods specified by the instructor of such a course.
d. Demonstrate to the satisfaction of the Division Staff fluency in a foreign language that has been approved by the staff. Approval of a language other than German, Russian, or French is by vote of the staff and is based upon the pertinence of the language to the candidate's field and interests.

Thesis and Paper for Publication. The doctoral candidate must complete his thesis and submit it in final form by May 10 of the year in which the degree is to be conferred. A first draft of the thesis *must* be submitted to the Division Chairman by March 1 of the year in which it is proposed to take the degree.

The candidate is expected to publish the major results of his thesis work. The manuscript should be reviewed by the member of the staff supervising the major research before being submitted for publication. The published paper should have a California Institute of Technology address and a Division of Geological Sciences Contribution Number, and five reprints should be sent to the Division.

Final Examination. The final oral examination for the doctorate will be scheduled following submission of the thesis and, in conformity with an Institute regulation, it must be scheduled at least two weeks before the degree is to be conferred.

Subject Minor in Geological and Planetary Sciences

A student majoring in another division of the Institute may, with the approval of the Division of Geological Sciences, elect a subject minor in any one of the major subjects listed above. Such a subject minor will normally include at least 45 units, including one or more 200-level courses as well as the 100-level supporting courses. The student should consult the Division Graduate Representative on the choice of courses and on the scheduling of the required oral examination.

MATERIALS SCIENCE

Degree of Master of Science in Materials Science

Study for the degree of Master of Science in Materials Science ordinarily will consist of three terms of course work totaling at least 135 units. Each student is assigned to a member of the faculty, who will serve as the student's adviser and who will assist the student in planning his course of study. The program of study must be approved by the adviser, and any subsequent changes must also have the adviser's approval.

The schedule of courses is given below:

		Units for term 1st	2nd	3rd
E 150 abc	Seminar (1-0-0)	1	1	1
MS 104 abc	Materials Science Laboratory	9	9	9
	Electives as below*	Minimum	48 for year	
	Free electives**	Minimum	27 for year	
	Total	Minimum	135 for year	

Approved electives

		1st	2nd	3rd
Ae 102 abc	Basic Solid Mechanics (3-0-6)	9	9	9
Ae 213	Fracture Mechanics (3-0-6)	.	9	.
Ae 221	Theory of Viscoelasticity (3-0-6)	Any term.		
AMa 101 abc	Methods of Applied Mathematics (3-0-6)	9	9	9
AMa 105 ab	Introduction to Numerical Analysis (3-2-6)	.	11	11
AM 112 abc	Structural Mechanics (3-0-6)	9	9	9
AM 125 abc	Engineering Mathematical Principles (3-0-6)	9	9	9

*Elective units may be divided among the three terms in any desired manner. Students who have not had the equivalent of AM 95 abc are required to take AM 113 abc, which *must* be included in the free electives and *cannot* be included in the nonfree electives. Substitution for electives given below may be made with the approval of the student's adviser and the Faculty in Materials Science.

**Students are urged to consider including a humanities course in the free electives.

AM 140 abc	Plasticity (3-0-6)	9	9	9
AM 141 abc	Wave Propagation in Solids (3-0-6)	9	9	9
AM 151 abc	Dynamics and Vibrations (3-0-6)	9	9	9
AM 155	Dynamic Measurements Laboratory (1-6-2)	9	.	.
ChE 107 abc	Polymer Science (3-0-6)	9	9	9
EE 131 abc	Physics of Semiconductor and Semiconductor Devices (3-0-6)	9	9	9
ES 101 abc	Nuclear Reactor Theory (3-0-6)	9	9	9
ES 102 abc	Applied Modern Physics (3-0-6)	9	9	9
ES 103	Nuclear Radiation Measurements Laboratory (1-4-4)	.	9	.
ES 104	Nuclear Engineering Laboratory (1-4-4)	.	.	9
ES 130 abc	Introduction to Classical Theoretical Physics I (3-0-6)	9	9	9
ES 131 abc	Introduction to Classical Theoretical Physics II (3-0-6)	9	9	9
MS 101 abc	Physical Metallurgy (3-0-6)	9	9	9
MS 103 ab	Physical Metallurgy Laboratory (0-9-0) (0-6-0)	9	6	.
MS 105	Mechanical Behavior of Metals (3-0-6)	.	9	.
MS 110	Special Topics in Physical Metallurgy (3-0-6)	.	.	9
MS 115	Crystal Structure of Metals and Alloys (3-0-6)	.	9	.
MS 120	Physics of Solids (3-0-6)	.	9	.
MS 125	Transmission Electron Microscopy of Crystals (3-0-6)	9	.	.
MS 126	Transmission Electron Microscopy Laboratory (0-3-6)	.	9	.
MS 205 a	Theory of Crystal Dislocations (3-0-6)	.	9	.
MS 205 b	Dislocations and the Mechanical Properties of Crystalline Solids (3-0-6)	.	.	9
Ma 112 ab	Elementary Statistics (3-0-6)	9 or	9	9
ME 101 abc	Advanced Design (1-6-2)	9	9	9
ME 118 abc	Advanced Thermodynamics and Energy Transfer (3-0-6)	9	9	9
Ph 106 abc	Topics in Classical Physics (3-0-6)	9	9	9
Ph 113 abc	Introduction to Solid State Physics (3-0-6)	9	9	9
Ph 125 abc	Quantum Mechanics (4-0-5)	9	9	9
Ph 129 abc	Methods of Mathematical Physics (3-0-6)	9	9	9

Degree of Doctor of Philosophy in Materials Science

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

Upon admission to work toward the Ph.D. degree in Materials Science, a counselling committee of three members of the faculty is appointed to advise the student on his program. One member of the committee who is most closely related to the student's field of interest serves as the adviser and the chairman.

To be recommended for candidacy for the Ph.D. degree in Materials Science, the student must, in addition to the general Institute requirements:

a. Complete 12 units of research.

b. Complete at least 50 units of advanced courses arranged by the student in conference with his adviser and approved by his counselling committee and the faculty in Materials Science.

c. Pass with a grade of at least C an advanced course in mathematics or applied mathematics, such as AM 125 abc, Ph 129 abc, or AMa 101 abc, acceptable to the student's committee and the faculty in Materials Science. The requirement in mathematics shall be in addition to requirement (b) above, and shall not be counted toward the minor requirement.

d. Complete the required number of units for either a subject or a general minor, as arranged by the student in conference with his adviser and approved by his counselling committee, the faculty in Materials Science, and the faculty concerned with the subject minor. While foreign languages are not required, the student is encouraged to discuss with his adviser the desirability of taking foreign languages, which may be included in a general minor or a subject minor with the proper approvals.

e. Pass an oral examination on the major subject, and if the student has a subject minor, examination on the subject of that program may be included at the request of the discipline offering that subject minor.

A final oral examination will be given after the thesis has been formally completed. This thesis examination will be a defense of the doctoral thesis and a test of the candidate's knowledge in his specialized field of research.

Subject Minor in Materials Science

A student majoring in another branch of engineering, or another division of the Institute may, with the approval of the faculty in Materials Science and the faculty in his major field, elect Materials Science as a subject minor. The group of courses shall differ markedly from the subject of study or research.

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 are 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 163. 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 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 which are offered are listed in Section V. They are divided in three categories. The courses numbered between 100 and 199 are basic graduate courses open to all graduate students. The course Ma 108 is the fundamental course in Analysis. It is a prerequisite to most courses, and its equivalent is expected to be part of the undergraduate curriculum of the entering graduate student. The basic course in Algebra, Ma 120, presupposes an undergraduate introductory course in modern algebra similar to Ma 5 abc. Particular mention is made of Ma 190. It is a seminar required of all first-year graduate students and restricted to them. It is intended to stimulate independent work, to train students in the presentation of mathematical ideas, and to develop an independent critical attitude.

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 include the more special courses, the research courses, and the seminars. They are given on an irregular basis depending on demand and interest.

The first-year graduate program, in addition to the elementary seminar Ma 190, will consist as a rule of two or three 100-series courses.

Beginning with the second year, at the latest, the student will be expected to begin his independent research work and will be strongly encouraged to participate in seminars.

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.

The recipient of a master's degree will be expected to have acquired, in the course of his 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 115 and may include a master's thesis.

Degree of Doctor of Philosophy in Mathematics Candidacy Examination

To be recommended for candidacy for the degree of Doctor of Philosophy in Mathematics the applicant must pass an oral candidacy examination. This examination will usually be held prior to the end of the first term of the second year of graduate study, but in special cases the department may change the date. The purpose of this examination is to evaluate the work of the student, including independent work done by the candidate during his first year. On the basis of the performance, the examining committee will specify the course and research requirements which he will have to satisfy to be admitted to candidacy. At the discretion of the department the examination may be supplemented by a written examination.

Students are urged to satisfy the requirements for admission to candidacy as early as possible. Under any circumstances they must have been admitted to candidacy before the beginning of the spring term of the year in which the degree will be conferred.

Language Requirement. The language requirement for mathematics may be satisfied by demonstrating a good reading knowledge of at least two foreign languages or an extensive knowledge of at least one foreign language, chosen among French, German, and Russian. Credit will be given for previous language study.

Thesis and Final Examination. On or before the first Monday in April of the year in which the degree is to be conferred, a candidate for the degree of Doctor of Philosophy must deliver a typewritten or reproduced copy of his thesis to his supervisor. This copy must be complete and in exact form in which it will be presented to the members of the examining committee. The candidate is also responsible for supplying the members of his examining committee, at the same time or shortly thereafter, with reproduced copies of his thesis. The department will assign to the candidate, immediately after the submission of his thesis, a topic of study outside his field of specialization. During the next four weeks the candidate is expected to assimilate the basic methods and the main results of the assigned topic with the aim of recognizing the direction of further research in this field.

The final oral examination in mathematics will be held as closely as possible to four weeks after the date the thesis has been handed in. It will cover the thesis and fields related to it and the assigned topic of study.

Subject Minor in Mathematics. Students majoring in other fields may take a subject minor in mathematics (see page 244) provided their program consists of 45 units of more advanced work in mathematics and is approved by the Mathematics Committee on Minors. The required oral examination in the subject minor will normally be a separate examination but may be a part of one of the oral examinations in the major subject. It is the responsibility of the candidate to submit the proposed program for approval and to arrange for the examination.

MECHANICAL ENGINEERING

Degree of Master of Science in Mechanical Engineering

Study for the degree of Master of Science in Mechanical Engineering ordinarily will consist of three terms of course work totaling at least 135 units. Each student is assigned to a member of the faculty, who will serve as the student's adviser and who will assist the student in planning his course of study. The program of study must be approved by the adviser, and any subsequent changes must also have the adviser's approval.

The schedules of courses are given below:

GENERAL MECHANICAL ENGINEERING

		Units per Term 1st	2nd	3rd
E 150 abc	Seminar (1-0-0)	1	1	1
	Electives as below*	Minimum	75 per year	
	Free electives**	Minimum	27 per year	
	Total	Minimum	135 per year	

*Elective units may be divided among the three terms in any desired manner. Students who have not had the equivalent of AM 95 abc are required to take AM 113 abc, which *must* be included in the free electives and *cannot* be included in the nonfree electives. Substitution for electives given below may be made with the approval of the student's adviser and the faculty in Mechanical Engineering.

**Students are urged to consider including a humanities course in the free electives.

Approved Electives

Ae 101 abc	Basic Fluid and Gasdynamics (3-0-6)	9	9	9
Ae 102 abc	Basic Solid Mechanics (3-0-6)	9	9	9
AMa 104	Matrix Algebra (3-0-6)	9	.	.
AMa 105 ab	Introduction to Numerical Analysis (3-2-6)	.	11	11
AMa 101 abc	Methods of Applied Mathematics (3-0-6)	9	9	9
AM 112 abc	Structural Mechanics (3-0-6)	9	9	9
AM 125 abc	Engineering Mathematical Principles (3-0-6)	9	9	9
AM 141 abc	Wave Propagation in Solids (3-0-6)	9	9	9
AM 151 abc	Dynamics and Vibrations (3-0-6)	9	9	9
AM 155	Dynamic Measurements Laboratory (1-6-2)	9	.	.
ChE 107 abc	Polymer Science (3-0-6)	9	9	9
EE 172 abc	Feedback Control Systems (3-0-6)	9	9	9
ES 101 abc	Nuclear Reactor Theory (3-0-6)	9	9	9
ES 102 abc	Applied Modern Physics (3-0-6)	9	9	9
ES 103	Nuclear Radiation Measurements Laboratory (1-4-4)	.	9	.
ES 104	Nuclear Energy Laboratory (1-4-4)	.	.	9
Hy 101 abc	Fluid Mechanics (3-0-6)	9	9	9
Hy 121	Advanced Hydraulics Laboratory	6	6	6
Hy 201 abc	Hydraulic Machinery (2-0-4)	6	6	6
Hy 203	Cavitation Phenomena (2-0-4)	6	.	6
JP 120 abc	Thermodynamics of Propulsion Systems (3-0-6)	9	9	9
JP 121 abc	Jet Propulsion Systems and Trajectories (3-0-6)	9	9	9
JP 170	Jet Propulsion Laboratory (0-9-0)	.	.	9
MS 101 abc	Physical Metallurgy (3-0-6)	9	9	9
MS 104 abc	Materials Science Laboratory (0-6-3)	9	9	9
MS 105	Mechanical Behavior of Metals (3-0-6)	.	9	.
Ma 112 ab	Elementary Statistics (3-0-6)	9 or	9	9
ME 101 abc	Advanced Design (1-6-2)	9	9	9
ME 118 abc	Advanced Thermodynamics and Energy Transfer (3-0-6)	9	9	9
ME 126	Fluid Mechanics and Heat Transfer Laboratory (0-6-3)	.	.	9
ME 200	Advanced Work in Mechanical Engineering	.	.	.
ME 300	Thesis Research	.	.	.
Ph 106 abc	Topics in Classical Physics (3-0-6)	9	9	9

JET PROPULSION OPTION

		Units per Term 1st	2nd	3rd
E 150 abc	Seminar (1-0-0)	1	1	1
JP 120 abc	Thermodynamics of Propulsion Systems (3-0-6)	9	9	9
JP 121 abc	Jet Propulsion Systems and Trajectories (3-0-6)	9	9	9
	Electives as below*	Minimum 21 per year		
	Free electives**	Minimum 27 per year		
	Total	Minimum 135 per year		

*Elective units may be divided among the three terms in any desired manner. Students who have not had the equivalent of AM 95 abc are required to take AM 113 abc which *must* be included in the free electives and *cannot* be included in the nonfree electives. Substitution for electives given blow may be made with the approval of the student's adviser and the faculty in Mechanical Engineering.

**Students are urged to consider including a humanities course in the free electives.

Approved Electives

Ae 102 abc	Basic Solid Mechanics (3-0-6)	9	9	9
Ae 105 abc	Fluid Mechanics Laboratory (1-3-2)	6	6	6
Ae 106 abc	Solid Mechanics Laboratory (1-3-2)	6	6	6
AM 112 abc	Structural Mechanics (3-0-6)	9	9	9
AM 151 abc	Dynamics and Vibrations (3-0-6)	9	9	9
AM 155	Dynamic Measurements Laboratory (1-6-2)	9	.	.
EE 172 abc	Feedback Control Systems (3-0-6)	9	9	9
ES 103	Nuclear Radiation Measurements Laboratory (1-4-4)	.	9	.
ES 104	Nuclear Energy Laboratory (1-4-4)	.	.	9
Hy 101 abc	Fluid Mechanics (3-0-6)	9	9	9
JP 170	Jet Propulsion Laboratory (0-9-0)	.	9	.
ME 118 abc	Advanced Thermodynamics and Energy Transfer (3-0-6)	9	9	9
ME126	Fluid Mechanics and Heat Transfer Laboratory (0-6-3)	.	.	9

NUCLEAR ENERGY OPTION

		Units per Term		
		1st	2nd	3rd
E 150 abc	Seminar (1-0-0)	1	1	1
ES 101 abc	Nuclear Reactor Theory (3-0-6)	9	9	9
ES 102 abc	Applied Modern Physics (3-0-6)	9	9	9
ES 103	Nuclear Radiation Measurements Laboratory (1-4-4)	.	9	.
ES 104	Nuclear Energy Laboratory (1-4-4)	.	.	9
	Free Electives*	Minimum 60 per year		
	Total	Minimum 135 per year		

Suggested Electives

Ae 102 abc	Basic Solid Mechanics (3-0-6)	9	9	9
AMa 101 abc	Methods of Applied Mathematics I (3-0-6)	9	9	9
AMa 104	Matrix Algebra (3-0-6)	9	.	.
AMa 105 ab	Introduction to Numerical Analysis (3-2-6)	.	11	11
AM 112 abc	Structural Mechanics (3-0-6)	9	9	9
AM 125 abc	Engineering Mathematical Principles (3-0-6)	9	9	9
AM 151abc	Dynamics and Vibrations (3-0-6)	9	9	9
EE 172 abc	Feedback Control Systems (3-0-6)	9	9	9
Hy 101 abc	Fluid Mechanics (3-0-6)	9	9	9
JP 121 abc	Jet Propulsion Systems and Trajectories (3-0-6)	9	9	9
Ma 112 ab	Elementary Statistics (3-0-6)	9 or	9	9
ME 118 abc	Advanced Thermodynamics and Energy Transfer (3-0-6)	9	9	9
MS 115 ab	Crystal Structure and Properties of Metals and Alloys (3-0-6)	9	9	.
Ph 106 abc	Topics in Classical Physics (3-0-6)	9	9	9

*Elective units may be divided among the three terms in any desired manner, and may include graduate courses from any option, including Humanities. Students who have not had the equivalent of AM 95 abc are required to take AM 113 abc as a part of the free electives.

Degree of Mechanical Engineer

Work toward the degree of Mechanical Engineer requires a minimum of two years following completion of the bachelor's degree or the equivalent. Upon admission to work toward the M.E. degree, a committee of three members of the faculty are appointed to advise the student on his program. One member of the committee who is most closely related to the student's field of interest serves as the adviser and the chairman. The student shall meet with the committee before registration for the purpose of planning the student's work.

Not less than a total of 55 units of the work shall be for research and thesis; the exact number shall be determined by the supervising committee appointed by the Dean of Graduate Studies, which succeeds the counselling committee. The courses shall be closely related to Mechanical Engineering, and the specific courses to be taken and passed with a grade of C or better by the candidate shall be planned with the counselling committee and finally determined by the supervising committee. The courses must include an advanced course in mathematics or applied mathematics, such as AM 125 abc or Ph 129 abc, acceptable to the faculty in mechanical engineering. A list of possible courses from which a program of study may be organized is given below:

Suggested Courses

Ae 201 abc	Advanced Fluid Mechanics
Ae 210 abc	Advanced Solid Mechanics
Ae 213	Fracture Mechanics
Ae 232 abc	Ionized Gas Theory
Ch 226 abc	Molecular Quantum Mechanics
Ch 229	X-Ray Diffraction Methods
ChE 163 ab	Introduction to Thermodynamics
ES 201 abc	Neutron Transport Theory
Hy 200	Advanced Work in Hydraulic Engineering
Hy 201 abc	Hydraulic Machinery
Hy 203	Cavitation Phenomena
Hy 210 ab	Hydrodynamics of Sediment Transportation
Hy 300	Thesis
JP 240 ab	Heat Transfer in Propulsion Systems
JP 250 abc	Fluid Mechanics of Turbomachines
JP 280 abc	Jet Propulsion Research (Thesis)
MS 101 abc	Physical Metallurgy
MS 103 ab	Physical Metallurgy Laboratory
MS 104 abc	Materials Science Laboratory
MS 115	Crystal Structure of Metals and Alloys
MS 205 ab	Theory of Mechanical Behavior of Metals
MS 217	X-Ray Metallography
ME 200	Advanced Work in Mechanical Engineering
ME 300	Thesis—Research
Ph 205 abc	Advanced Quantum Mechanics
Ph 227 ab	Thermodynamics, Statistical Mechanics, and Kinetic Theory

Degree of Doctor of Philosophy in Mechanical Engineering

Work toward the degree of Doctor of Philosophy in Mechanical Engineering requires a minimum of three years following completion of the bachelor's degree or the equivalent. Approximately two years of this time is devoted to research work leading to a doctoral thesis.

Upon admission to work toward the Ph.D. degree in Mechanical Engineering, a counselling committee of three members of the faculty is appointed to advise the student on his program. One member of the committee who is most closely related to the student's field of interest serves as the adviser and the chairman.

To be recommended for candidacy for the Ph.D. degree in Mechanical Engineering, the student must, in addition to the general Institute requirement:

a. Complete 12 units of research.
b. Complete at least 50 units of advanced courses arranged by the student in conference with his adviser and approved by his counselling committee and the faculty in Mechanical Engineering.
c. Pass with a grade of at least C an advanced course in mathematics or applied mathematics, such as AM 125 abc, Ph 129 abc, or AMa 101 abc, acceptable to the student's committee and the faculty in Mechanical Engineering. The requirement in mathematics shall be in addition to requirement (b) above, and shall not be counted toward the minor requirement.
d. Complete the required number of units for either a subject or a general minor as arranged by the student in conference with his adviser, and approved by his counselling committee, the faculty in Mechanical Engineering, and the faculty concerned with the subject minor. While foreign languages are not required, the student is encouraged to discuss with his adviser the desirability of taking foreign languages, which may be included in a general minor or a subject minor with the proper approvals.
e. Pass an oral examination on the major subject, and if the student has a subject minor, examination on the subject of that program may be included at the request of the discipline offering that subject minor.

A final oral examination will be given after the thesis has been formally completed. This thesis examination will be a defense of the doctoral thesis and a test of the candidate's knowledge in his specialized field of research.

Subject Minor in Mechanical Engineering

A student majoring in another branch of engineering, or another division of the Institute, may elect Mechanical Engineering as a subject minor, with the approval of the faculty in Mechanical Engineering and the faculty in his major field. The group of courses shall differ markedly from the major subject of study or research.

PHYSICS

Aims and Scope of Graduate Study in Physics

The Physics Department offers a program leading to the degree of Doctor of Philosophy in Physics. This program seeks to prepare students for careers in scientific research, or research combined with teaching, and independent research is an essential part of the graduate program. Courses are offered which will help a beginning graduate student prepare himself for research and provide a broad, sound knowledge of physics. These courses are not required; each student takes only those courses that he needs. Instead of formal course requirements, each student must pass a candidacy examination which seeks to determine his readiness to undertake original research on his own, and his basic knowledge of physics.

To broaden the student's experience beyond the narrow limits of his own research interest, each student is required to take 54 units (12 semester hours) of advanced physics courses selected from a variety of topics in physics. To broaden his experience outside the limits of physics, a minor program is required. This program may concentrate in a specific subject area or may range over a variety of subjects.

A Master of Science degree may be awarded upon the completion of a one-year program of courses. A student is not normally admitted to work toward the M.S. degree in physics unless he is also working for a Ph.D.

Admission

Application blanks for admission to graduate standing and for assistantships should be obtained from the Dean of Graduate Studies, California Institute of Technology, Pasadena, California 91109, and submitted as early as convenient. While late applications will be considered, applications should whenever possible reach the Graduate Office by February 15, 1971. Special inquiries will be welcomed by Professor R. W. Kavanagh, Chairman, Physics Graduate Admissions Committee. It is recommended that applicants take the November or January Graduate Record Aptitude Test and Advanced Physics Test. Information may be obtained from the Educational Testing Service, 20 Nassau Street, Princeton, New Jersey 08540.

Placement Examinations

On Thursday and Friday preceding the beginning of instruction for his 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, Atomic and Nuclear Physics, Quantum Mechanics, and Mathematical Physics, approximately as covered in Ph 106, Ph 112, and Phy 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. In cases in which there is a clear basis for ascertaining the status of the entering graduate student, the placement examinations may be waived.

Physics Course List

When courses are mentioned by number in these regulations, reference is made to the following list. These courses are described fully on pages 377-383 of this Bulletin.

Ph 129 Methods of Mathematical Physics
Ph 203 Nuclear Physics
Ph 204 Low Temperature Physics
Ph 205 Advanced Quantum Mechanics
Ph 209 Electromagnetism and Electron Theory
Ph 213 Nuclear Astrophysics
Ph 214 Solid State Physics
Ph 216 Plasma Physics
Ph 221 Topics in Solid State Physics
Ph 224 Topics in Space Physics
Ph 227 Statistical Physics
Ph 230 Elementary Particle Theory
Ph 231 High Energy Physics
Ph 234 Topics in Theoretical Physics
Ph 236 Relativity
Ph 237 Theoretical Nuclear Physics

Ph 240 Current Theoretical Problems in Particle Physics
Ay 131 Astrophysics I
or
Ay 132 Astrophysics II
Ay 133 Radio Astronomy

Master's Degree in Physics

A student is not normally admitted to work toward the M.S. degree in physics unless he is also working for a Ph.D.

A Master of Science in Physics degree 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 and a satisfactory score made on the placement examination, it may be replaced by 27 units of any graduate courses.)

Physics Electives .... 81 units

These must be selected from Ph 129 abc, Ph 203 abc, Ph 205 abc, Ph 209 abc, Ph 213 abc, Ph 214 ab, Ph 216 abc, Ph 221, Ph 227 abc, Ph 230 abc, Ph 231 abc, Ph 236 abc, Ph 237 abc.

Non-Physics Electives .... 27 units

These must be graduate courses from any option, including Humanities, except Physics.

With the approval of the Departmental Representative, a student who has the proper preparation may substitute other graduate courses in science or engineering for some of those listed above.

Doctor of Philosophy Degree in Physics

Requirements for the Ph.D. include passing a written candidacy examination, typically taken in the first or second year, covering basic material in physics; an oral candidacy exam in the area in which the student proposes to do research; 54 units (equivalent to 12 semester-hours) of advanced electives in physics; writing a thesis which describes the results of independent research, and passing a final oral examination based on this thesis and research.

A minor is also required. The requirements are discussed on pages 243-244.

Graduate students working toward the Ph.D. degree should complete the requirements for admission to candidacy for the doctor's degree as soon as possible. No courses are specifically required for candidacy, but the average student will profit from taking several of the basic graduate courses, such as Ph 129, Ph 205, and Ph 209.

Course Requirements. In order to be recommended for the Ph.D. degree, each candidate must, in addition to the requirements for candidacy and the general Institute requirements for a Ph.D. degree, pass satisfactorily a total of 54 units from the courses enumerated in the above Physics Course List. Ph 129, Ph 205 and Ph 209 are excluded from the list. These three courses will presumably be of use to the student in preparing for the written candidacy examination, but are not required, nor may they be counted toward course requirements. The purpose of course requirements is to broaden the student's knowledge of physics and acquaint him with material outside his own field of specialization; for this reason, no more than 18 units of any given course in the above list may be counted toward any requirements for these courses. In addition to these requirements, the student will normally take other advanced courses, particularly in his field of specialization. In general a student will find it desirable to continue his graduate study and research for two years after admission to candidacy.

The student is expected to obtain a grade of C or better in each of his courses. If he obtains grades below C in his courses, or an unsatisfactory grade on his written or oral candidacy examination, the Physics Graduate Committee will review the student's entire record, and if it is unsatisfactory will refuse permission for him to continue work for the Ph.D.

Candidacy Examinations. A written candidacy examination, in several parts and requiring a total of about twelve hours, is given each year in the third term. Each student must pass this examination before being permitted to register for his third year of graduate study. The examination covers that body of knowledge felt to be essential no matter what the candidate's ultimate field of specialization.

An oral candidacy examination is also required. This examination may be taken no sooner than one month after the written examination is passed, and is primarily a test of the candidate's suitability for research in his chosen field. The candidate must have passed at least 15 units of Ph 171 or Ph 173 before taking his candidacy oral examination. A student who is admitted to work toward the Ph.D. degree and who does not pass both these examinations before the end of his third year of graduate study at the Institute will not be permitted to register for a subsequent academic year.

The written and oral candidacy examinations are the only departmental requirements for admission to candidacy, beyond the general Institute requirements enumerated on pages 244-245.

Research Requirements. There is no specific requirement, but in general a substantial effort is required to master the research techniques in a given field and carry out a significant piece of original research. Each student is strongly advised to start research as soon as possible and carry it on in parallel with course work.

The Minor. There are no Departmental requirements in addition to the general requirements listed on page 243.

Language requirements. There are no language requirements for a Ph.D. in physics, but mastery of one or more foreign languages will be highly advantageous.

Thesis and Final Examination. A final examination will be given not less than one month 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 himself is responsible for completing his thesis early enough to allow the fulfillment of all Division and Institute requirements, having due regard for possible conflicts in the scheduling of more than one final oral examination per day.

Subject Minor in Physics

A subject minor in physics (see page 244) will be approved by the minor division if it includes at least 18 units of physics courses, chosen from the courses in the Physics Course List, but excluding Ph 129, Ay 131, Ay 132, Ay 133, and any specific courses in physics required for the student's major program. Physics courses with numbers over 100 will be allowed for the subject minor, but, where reduced credit is given to physics graduate students, will count at the same reduced rate toward the required total of 45 units. The required oral examination in the subject minor will normally be a separate examination but may be part of one of the oral examinations in the major subject if sufficient time is made available. It is the responsibility of the candidate to make arrangements for this examination with the Chairman of the Physics Graduate Committee.

Graduate Expenses

The tuition charge for all students registering for graduate work is currently $2,385 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 petition therefor on a blank obtained from the Registrar. If reduced registration is permitted, the tuition for each term is at the rate of $22 a unit for fewer than 36 units with a minimum of $220 a term. Adjustments of tuition charges may be arranged for changes in units if reported during the first three weeks of a term. Additional tuition will be charged to students registering for special courses made available to them which 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 of the student, which may consist in the prosecution of research, in independent reading, or in the writing of a thesis or other dissertation, as well as in 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.

A yearly health fee of $40 is charged to every student. This fee is applied to provide medical services; for details, see page 219. A summer fee of $10 must be paid by students who register for summer work, and who have not paid the $40 health fee during the preceding academic year.

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 his work in regular courses of study. Upon completion of his 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 delinquent may be refused registration for the term following that in which the delinquency occurs. No degrees are awarded until all bills due the Institute have been paid. Transcripts cannot be released until all bills due the Institute have been paid or satisfactory arrangements have been made with the business office for repayment.

Information regarding fellowships, scholarships, and assistantships is discussed on pages 290-295 of the catalog. Students of high scholastic attainment may be awarded graduate scholarships covering all or a part of the tuition fee. Loans also may be arranged by making an application to the Scholarships and Financial Aid Committee.

EXPENSE SUMMARY

	1970-71	1971-72
General:		
General Deposit[1]	$ 25.00	$ 25.00
Tuition	2,385.00	2,565.00
Health Fee	40.00	55.00
	$2,450.00	$2,645.00
Other:[2]		
Books and Supplies (approx.)	$ 150.00	

Graduate House Living Expenses (see page 289 for details)
Room — $495.00 to $558.00 per academic year[3]
(Rates are subject to revision prior to August 1st of any year)
Meals — Available at Chandler Dining Hall or
the Athenaeum (members only)

[1]This charge is made only once during residence at the Institute (see page 222).
[2]Other annual expenses for the Academic Year 1971-72 are not available at this time.
[3]Room rent is billed one month in advance and is payable upon receipt of the monthly statement.

The following is a list of graduate fees at the California Institute of Technology for the Academic Year 1970-71, together with the dates on which they are due:

	First Term	*Fee*
September 28, 1970	General Deposit (see page 222)	$ 25.00
	Tuition	795.00
	Health Fee	40.00
	Second Term	
January 4, 1971	Tuition	795.00
	Third Term	
March 29, 1971	Tuition	795.00
Summer Accident Insurance Fee[1]		10.00

Tuition fees for fewer than normal number of units:

Over 35 units	Full Tuition
Per unit per term	22.00
Minimum per term	220.00
Auditor's Fee (p. 189) $30.00 per term per lecture hour.	

Associated Student Body Dues. Graduate students are eligible for membership in the Associated Student Body of Caltech, pursuant to By-Laws thereof. Dues are $22 annually (see page 221).

Room Deposit. A $50.00 deposit must accompany each room application and is subject to refund upon termination of the contract. (This deposit should not be confused with the General Breakage Deposit of $25.00.)

Winnett Student Center. A charge of $1.00 a year ($.50 for ASCIT members) is made to each student who is provided a key to the Winnett Student Center game room, to help defray the expenses.

Withdrawals. Students withdrawing from the Institute during the first three weeks of a term, for reasons deemed satisfactory to the Institute, are entitled to a refund of tuition fees paid, less a reduction of 20 percent and a pro rata charge of time in attendance.

Living Accommodations for Graduate Students

Housing Facilities. The Institute has four residence houses providing single rooms for 167 graduate students. These handsome and comfortable residences, located on campus, were donated by William M. Keck Jr., Samuel B. Mosher and Earle M. Jorgensen, David X. Marks Foundations, and the family of Carl F. Braun. The rates per academic year vary depending upon the accommodations and services provided. During the summer only, rooms may be rented on a month-to-month basis. Complete information may be obtained and reservations made by writing to the Office of Residence and Dining Halls, California Institute of Technology.

A limited number of rooms are available for women graduate students. Information about membership and rates may be obtained from the same office as above.

There are no facilities on the campus at present for married graduate students. They should write to the Off-Campus Office, California Institute of Technology, for assistance in finding suitable accommodations in the community.

[1]An Accident Insurance Fee of $10.00 will be charged to all students taking summer research who were not enrolled during the previous academic year.

Dining Facilities. Graduate students are privileged to join the Athenaeum (Faculty Club), which affords the possibility of contact with fellow graduate students and with others using the Athenaeum, including the Associates of the Institute, distinguished visitors, and members of the professional staffs of the Mount Wilson Observatory, the Huntington Library, and the California Institute.

The Chandler Dining Hall, located on the campus, is open Monday through Friday and most weekends when the Institute is in session. Breakfast, lunch, dinner, and snacks are served cafeteria style.

The International Desk. The International Desk is maintained to help foreign students and visiting scholars with non-academic problems. The desk, which operates under the Faculty Committee on Foreign Students and Scholars, is attended by the Administrative Secretary, International Desk. Foreign students and scholars will find the services of the desk very helpful, particularly when they first arrive on campus.

Financial Assistance

The Institute offers in each of its divisions a number of fellowships, scholarships, and graduate assistantships. In general, scholarships carry tuition awards; assistantships, cash stipends; and fellowships often provide both tuition awards and cash grants. Graduate assistants are eligible to be considered for scholarship grants.

A request for financial assistance is included on the application for admission to graduate standing. These applications should reach the Institute by February 15. Appointments to fellowships, scholarships, and assistantships are for one year only; and a new application must be filed each year by all who desire appointments for the following year, whether or not they are already holders of such appointments.

In addition, loans are available to graduate students who need such aid to continue their education. They are made upon application, subject to the approval of the Scholarships and Financial Aid Committee, and the extent of the available funds. In addition to loans, the Deferred Payment Plan is also available to graduate students.

Graduate Assistantships

Graduate Assistants devote, during the school year, not more than fifteen hours a week to teaching, laboratory assistance, or research of a character that affords them useful experience. This time includes that required in preparation and in marking notebooks and papers, as well as that spent in classroom and laboratory. The usual assistantship assignment calls for fifteen hours per week at most and ordinarily permits the holder to carry a full graduate residence schedule as well.

Graduate Scholarships and Fellowships

The Institute offers a number of tuition awards to graduate students of exceptional ability who wish to pursue advanced study and research. Several of these funds also provide a monthly stipend for living expenses.

Earle C. Anthony Fellowship: A fund has been established by Mr. Earle C. Anthony for fellowships for graduate students.

ARCS Foundation (Achievement Rewards for College Scientists) of Los Angeles: The ARCS Foundation has established a fund for the award of several graduate and undergraduate fellowships.

Meridan Hunt Bennett Scholarships: The scholarships for graduate students are granted from the Meridan Hunt Bennett Fund as stated on page 226.

Blacker Scholarships: The Robert Roe Blacker and Nellie Canfield Blacker Scholarship Endowment Fund, established by the late Mr. R. R. Blacker and Mrs. Blacker, provides in part for the support of graduate men engaged in research work. The recipients are designated as Blacker Scholars.

Bridge Fellowship: The late Dr. Norman Bridge provided a fund, the income of which is used to support a research fellowship in physics. The recipient is designated as the Bridge Fellow.

Edith Newell Brown Scholarships: The income from the Edith Newell Brown Fund is used to maintain scholarships for graduate students. The recipients are designated as Edith Newell Brown Scholars.

Theodore S. Brown Scholarships: The income from the Theodore S. Brown Fund is used to maintain scholarships for graduate students. The recipients are designated as Theodore S. Brown Scholars.

CIT Research Foundation Fellowships: These graduate fellowships are supported by annual contributions from the California Institute of Technology Research Foundation.

Lucy Mason Clark Fellowship: This fellowship, in the field of plant physiology, is supported by a fund contributed by Miss Lucy Mason Clark.

Samuel H. and Dorothy Breed Clinedinst Foundation Scholarship: The income of this fund is designated for graduate scholarship aid.

Ray G. Coates Scholarship: Provided by the income from a bequest made by the late Mrs. Alice Raymond Scudder Coates, to maintain a scholarship for a student of physics. The graduate student recipient is designated as the Ray G. Coates Scholar.

Cole Fellowships: The income from the Cole Trust, established by the will of the late Mary V. Cole in memory of her husband, Francis J. Cole, is used to provide three scholarships annually, one in each of the following fields: electrical engineering, mechanical engineering, and physics. The recipients are designated as Cole Fellows.

Caroline W. Dobbins Scholarships: The income from the Caroline W. Dobbins Scholarship Fund, provided by the late Mrs. Caroline W. Dobbins, is used to maintain scholarships at the Institute. Graduate student recipients are designated as Caroline W. Dobbins Scholars.

Drake Scholarships: The income from the Drake Fund, provided by the late Mr. and Mrs. Alexander M. Drake, is used to maintain scholarships in such numbers and amounts as the Board of Trustees determines. Graduate students who are recipients from this fund are designated as Drake Scholars.

Richard P. Feynman Fellowships: The income from a fund provided by the H. Dudley Wright Research Foundation is to be used to provide graduate fellowships in the field of Physics, with preference to a student in Theoretical Physics. Recipients are designated as Richard P. Feynman Fellows.

Lawrence A. Hanson Foundation: The gifts made by this Foundation are to be used for student aid.

Clarence J. Hicks Memorial Fellowship in Industrial Relations: This fellowship is supported by a fund made available by Industrial Relations Counselors, Inc. and other contributors. The fellowship is granted to a graduate student who undertakes some studies in industrial relations, as approved by the Director of the Industrial Relations Center.

Saul Kaplun Scholarships: Funds given by Mr. Morris J. Kaplun in memory of his son, to be used for fellowships in Applied Mathematics. Graduate student recipients are designated Saul Kaplun Fellows.

Henry Laws Scholarships: The income from a fund given by the late Mr. Henry Laws is used to provide scholarships for research in pure science, preferably in physics, chemistry, and mathematics. The recipients are designated as Henry Laws Scholars.

Robert L. Leonard: A fund contributed by Mrs. Robert L. Leonard, income from which is for graduate scholarships.

Joseph F. Manildi: A fund contributed as a memorial to Dr. Joseph F. Manildi. The income may be used for graduate or undergraduate scholarships.

Metabolic Dynamics Foundation Award: Given by the Foundation to the graduate student who has contributed most to the field of Homeostatic Control Systems.

Clark B. Millikan Scholarships: Provided by gifts made in memory of the late Clark B. Millikan. Graduate student recipients are designated as Clark B. Millikan Scholars.

Greta B. Millikan Fellowships: Provided by the income from a bequest made by the late Greta B. Millikan, to be used for graduate fellowships in Physics. Recipients are designated as Robert A. Millikan Fellows.

Blanche A. Mowrer: A bequest from Blanche A. Mowrer, income from which is for the benefit of graduate students in the pursuance of postgraduate work in the study of chemistry.

David Lindley Murray Scholarships: The income from the David Lindley Murray Educational Fund is used in part to provide scholarships for graduate students. The recipients are designated as Murray Scholars.

May McManus Oberholtz Scholarship Endowment Fund: The income from this fund is to be used for scholarships.

Elbert G. Richardson Scholarship and Fellowship Fund: The income from this fund is used to maintain scholarships and fellowships for graduate students.

Frederick Roeser Scholarship: This scholarship is granted from the Frederick Roeser Loan, Scholarship, and Research Fund. The recipient is designated as the Roeser Scholar.

Eben G. Rutherford Scholarship Fund: The income derived from this fund is used for graduate scholarships.

Ralph L. Smith Scholarship: This scholarship is supported by yearly grants.

Royal W. Sorensen Fellowship: The income from a fund created in honor of Royal W. Sorensen is used to provide a fellowship or a scholarship for a student in electrical engineering.

Keith Spalding Memorial Scholarship Fund: A fund contributed in memory of Mr. Keith Spalding, the income to be used for either graduate or undergraduate scholarships.

Van Maanen Fellowship: One or more predoctoral or postdoctoral fellowships are provided in the department of astronomy from the Van Maanen Fund. The recipients are known as Van Maanen Fellows.

Von Karman Scholarship Fund: Given by Dr. William Bollay for scholarships for sons or daughters of Aerophysics Development Corporation employees. The recipients are designated as von Karman Scholars.

Special Fellowships and Research Funds

In addition to the National Science Foundation, the Department of Health, Education and Welfare, the National Aeronautics and Space Administration, the Ford Foundation, and the California State Scholarship Fund, the following corporations, foundations and individuals contribute funds for the support of Graduate Fellowships:

Atlantic Richfield Company
R. C. Baker Foundation
Bell Telephone Laboratories
The Boeing Company
Fairchild Camera and Instrument Corporation
Fluor Foundation
General Electric Foundation
General Telephone and Electronics Corporation
Gulf General Atomic Corporation
Fannie and John Hertz Foundation
Hughes Aircraft Company Corporation
Imperial Oil of Canada, Ltd.
International Business Machines
Paul E. Lloyd
Lockheed Leadership Fund
William F. Marlar Foundation
Arthur McCallum Fund
North American Aviation, Inc.
Northrop Corporation
Radio Corporation of America
Schlumberger Foundation
Shell Companies Foundation
Alfred P. Sloan Foundation
Standard Oil Company of California
Tektronix Foundation
TRW Systems
United States Steel Foundation

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.

Daniel and Florence Guggenheim Fellowships in Jet Propulsion: These are fellowships established with the Guggenheim Jet Propulsion Center by the Daniel and Florence Guggenheim Foundation for graduate study in jet propulsion.

GALCIT Wind Tunnel Fellowships: These are fellowships established with the Guggenheim Aeronautical Laboratory for graduate study in the field of aeronautics.

AEC Special Fellowships in Nuclear Science and Engineering: These fellowships are made available and are administered by the Atomic Energy Commission to support study in the general field of nuclear energy technology. The California Institute is a participating school at which AEC Fellows may pursue graduate study. See Nuclear Energy Option in Mechanical Engineering, page 282, and note under Mechanical Engineering, page 165.

Postdoctoral Fellowships

A number of government agencies, foundations, societies, and companies support fellowships for the encouragement of further research by men who hold the doctor's degree. These grants usually permit choice of the institution at which the work will be done, and include, among others, those administered by the National Research Council, Rockefeller Foundation, John Simon Guggenheim Memorial Foundation, Commonwealth Fund, American Chemical Society, Bell Telephone Laboratories, E. I. du Pont de Nemours and Company, Merck and Company, Inc., American Cancer Society, the Atomic Energy Commission, the U. S. Public Health Service, the National Science Foundation, the National Foundation, and other government agencies, as well as various foreign governments. Applications for such fellowships should in general be directed to the agency concerned.

Institute Research Fellowships: The Institute each year appoints as Research Fellows a number of men holding the degree of Doctor of Philosophy who desire to pursue further research. Application for these appointments, as well as for other special fellowships listed below, should be made on forms provided by the Institute. These forms may be obtained from the Chairman of the Division in which the applicant wishes to work.

Gosney Fellowships: In 1929 Mr. E. S. Gosney established and endowed the Human Betterment Foundation. Following the death of Mr. Gosney in 1942, the Trustees of this Foundation transmitted the fund to the California Institute for the study of biological bases of human characteristics. The Trustees of the Institute have, for the present, set the income aside for the establishment of Gosney Fellowships. These are postdoctoral research fellowships awarded for varying periods of time dependent upon the needs of the research program.

Arthur Amos Noyes Fellowships: Dr. Arthur Amos Noyes, for many years Professor of Chemistry and Director of the Gates and Crellin Laboratories of Chemistry, left most of his estate to the Institute to constitute a fund to be known as the "Noyes Chemical Research Fund." The purpose of this fund, as stated in his will, is to provide for the payment of salaries or grants to competent persons who shall have the status of members of the staff of the Institute, and shall devote their time and attention mainly to the execution at the Institute of experimental and theoretical researches upon the problems of pure science (as distinct from those of applied science) in the field of chemistry.

Millikan Fellowship: Established by Dr. Robert A. and Greta B. Millikan. Postdoctoral fellowship in the field of physical sciences, the recipients to be known as Millikan Fellows.

Richard Chace Tolman Fellowships: A fellowship in theoretical physics established in honor of Dr. Tolman, late Professor of Physical Chemistry and Mathematical Physics.

Loans and Deferred Payments

There are two sources of loans available to graduate students: Federal loans under the NDEA and loans from special funds of the California Institute of Technology. The terms and conditions for these loans are the same as those outlined for undergraduate students on pages 222 and 231, except that the maximum amount which may be borrowed in one year under the NDEA by a qualified graduate student is $2,500. The total of loans made to such a student from this source for all years, including any loan made to him as an undergraduate, may not exceed $10,000. Loans from Institute funds for graduate students are limited to $1,000 per year and cannot exceed $9,000 during the student's undergraduate and graduate study; loans from these funds for graduate students will be subject to interest charges from the time the loan is made.

The Deferred Payment Plan is also available to graduate students and the conditions for this plan are as outlined on page 223.

Loans and the deferred payment plan may also be used in combination, but the total amount from all sources may not exceed $2,500 in any one year of graduate study and cannot exceed $14,000 during the student's undergraduate and graduate study.

Institute Guests

Members of the faculties of other educational institutions, including research appointees already holding the doctor's degree, who desire to carry on special investigations, may be invited to make use of the facilities of the institute provided the work they wish to do can be integrated with the over-all research program of the Institute and does not overcrowd its facilities. Arrangement should be made in advance with the chairman of the division of the Institute concerned. Such guests are given official appointment as Research Fellows, Senior Research Fellows, Research Associates, Visiting Associates, or Visiting Professors, and thus have faculty status during their stay at the Institute.

Section V

SUBJECTS OF INSTRUCTION

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, laboratory, and 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).[1]

Aeronautics

ADVANCED SUBJECTS

Ae 101 abc. Basic Fluid and Gasdynamics. *9 units (3-0-6); each term. Prerequisites: ME 17, ME 19, AM 95 (or AM 113 may be taken concurrently).* A course intended to give an overall picture of fluid and gasdynamics, the relationship of various regimes to each other, to thermodynamics and kinetic theory, and to experiment. Topics may include: aerothermodynamics; steady and non-steady gasdynamics; acoustics and wave motion; subsonic and supersonic inviscid flow; incompressible and compressible viscous flows; boundary layer effects; rarefied gasdynamics. Instructor: Liepmann.

Ae 102 abc. Basic Solid Mechanics. *9 units (3-0-6); each term. Prerequisites: AM 95, AM 97 or equivalent (AM 113 may be taken simultaneously).* An introduction to the study of deformable solids covering the subjects necessary for the systematic development of the analysis of the behavior of solids under load. Governing equations for various classes of solids. Elastic, plastic, and time dependent materials will be treated. Applications to engineering problems with a critical evaluation of available methods of solution. Instructor: Sechler.

Ae 103 abc. Applied Aerodynamics and Flight Mechanics I. *9 units (3-0-6); each term. Prerequisite: AM 95 ab or instructor's approval.* An integrated picture of modern applied aerodynamics up to and including stability and control of aerospace vehicles. Topics include: Basic field and conservation equations of continuum fluids. Momentum generating devices. Laminar and turbulent boundary layers with pressure gradients. Stream functions, vector and scalar potentials. Lift in two and three dimensions. Applications of the complex variable and conformal mapping to airfoil, lifting line, and Trefftz plane theory. Real airfoils and wings. Generalized vehicle performance. Stability and control; small disturbance dynamic stability and control response. Instructor: Harris.

[1]The units used at the California Institute may be reduced to semester hours by multiplying the Institute units by the fraction of 2/9. Thus a twelve-unit course taken throughout the three terms of an academic year would total thirty-six Institute units or eight semester hours. If the course were taken for only one term, it would be the equivalent of 2.6 semester hours.

Ae 104. Experimental Techniques. *8 units (4-0-4); first term.* Properties of materials and of mechanical, electrical and electronic devices; design and use of instruments, with emphasis on digital methods. Instructors: Sturtevant, Babcock.

Ae 105 bc. Fluid Mechanics Laboratory. *8 units (1-3-4); second and third terms. Prerequisite: Ae 101 abc (may be taken concurrently), Ae 104.* Experimental methods in fluid mechanics research. Emphasis on broad coverage of instrumentation and subject areas, particularly areas not ordinarily treated in analytical course work. Subsonic and supersonic wind tunnels, shock tubes, water channels. Hot wires, film gauges, schlieren and hydrogen-bubble flow visualization. Low speed aerodynamics, turbulence, steady and nonsteady gasdynamics, analogies. Instructors: Staff.

Ae 106 bc. Solid Mechanics Laboratory. *8 units (1-3-4); second and third terms. Prerequisite: Ae 104.* Experimental techniques in solid mechanics and applied elasticity. Experiments will demonstrate the basic principles of solid continuum mechanics and will show the advantages and disadvantages of the experimental method. Solution of structural analysis problems by analog techniques including photoelasticity. Analysis and presentation of experimental data will be discussed. Instructors: Staff.

Ae 150 abc. Aeronautical Seminar. *1 unit (1-0-0); each term.* Speakers from campus and outside research and manufacturing organizations discuss current problems and advances in aeronautics.

Ae 200 abc. Research in Aeronautics. *Units to be arranged.* Theoretical and experimental investigations in the following fields: aerodynamics, compressibility, fluid and solid mechanics, supersonic and hypersonic flow, aeroelasticity, structures, thermoelasticity, fatigue, photoelasticity. Instructors: Staff.

Ae 201 abc. Advanced Fluid Mechanics. *9 units (3-0-6); each term. Prerequisites: Ae 101 or Hy 101; AM 125 or AMa 101 (may be taken concurrently).* Foundations of the mechanics of real fluids. Basic concepts will be emphasized. Subjects covered (not necessarily in the order listed) include: physical properties of real gases; the equations of motion of viscous and inviscid fluids; the dynamical significance of vorticity; exact solutions; motion at high Reynolds number emphasizing boundary layer concepts and their mathematical treatment; inviscid compressible flow theory; shock waves; similarity for subsonic, transonic, supersonic and hypersonic flows. In addition topics will be selected from the following subjects: low Reynolds number approximate solutions; hypersonic aerodynamics; acoustics; flow of mixtures with chemical changes and energy transfer; stability and turbulence; rotating and stratified fluids. Instructor: Coles.

Ae 203 abc. Applied Aerodynamics and Flight Mechanics II. *9 units (3-0-6); each term. Prerequisites: Ae 102, Ae 103, AM 113.* Atmospheric flight mechanics, controlled motion of airplanes and rockets, atmospheric perturbation effects, gyroscopic coupling effects. Orbital flight mechanics, launching trajectories, space trajectories, orbital perturbations. Multi-stage rocket performance. Re-entry mechanics and aerodynamic heating. Special topics in wing theory, linearized incompressible and supersonic lifting surface theory and non-stationary wing theories. Reverse flow theorems and minimum drag theorems for incompressible and supersonic flow. Instructor: Stewart.

Ae 204 abc. Advanced Vehicle Design. *9 units (3-0-6); each term. Prerequisites: Ae 101, Ae 102, Ae 103.* A number of specific topics of current importance in vehicle design are treated with an emphasis on rational and analytical solutions of advanced engineering problems. Theoretical background in prerequisite courses as well as current reading is used as a foundation for a design solution to given problems. Course consists of lectures relating to relevant theory followed by student projects in depth using computer techniques. Topics will vary but are drawn mainly from applied fluid dynamics, stability/control and design optimization including: wing design; V/STOL, jet flap and high lift systems; ground vehicle dynamics and control; marine vehicles; hydrofoils and gems.

Ae 208 abc. Fluid Mechanics Seminar. *1 unit (1-0-0); each term.* A seminar course in fluid mechanics. Weekly lectures on current developments are presented by staff members, graduate students, and visiting scientists and engineers. Instructor: Liepmann.

Ae 209 abc. Seminar in Solid Mechanics. *1 unit (1-0-0); each term.* A seminar for staff and students of all divisions whose interests lie in the general field of solid mechanics. Reports on current research by staff and students on the campus are intermixed with seminars given by invited lecturers from companies and other research institutions. Instructors: Staff.

Ae 210 abc. Advanced Solid Mechanics. *9 units (3-0-6); each term. Prerequisite: Ae 102 or equivalent.* Solution methods in the linear theory of elasticity: Potentials in two or three dimensions; Kolosov-Muskhelishvili method of complex variables; integral transforms and integral equation methods. Anisotropic and non-simple materials. Introduction to wave mechanics. Variational methods. Principles of potential and complementary energy; Reissner's and Hamilton's principles. Application to the derivation of plate and shell equations, to discrete element methods and structural stability. Deformation and incremental theories of plasticity. Problems in large deformations, involving kinematic and material non-linearities. Instructor: Knauss.

Note: The following group of courses, Ae 212 to 225, represents a series of one-term courses in Advanced Solid Mechanics. They will be given as student demand requires and staff facilities permit.

Ae 212. Shell Theory. *9 units (3-0-6); one term.* General mathematical formulation of the theory of thin elastic shells. Membrane and bending stresses in shells. Elastic stability. Surveys of recent advances in the non-linear theories of stressing and buckling of shells.

Ae 213. Fracture Mechanics. *9 units (3-0-6); one term. Prerequisite: Ae 210 or equivalent.* An advanced course stressing the interdisciplinary approach to the fracture of material, both metallic and non-metallic. The Griffith macroscopic theory of brittle fracture and its extension to ductile and viscoelastic materials. Mechanics of crack propagation including dynamic effects of running cracks.

Ae 214. Special Problems of Space Environment. *9 units (3-0-6).* The effect of space environment on living bodies, materials, and structures. Hard vacuum, ionizing and particle radiation. Micrometeoroid impact, damage, and protection. Radiation shielding. Differences between short time and long time missions. Solar radiations, flares, and storms. Instructor: Sechler.

Ae 221. Theory of Viscoelasticity. *9 units (3-0-6); one term. Prerequisite: Ae 210 or equivalent.* 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. Approximate methods of viscoelastic stress analysis and discussion of the state-of-the-art of failure analysis and non-linear viscoelasticity. Instructor: Knauss.

Ae 223. Design Criteria for Missiles, Boosters, and Spacecraft. *9 units (3-0-6); one term.* A review of the static and dynamic design criteria for structural components relating to the missile and space program. Items affecting payload capability for a given mission and the relationship between reliability and design criteria. The impact of new materials and analysis methods on the designer. Instructor: Sechler.

Ae 225 abc. Special Topics in Solid Mechanics. *9 units (3-0-6); each term.* Subject matter will change from term to term depending upon staff and student interest but may include such topics as structural dynamics; aeroelasticity; thermal stress; mechanics of inelastic materials; and non-linear problems. Enrollment is by permission of the instructor.

Note: The following group of courses, Ae 231 to Ae 250, includes one-term advanced courses in Fluid Mechanics which will be offered from time to time as demand warrants and staff availability permits. The courses which will be offered in 1970-71 are indicated.

Ae 231. Low Density Aerodynamics *(3-0-6); offered third term 1970-71. Prerequisites: Ae 101, AM 125 or equivalent.* The Aerodynamics of bodies at high altitude with emphasis on the transition regime between free molecule and continuum flow. Approximate analytical and numerical solutions to the Boltzmann equation. Shock wave and boundary layer structure. Moment and discrete ordinate methods. The BGK equation. Instructor: Broadwell.

Ae 232 abc. Ionized Gas Theory. *6 units (2-0-4); each term. Prerequisites: Ae 101 or equivalent, AM 95 or equivalent.* Introduction to the subject, stressing physical understanding. Review of electromagnetic theory. Elastic collisions. Kinetic theory concepts. Boltzmann equation. Moment equations, closure. The Chapman-Enskog procedure for a simple gas, transport properties. Coulombic interactions. Relaxation processes. Phenomena at solid boundaries. The fluid dynamics of dense, weakly ionized gases. Applications. Instructor: Sajben.

Ae 233. Topics in High Temperature Gasdynamics. *9 units (3-0-6). Prerequisites: Ae 101, Ae 201, AM 113, or AM 125 or AMa 101.* Some aspects of the effects of gasdynamics of chemical reactions and departures from local thermodynamic equilibrium at high temperatures and low densities. Flow around bodies and in wakes at hypersonic speeds; importance of energy transfer by diffusion and by radiation. Ionized gases at low density.

Ae 234. Hypersonic Aerodynamics. *9 units (3-0-6). Prerequisites: Ae 101, Ae 201 a, AM 125.* 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. Text: *Hypersonic Flow Theory*, Hayes and Probstein. Instructor: Kubota.

Ae 235. Magneto-Fluid Dynamics. *9 units (3-0-6). Prerequisites: Ae 101, AM 125 or equivalents.* Review of electrodynamics: Maxwell stresses, field and momentum-energy tensors. Thermodynamics of fluids in electrodynamic fields. Equations of motion of a conducting gas. Characteristics, shock waves. Discussion of some typical flow problems. Limitation of the one fluid approach and discussion of possible generalizations.

Ae 236. Rotating and Stratified Fluids. *9 units (3-0-6); one term. Prerequisite: Ae 201 or equivalent.* Equations of motion in rotating coordinates. Inertial waves. Ekman layers. Motions at low Rossby number; Taylor columns; the structure of vertical shear layers.

Laboratory models of oceanic circulation. Unsteady motions in closed containers; spin up; inertial oscillations. Finite Rossby number effects. Equations of motion of stratified fluids. Analogy between rotating and stratified fluids. Internal waves. Boundary layers and free shear layers. Stability of rotating and stratified flows. Not offered 1970-71 — see Env 214 abc.

Ae 237 ab. Non-Steady Gasdynamics. *9 units (3-0-6); offered second and third terms 1970-71. Prerequisites: Ae 101, AM 95 or AM* 113. Review of shock waves in moving coordinate systems, in real and perfect gases. Simple expansion waves. Basic shock tube equation. Reflected shock waves. Wave interactions and geometrical effects. Shock-tube applications; non-ideal behavior in shock tubes, diaphragm opening effects, boundary layer effects. Shock tube techniques and measurements. Driver types and characteristics. Illustrations of shock tube applications; shock wave structure, shock wave interactions, experiments on chemical and physical properties of gases, reaction rates, aerodynamic experiments, light gas guns, etc. Instructors: Roshko, Sturtevant.

Ae 238. Homogeneous Turbulence. *9 units (3-0-6). Prerequisites: Ae 201 or permission of instructor.* Kinematics of homogeneous turbulence, correlation and spectrum tensors. Properties of the large eddy structure. The universal equilibrium theory. The fine scale structure of turbulence. Turbulent diffusion. Magnetohydrodynamic turbulence. Analytical theory of homogeneous turbulence.

Ae 239. Turbulent Shear Flows. *9 units (3-0-6); offered first term 1970-71. Prerequisites: Ae 101, AM 113.* Mean and fluctuating values. Equations of mean motion; Reynolds stresses; turbulent energy balance. Similarity arguments for turbulent shear flows; free shear layers, wakes, jets, boundary layers. Separated flows. Effects of density nonuniformity. Discussion of the experimental literature. Engineering methods. (Subject matter will vary from year to year). Instructor: Roshko.

Ae 240 abc. Special Topics in Fluid Mechanics. *9 units (3-0-6); each term.* Subject matter will change from term to term depending upon staff and student interest. Enrollment is by permission of the instructor.

Ae 250 abc. Special Topics in Flight Mechanics. *9 units (3-0-6); each term.* Subject matter may change from term to term and from year to year depending upon staff. It is planned to invite senior personnel from universities, research laboratories, and industry to give courses in such subjects as design, control systems, and systems engineering for both aircraft and spacecraft systems.

Aeronautics — Jet Propulsion

(For Jet Propulsion see pages 361-362)

Air Force — Aerospace Studies

AS 1. Communicative Skills. *1 unit (1-0-0); first term. Prerequisite: Enrollment in AS 30a and AS 10a or instructor's permission.* Provides students with a common foundation in basic communicative skills. Students learn general techniques of good speaking, how to present informative speeches and briefings, how to prepare and use visual aids, how to write effectively, and other related skills. Instructor: Thompson.

AS 10 abc. Introductory Air Force Management Laboratory. *1 unit (0-1-0); each term. Prerequisite: Enrollment in AS 30 abc or instructor's permission.* A practical study in group interaction from the point of view of a staff member in a typical Air Force organization. Students perform staff tasks under the direction and supervision of AS 20 abc students. Students are rotated throughout the staff agencies of the organization in order that they may encounter the maximum number of management problems and become thoroughly familiar with the entire organization. The organization is given various tasks to perform and its performance is analyzed with emphasis upon determining where and how breakdowns in communications, organization,etc. occur. Instructor: Thompson.

AS 20 abc. Advanced Air Force Management Laboratory. *1 unit (0-1-0); each term. Prerequisite: AS 10 abc and enrollment in AS 40 abc or permission of instructor.* A continuation of AS 10 abc, the AS 20 course allows students to work within an Air Force organization as supervisors. They learn the practical aspects of the functions of management (planning, organizing, coordinating, directing and controlling) in supervising the accomplishment of tasks assigned the organization. As with the staff functions in AS 10, the AS 20 students are rotated throughout the supervisory levels of the organization in order to insure maximum exposure to management problems. The accomplishment of tasks is analyzed to provide practical lessons in management to all students. Instructor: Thompson.

AS 30 abc. Growth and Development of Aerospace Power. *6 units (3-0-3); each term. Prerequisite: AS 1 (normally taken concurrently) or permission of instructor.* AS 30 a deals with the History of Aerospace Power, a course tracing the development of the Air Force from the days of balloons to the Space Age. AS 30 b is concerned with Aerospace Power Today, a study of the theory and practice of employment of aerospace power and of the existing and planned aerospace systems in the United States and abroad. AS 30 c is a survey of astronautics and space operations, dealing with the evolution of the national space program, planned capabilities for space operations, and the operating principles, characteristics and problems of space vehicles systems. Instructor: Thompson.

AS 40 abc. Air Force Management. *6 units (3-0-3); each term. Prerequisite: AS 30 abc or instructor's permission.* The course begins with a study of leadership, with emphasis on human behavioral and group interactional patterns affecting leadership, and some of the distinctive variables affecting leadership in the Air Force. This is followed by a study of military management with its primary units the management functions of planning, organizing, coordinating, directing, and controlling. Within these functions there is a development of normal command and staff functioning in problem solving, advising, and decision-making situations. Instructor: Bendel.

Anthropology

An 1. Race, Language and Culture. *9 units (3-0-6); first term.* Human and cultural evolution. Descriptive analysis of hunting and gathering societies in the Old and New Worlds. The development of racial, linguistic and cultural diversity. The agricultural revolution and the rise of the preindustrial city. Instructor: Scudder.

An 123 ab. The Anthropology of Development. *9 units (3-0-6); second and third terms.* Social change in contemporary tribal and peasant societies. Emphasis will be placed on the impact of modernization, especially through urbanization, industrialization and the intensification of agriculture, and of revitalization, on the social organization of selected societies in Latin America, Europe, Africa and elsewhere over the past half century. Instructor: Scudder.

Applied Mathematics

ADVANCED SUBJECTS

AMa 101 abc. Methods of Applied Mathematics I. *9 units (3-0-6); three terms. Prerequisite: Ma 108 or equivalent.* Review of basic complex variable analysis; analytic continuation; ordinary linear differential equations with applications to special functions; asymptotic expansions; integral transforms. Applications to boundary value problems and integral equations. Instructor: Franklin.

AMa 104. Matrix Theory. *9 units (3-0-6); first term. Prerequisite: AM 95 abc or equivalent.* Theory of matrices from the standpoint of mathematical physics and as used in the formulation of problems on high-speed analog and digital computers. Canonical forms are developed for self adjoint and for general matrices. Text: *Matrix Theory,* Franklin. Instructor: Varah.

AMa 105 ab. Introduction to Numerical Analysis. *11 units (3-2-6); second and third terms. Prerequisites: Ma 108 or AM 95 or equivalent; Ma 5, Ma 31 or AMa 104 or equivalent; and familiarity with coding procedures by the middle of the first quarter of the course.* The topics considered include: Interpolation and quadrature. Numerical solution of algebraic and transcendental equations. Matrix inversion and determination of eigenvalues. Numerical solution of ordinary differential equations. Numerical solution of elliptic, parabolic, and hyperbolic partial differential equations. Instructor: Varah.

AMa 110. Introduction to the Calculus of Variations. *9 units (3-0-6); three terms. Prerequisite: Ma 108 or equivalent.* The first variation and Euler's equation for a variety of classes of variational problems from mathematical physics. Natural boundary conditions. Subsidiary conditions. The theory of extremal fields for single-variable variational problems. Conjugacy and the second variation. Hamilton-Jacobi theory. An introduction to the direct methods of Rayleigh, Ritz, and Tonelli and their application to equilibrium and eigenvalue problems. Some simple aspects of control problems. Offered as a first term course 1970-71. Instructor: Whitham.

AMa 151 abc. Perturbation Methods. *9 units (3-0-6); three terms. Prerequisite: AMa 101 or equivalent.* The course discusses uniformly valid approximations in various physical problems. Generalized boundary layer technique. Coordinate straining techniques; Poincare's method. Problems with several time scales; averaging techniques; method of Krylov-Bogoliubov. Eigenvalue problems. Examples taken from linear and nonlinear vibrations, orbital problems, viscous flow, elasticity. Instructor: Cohen.

AMa 152 abc. Linear and Nonlinear Wave Propagation. *9 units (3-0-6); three terms. Prerequisite: AMa 101 or equivalent.* Mathematical formulation, hyperbolic equations, characteristics, shocks. Combined effect of nonlinearity and diffusion. Wave propagation with relaxation effects. Dispersive waves, group velocity, geometry of waves, nonlinear dispersive waves. Diffraction theory. The emphasis is on solving physical problems and the mathematical theory is developed through a wide variety of problems in gasdynamics, water waves, plasma physics, electromagnetism. Not offered 1970-71.

AMa 153 abc. Stochastic Processes. *9 units (3-0-6); three terms. Prerequisite: Ma 108; or AM 95 and 113.* An introductory course designed to proceed from an elementary and often heuristic discussion of a variety of stochastic processes in physics to a unified mathematical treatment of the subject. Topics will include: Concepts of power spectra and correlation functions and their use in problems like shot effect, Brownian motion, wave propagation in media with random inhomogeneities, turbulence, etc. Response of systems of oscillators to random inputs. Fokker-Planck equation and its application to nonlinear oscillator problems. General theory of Markoff processes. Not offered 1970-71.

AMa 181 ab. Linear Programming. *9 units (3-0-6); second and third terms. Prerequisite: AMa 104 or Ma 5 abc.* Engineering and economic applications of linear programming. Duality and equilibrium theorems. The simplex method. Integral linear programming. Assignment transshipment, and transportation problems. Applications to game theory. Computational methods. Instructor: Lagerstrom.

AMa 190. Reading and Independent study. *Units by arrangement.*

AMa 201 abc. Methods of Applied Mathematics II. *9 units (3-0-6); three terms. Prerequisite: AMa 101 or equivalent.* First order partial differential equations; classification of higher order equations; well-posed problems. Fundamental solutions and Green's functions; eigenfunction expansions; solution by integral transforms. Singular integral equations. Offered second and third terms 1970-71. Instructor: Keller.

AMa 204 abc. Numerical Solution of Differential and Integral Equations. *9 units (3-0-6). Prerequisite: AMa 101 and AMa 104 or some familiarity with: elementary numerical methods, as in AMa 105 a, digital computing techniques, partial differential equations.* A study of practical methods for "solving" various linear and nonlinear, ordinary and partial differential and integral equation problems with the aid of modern digital computers. The theory of stability, convergence and accuracy of methods will be stressed. Computations on some nontrivial problems from each student's area of specialization will be undertaken. Complementary material is given in Ma 205. Not offered 1970-71.

AMa 251 abc. Applications of Group Theory. *9 units (3-0-6); first and second terms. Prerequisite: Some knowledge of linear algebra.* Applications of group theory to differential equations and to physics, in particular quantum mechanics, will be discussed. Mathematical topics to be covered include: Basic concepts of group theory. Infinitesimal transformations and Lie algebras. General notions of group representations. Detailed discussion of classical groups (symmetric, orthogonal, unitary, Lorentz, etc.) and of their representations. Not offered 1970-71.

AMa 260 abc. Special Topics in Continuum Mechanics. *9 units (3-0-6); three terms. Prerequisite: Some knowledge of elasticity or fluid mechanics and permission of instructor.* A course designed to reflect recent and current research interests of the staff and students working on mathematical problems in the areas of elasticity, fluid mechanics and related fields. Instructors: Keller, Whitham.

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

AMa 291. Seminar in Applied Mathematics. *Units by arrangement.*

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

Other courses particularly suitable in making up a program in Applied Mathematics include:

Ma 109	Delta Functions and Generalized Functions
Ma 141	Introduction to Ordinary Differential Equations
Ma 143	Functional Analysis
Ma 144	Probability
Ma 205	Numerical Analysis
AM 135	Mathematical Elasticity Theory
AM 136	Advanced Mathematical Elasticity Theory
AM 175	Advanced Dynamics
ES 130	Introduction to Classical Theoretical Physics I
ES 131	Introduction to Classical Theoretical Physics II
ES 204	Hydrodynamics of Free Surface Flows
Ph 125	Quantum Mechanics
Ph 209	Electromagnetism and Electron Theory
Ph 227	Statistical Physics

Applied Mechanics

UNDERGRADUATE SUBJECTS

AM 95 abc. Engineering Mathematics. *12 units (4-0-8); first, second, and third terms. (Graduate students needing this material should take AM 113 abc.) Prerequisites: Ma 1 abc, Ma 2 abc, or equivalent.* A course in the mathematical treatment of problems in engineering and physics. Emphasis is placed on the formulation of problems as well as their mathematical solution. The topics studied include: vector analysis as applied to formulation of field theory problems; a basic introduction to analytic functions of complex variables; special functions such as the Bessel functions and Legendre functions; series of orthogonal functions; partial differential equations and boundary value problems, and an introduction to integral transforms.

AM 97 abc. Analytical Mechanics of Deformable Bodies. *9 units (3-0-6); first, second, and third terms. Prerequisites: Ph 1 abc and Ma 2 abc.* Basic principles of stress and strain, displacements and strains in a continuum, stress-strain relations, strain energy methods, and stress failures. Equations of the Theory of Elasticity, uniqueness, and St. Venant's principle. Applications to beams, elastic instability, axially symmetrical problems, stress concentrations, torsion, plates and shells, wave propagation and plastic and inelastic behavior, stresses and strains as tensors, numerical methods and experimental methods in stress analysis, variational methods. Instructors: Housner, Hudson, Jennings.

ADVANCED SUBJECTS

AM 112 abc. Structural Mechanics. *9 units (3-0-6); first, second, and third terms. Prerequisite: AM 97 abc or equivalent.* Static and dynamic analysis of structures and structural elements to determine stresses, forces, strains, displacements, and stability in continuous and discrete systems. Systems such as beams, columns, plates, shells, and framed structures with elastic and inelastic properties will be studied. A variety of methods, including energy and variational techniques, relaxation methods, and finite element analysis, will be used to develop solutions to specific problems. Instructors: Housner, Jennings.

AM 113 abc. Engineering Mathematics. *12 units (4-0-8); first, second, and third terms. For graduate students only. Prerequisites: Ma 1 abc, Ma 2 abc, or equivalent.* A course for graduate students who have not had the equivalent of AM 95 abc. Emphasis is placed on the setting up of problems as well as their mathematical solution. The topics studied include: vector analysis; analytic functions of a complex variable and applications; ordinary differential equations, emphasizing power series solutions; special functions such as the Bessel and Legendre functions; partial differential equations and boundary value problems, with emphasis on applications of series of orthogonal functions; and an introduction to transform methods. Instructor: Wayland.

AM 125 abc. Engineering Mathematical Principles. *9 units (3-0-6); first, second, and third terms. Prerequisites: AM 95 abc or AM 113 abc, or Ma 108, or equivalent.* Nonlinear first-order ordinary differential equations; ordinary linear differential equations of second order, Sturm-Liouville theorems, Green's functions, asymptotic expansions and method of steepest descent; integral transform theory; partial differential equations of first and second order; applications to vibrations, elasticity, acoustic and electromagnetic wave propagation, kinetic theory and fluid mechanics problems. Instructor: Caughey.

AM 135 abc. Mathematical Elasticity Theory. *9 units (3-0-6); first, second, and third terms. Prerequisite: suitable background in advanced calculus.* Foundations and applications of linear elasticity theory. Elements of cartesian tensor analysis. Kinematics of deformation, analysis of stress, stress-strain relations, strain-energy. Alternative formulations of boundary-value problems in elastostatics and elastodynamics. Reciprocal and uniqueness theorems, minimum and variational principles. Theory of stress functions. Orthogonal curvilinear coordinates. Basic problems in elastostatics: fundamental singular solutions, problems of the half space, torsion and bending, plane problems. Instructor: Knowles.

AM 136 abc. Advanced Mathematical Elasticity Theory. *9 units (3-0-6); first, second, and third terms. Prerequisite: AM 135 abc or equivalent.* Special topics in the advanced linear theory and the nonlinear theory of elasticity; specific content may vary from year to year. Representative topics include: theory of Green's functions, mean value theorems and St. Venant's principle in the linear theory; linear thermoelasticity; integral transform and complex-variable methods in classical elasticity. Shell theory and problems of boundary layer type elasticity; elastic instability. Introduction to the nonlinear theory and applications. Instructor: Sternberg.

AM 140 abc. Plasticity. *9 units (3-0-6); first, second, and third terms. Prerequisites: AM 95 abc and AM 112 abc or permission of the instructor.* Yield criteria and stress-strain relations for perfectly plastic and strain-hardening materials; stable materials; uniqueness theorems. Plastic torsion and bending. Plane strain theory and problems of incipient flow for metals and soils. Axially symmetric problems. Limit analysis theorems and applications. Plasticity theories for beams, plates, and shells. Minimum weight design.

AM 141 abc. Wave Propagation in Solids. *9 units (3-0-6); first, second, and third terms. Prerequisites: AM 95 abc or AM 113 abc, or permission of the instructor.* Theory of wave propagation in solids with applications to problems. Waves in the infinite and semi-infinite elastic medium. Problems of wave scattering and diffraction. Dispersion of waves in bounded, elastic solids. Exact and approximate linear elasticity theories governing waves in rods, beams, plates and shells. Use of integral and multi-integral transforms and related techniques, to derive exact and approximate transient elastic wave solutions. Introduction to theory of waves in visco-elastic and plastic media. Instructor: Miklowitz.

AM 151 abc. Dynamics and Vibrations. *9 units (3-0-6); first, second, and third terms. Prerequisites: AM 95 abc, or permission of the instructor.* The mechanics of particles, groups of particles and rigid bodies is studied within the framework of Hamilton's principle and Newton's laws of motion. Topics considered include: conservation principles, Lagrange's and Euler's equations, central force field problems, resonant vibration theory, response of systems to periodic and transient excitation, random vibration theory, general normal mode theory, matrix methods for vibration problems, vibration of continuous systems, and methods of nonlinear analysis. Instructors: Hudson, Jennings.

AM 155. Dynamic Measurements Laboratory. *9 units (1-6-2); first term.* Experimental studies of the behavior of dynamic systems. Theory and practice of dynamic instrumentation. Dynamic tests of mechanical systems including steady state and transient excitation. Analog techniques applied to random load problems. Instructors: Caughey, Hudson, Iwan.

AM 160. Vibrations Laboratory. *6 units (0-3-3); second term. Prerequisite: AM 151 abc, or permission of the instructor.* Experimental analysis of typical problems in structural dynamics and mechanical vibrations. Measurement of strains, accelerations, frequencies, etc., in vibrating systems, and the interpretation of the results of such measurements. Consideration is given to the design, calibration, and operation of the various types of instruments used for the experimental study of dynamics problems. Instructors: Caughey, Hudson, Iwan.

AM 175 abc. Advanced Dynamics. *9 units (3-0-6); first, second, and third terms. Prerequisites: AM 125 abc and AM 151 abc or equivalents.* A lecture course dealing with the theory of dynamical systems. Topics considered will include linear and nonlinear vibrations of discrete and continuous systems, stability and control of dynamical systems, and stochastic processes with applications to random vibrations. Instructors: Caughey, Iwan.

AM 200. Special Problems in Advanced Mechanics. Dynamics of solid and deformable bodies, fluids, and gases; mathematical and applied elasticity. By arrangement with members of the staff, properly qualified graduate students are directed in independent studies. Hours and units by arrangement.

AM 250 abc. Research in Applied Mechanics. Research in the field of Applied Mechanics. By arrangement with members of the staff, properly qualified graduate students are directed in research. Hours and units by arrangement.

Astronomy

UNDERGRADUATE SUBJECTS

Ay 1. Introduction to Astronomy. *9 units (3-1-5); second term.* This course surveys astronomy, spectroscopy and astrophysics. Reading in an elementary text is supplemented by lectures on current topics, emphasizing the application of physics in astronomy. Instructor: Greenstein.

Ay 2. Current Problems in Astronomy. *9 units (3-0-6); third term. Prerequisite: Physics 1.* An elementary introduction to current problems in astronomy. This seminar will provide an opportunity to study individual topics in astronomy, radio astronomy, solar and space physics. Instructor: Zirin.

Ay 10. Introduction to Astrophysics. *8 units (2-2-4); first term. Prerequisites: Ay 1, or consult instructor.* An introduction to stellar atmospheres, spectroscopy, stellar interiors and evolution, gaseous nebulae and solar physics. Primarily for juniors and seniors not majoring in astronomy, who have an adequate background in physics. Astronomy majors should take Ay 112 abc and Ay 113 abc. Instructor: Greenstein.

Ay 15. Introduction to Radio Astronomy. *9 units (3-0-6); third term. Prerequisites: consult instructor.* A survey of the contributions which radio observations have made toward our understanding of celestial objects. Topics include the properties and interpretation of the radio emission from the sun, planets, interstellar gas, supernova remnants, radio galaxies and quasi-stellar radio sources. Primarily for juniors and seniors not majoring in astronomy. Seniors in astronomy should consider Ay 133 ab. Instructor: Cohen.

ADVANCED SUBJECTS*

Ay 112 abc. General Astronomy. *6 units (3-0-3); first, second, and third terms. Prerequisites: Ph 2 abc, Ma 2 abc.* Physical properties of the sun and stars and the spectral sequence. Binary and variable stars. Introduction to astrophysics, interstellar matter, stellar interiors and stellar atmospheres. Stellar distances and motions. Structure and dynamics of the galaxy. Extragalactic nebulae. Instructors: Schmidt, Zirin, Sargent. (Undergraduate and graduate students registered in astronomy and taking this course must also take Ay 113 abc concurrently.)

Ay 113 abc. General Astronomy Laboratory. *4 units (0-4-0); first, second, and third terms. Prerequisites: Ph 2 abc, Ma 2 abc.* A course of laboratory exercises based on the subjects covered in Ay 112 abc. This laboratory can only be taken concurrently with Ay 112 abc. Instructors: Schmidt, Zirin, Sargent.

Ay 131. Stellar Atmospheres. *9 units (3-0-6); second term. Prerequisites: Ay 112 abc, Ph 102 abc, or equivalents.* General survey of the methods for studying the structure and composition of stellar atmospheres. Radiative transfer. Sources of opacity. Convection. The construction of models. The line spectrum of normal stars. Coarse and fine analysis of stellar spectra. Composition and nucleosynthesis theory. Instructor: Münch.

Ay 132. Stellar Interiors. *9 units (3-0-6); first term. Prerequisites: Ay 112 abc, Ph 102 abc, or equivalents.* Polytropes, opacity and energy generation. Stellar models and evolution. White dwarfs. Pulsating stars. Problems of stellar rotation, convection, and stability. Instructors: Oke, Gunn.

* See also Ge 152, page 348.

Ay 133 abc. Radio Astronomy. *9 units (3-0-6); first, second, and third terms. For seniors and graduate students only. Prerequisites: Ay 112; may be taken concurrently.* Principles of radio receivers and telescopes. Noise and fluctuations. Aperture synthesis instruments. Observations and theory of galactic and extragalactic radio sources. Radiative transfer. Theory of bremstrahlung and synchrotron emission. Discrete sources and their identification. Radio galaxies and quasi-stellar sources. Radiation from the sun, geophysical effects. Microwave spectroscopy. The 21-cm hydrogen line and galactic structure. Interstellar molecules. Instructors: Moffet, Cohen.

Ay 134. The Solar Atmosphere. *9 units (3-1-5); second term.* The physical state of the solar atmosphere as derived from observations. Solar activity, flares, and magnetic fields and oscillatory motions. Deviations from local thermodynamic equilibrium in atomic processes. Not offered in 1970-71.

Ay 135. Topics in Modern Astronomy. *6 units (1-4-1); third term.* Seminar and laboratory course for graduate students on modern observational techniques and methods for analyzing astronomical date. Not offered in 1970-71.

Ay 136. Solar System Astrophysics. *9 units (3-0-6); first term, given in alternate years.* The Planets and their Satellites; internal structure and composition. Formation and evolution of planetary atmospheres. Comets and small bodies in the solar system. Theories of the origin of the solar system and the sun. Offered in 1970-71. Instructor: Münch.

Ay 137. Topics in Space Astronomy and Physics. *6 units (2-0-4); second term.* Experiments and observations of astronomical interest obtained from satellite and deep space vehicles. Instrumentation and methods. Interplanetary space. Fields and particles. Radiation of stars in the far ultraviolet and infrared. Given in alternate years. Not offered in 1970-71.

Ay 138. Interstellar Matter. *9 units (3-0-6); third term. Prerequisite: Ay 112, may be taken concurrently.* The interstellar gas and dust. Reddening, absorption and polarization of light. Interstellar absorption lines. Ionized and neutral regions. Excitation of emission lines. The dynamics of gas clouds. Star formation. Instructor: Münch.

Ay 139. Stellar Dynamics and Galactic Structure. *9 units (3-0-6); second term. Prerequisite: Ay 112, may be taken concurrently.* Dynamical and kinematical description of stellar motions. Galactic rotation and the density distribution. Dynamics of clusters; relaxation times. Structure and mass of the galaxy and eternal systems. Given in alternate years. Not offered in 1970-71.

Ay 141 abc. Research Conference in Astronomy. *2 units (1-0-1); first, second, and third terms.* These conferences consist of reports on investigations in progress at the Mount Wilson and Palomar Observatories and the Owens Valley Radio Observatory, and on other researches which are of current interest.

Ay 142. Research in Astronomy, Radio 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 with him. Approval of the instructor and the student's adviser must be obtained before registering. 36 units of Ay 142 or Ay 143 required for candidacy.

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 with him. Approval of the instructor and the student's adviser must be obtained before registering. 36 units of Ay 142 or Ay 143 required for candidacy.

Ay 151. Stellar Atmospheres Seminar. *9 units (3-0-6); second term, given in alternate years. Prerequisite: Ay 131.* Review of current problems in the field of atmospheric structure and abundance determinations. Line broadening theory. Departures from thermodynamic equilibrium. General source function for line formation. Time-dependent radiative processes. Selected topics in stellar spectroscopy; compositions of normal and peculiar stars. Not given in 1970-71.

Ay 152. Advanced Stellar Interiors. *9 units (3-0-6); third term.* Computation of stages of stellar evolution; nucleosynthesis; planetary nebulae; mass exchange in binaries; evolution toward the white dwarfs; thermal instabilities. The course is a logical but advanced continuation of our regular course, Ay 132, on stellar interiors. Given in alternate years. Instructor: Paczynski.

Ay 201 ab. Astronomical Instruments and Radiation Measurement. *9 units (3-1-5), (3-2-4); second and third terms. Prerequisite: Ay 112, may be taken concurrently.* The use of the photographic plate as a scientific instrument: quantitative techniques in laboratory photography. Astronomical optics. Theory of reflectors, schmidts and spectographs. Photoelectric detectors, photometric systems and their applications. Instructor: Oke.

Ay 207 abc. Galaxies and the Universe. *9 units (3-0-6) first, second, and third terms. Prerequisite: Ay 112 or equivalent.* Structure, stellar content, and evolution of normal galaxies. Galaxies of the Local Group. Mass determinations. The Luminosity function. Seyfert and compact galaxies, QSO's; and other peculiar objects. Dynamics of galaxies, clusters and small groups. The third term, which may be taken independently, will cover topics in observational cosmology, including dynamics, the microwave, and x-ray background, and the formation of galaxies and clusters. Given in alternate years — offered in 1970-71. Instructors: First term: Sargent and Searle; Second term: Sargent and Gunn; Third term: Gunn.

Ay 208. Modern Observational Astronomy. *6 units (1-0-5); first and third terms. Prerequisites: with permission of the instructor.* An observational course for graduate students in astronomy in which modern astronomical techniques are used in conjunction with the various telescopes and auxiliary instruments on Mount Wilson and Palomar Mountain. Students will be permitted to register for only one term. Instructors: Staff.

Ay 215 abc. Seminar in Theoretical Astrophysics. *6 units (2-0-4). Prerequisites: Ay 131 and/or Ay 132.* Seminar on recent developments for advanced students. The current theoretical literature will be discussed by the students. Ay 215 b not offered in 1970-71. Instructors: Goldreich, Sargent, Gunn.

Ay 217. Theoretical Astrophysical Spectroscopy. *9 units (3-0-6); first term. Prerequisite: Ph 125, or equivalent.* The analysis of radiation from astronomical sources not in thermodynamic equilibrium. Special attention to the formation of lines in atmospheres, and the calculation of excitation and ionization equilibria as well as individual atomic processes. Emission of radiation in dynamic plasmas; radiation and transition processes. Given in alternate years. Offered in 1970-71. Instructor: Zirin.

Ay 234. Seminar in Radio Astronomy. *6 units (2-0-4); second term. Prerequisite: Ay 133 abc.* Recent developments in radio astronomy for the advanced student. Current publications and research in progress will be discussed by students and staff. Instructors: Cohen, Moffet.

The following courses will be offered from time to time by members of the Institute and Observatories staffs:

Ay 203. Cosmical Electrodynamics.

Ay 204. Advanced Spectroscopy.

Ay 206. Variable Stars.

Ay 213. Selected Topics in Observational Cosmology.

Ay 214. Theoretical Cosmology.

Ay 216. Dynamics and Formation of Galaxies and Clusters

Biology

UNDERGRADUATE SUBJECTS

Bi 1. Introduction to Biology. *9 units (distribution to be arranged); second term.* A course of lectures, discussion and laboratory opportunities designed to permit a relatively free exploration of biological topics. Available only on a pass-fail basis. Individual arrangements are made to determine the number of laboratory units counting toward freshman laboratory requirements. Instructors: McMahon, and staff.

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 to students in advance of the discussions, with members of the Divisional faculty. Instructors: Owen, and staff.

Bi 3. Biology and Social Problems. *6 units (2-0-4); third term.* The relation of biological knowledge to major social problems. Topics may include over-population, environmental pollution, distribution of limited medical resources, "genetic engineering," biological warfare, the ethics of human medical research, etc. Instructor: Sinsheimer.

Bi 7. Organismic Biology. *12 units (3-5-4); first term.* A survey of the principal kinds of organisms and the problems they have solved in adapting to various environments. Instructors: Brokaw and McMahon.

Bi 9. Cell Biology. *9 units (3-3-3); third term.* Studies of life at the cellular level: nature, functions, and integration of ultrastructural components; physical and chemical parameters; influences of external agents and internal regulation. Instructors: Bonner, and staff.

Bi 22. Special Problems. *Units to be arranged; first, second, and third terms.* Special problems involving independent research in fields represented in the undergraduate biology curriculum; to be arranged with instructors before registration. Instructors: Biology staff.

Bi 23. Biology Tutorial. *Units (up to 6 maximum) to be arranged; first, second and third terms.* Study and discussion of special problems in biology involving regular tutorial sessions with instructors. To be arranged through the Undergraduate Adviser before registration. Instructors: Wood, and staff.

Bi 27. Biology Scholars Program. *Units to be arranged.* A program providing, by arrangement, a flexible combination of course work and independent study in Biology for selected students in the junior and senior years. Pass-fail grading may be permitted. Instructors: Wood, and staff.

ADVANCED SUBJECTS

[A] Subjects intended for graduate students but open to qualified undergraduates.

Bi 101. Invertebrate Biology. *12 units (2-6-4); second term. Recommended prerequisites: Bi 7 and Bi 9.* A survey of the invertebrates, with emphasis on physiological functioning. Will include laboratory work at the Kerckhoff Marine Laboratory in Corona del Mar. Offered alternate years; not offered in 1970-71. Instructor: Brokaw.

Bi 102. Vertebrate Biology. *12 units (2-5-5); second term. Recommended prerequisites: Bi 7 and Bi 9.* A survey of structure, function, and development in vertebrates, with emphasis on physiology. Offered alternate years; not offered in 1970-71. Instructors: Brokaw, and staff.

Bi 106. Introductory Developmental Biology of Animals. *12 units (2-6-4); second term. Prerequisite: Bi 7, or consent of instructor.* A lecture and laboratory course dealing with the development of various invertebrate and vertebrate animals, with emphasis on their common features as well as specialized adaptations. Principles and properties of developing systems are further illustrated by experimental embryological exercises and discussions. Instructors: Staff.

Bi 110 ab. Biochemistry. *10 units (3-0-7); first and second terms. Prerequisite: Ch 41 or consent of instructor.* A lecture and discussion course on the molecular basis of cell structure and function, emphasizing the chemical mechanisms by which living cells store and utilize energy and information. Instructors: Wood, Hood, and staff.

Bi 111. Biochemistry Laboratory. *10 units (0-8-2); second term. Open to students enrolled in Bi 110; others require consent of instructor.* An introduction to current methods in biochemical research, through laboratory projects suggested by the lecture and seminar material of Bi 110 and Bi 112. Instructors: Mitchell, and staff.

Bi 114. Immunology. *12 units (3-4-5); first term. Prerequisite: Bi 122 or equivalent.* A course on the principles and methods of immunology and their application to various biological problems. Instructors: Owen, Hood.

Bi 115. Virology. *10 units (3-4-3); third term. Prerequisite: Bi 110 or consent of instructor.* An introduction to the chemistry and biology of bacterial, plant, and animal viruses. The subject matter will include viral structure, the biochemistry and regulation of virus replication, viral genetics, and virus-induced changes in the host cell. Instructor: Strauss.

Bi 119. Advanced Cell Biology. *9 units (3-0-6); third term. Prerequisites: Bi 9, Bi 110 or consent of instructor.* This course covers the principles of general microbiology and of the growth and differentiation of the cells of higher organisms. Regulatory circuits in nucleic acid and protein synthesis; mechanisms of control of enzyme activity; regulation of cell multiplication; surface properties of cells. Not offered in 1970-71. Instructor: Attardi.

Bi 121 abc. Bio-Systems Analysis. *6 units (2-0-4); first, second, and third terms. Same as IS 121 abc.* This course presents a systematic consideration and application of the methods of systems analysis, information theory and computer logic to problems in neurobiology. The subjects to be considered include the mechanical properties of striated muscle, the analysis of neuronal integrative mechanisms and reflex behavior in terms of logical net theory. The course will seek to describe some aspects of human cortical activity in terms of information theory and conceptual modeling. The course will be conducted as a research seminar and the detailed subject matter will change from year to year. Instructors: Fender, and staff.

Bi 122. Genetics. *12 units (3-3-6); third term. Prerequisite: Bi 1 or Bi 9, or consent of instructor.* A lecture, discussion, and laboratory course covering the basic principles of genetics. Instructors: Lewis, Horowitz, and staff.

Bi 123. Genetics Colloquium. *6 units (2-0-4); third term. To be taken simultaneously with Bi 122.* Informal seminars in which certain topics will be dealt with in greater depth and with direct student participation. Not offered in 1970-71. Instructors: Lewis, Emerson, Horowitz.

Bi 124. Genetics Laboratory. *Units to be arranged; third term.* Research projects involving different organisms and different problems. Instructors: Lewis, Horowitz, and Emerson.

Bi 128. Advanced Microtechnique. *6 units (1-4-1); third term.* Theory and practice of preparing biological material for microscopic examination; histochemical methods; phase contrast microscopy; methods in electron microscopy. Not offered 1970-71.

Bi 129. Biophysics. *6 units (2-0-4); second term.* The subject matter to be covered will be repeated approximately in a three-year cycle. The subject matter will be organized according to various biological functions, such as replication, contractility, sensory processes, endogenous rhythms, etc. Each function will be discussed in its various biophysical aspects. This course together with Bi 132 constitutes an integrated program covering the physical and physicochemical approaches to biology. Instructor: Delbruck.

Bi 132 ab. Biophysics of Macromolecules. *9 units (3-0-6); first, second terms. Prerequisite: Ch 21 or equivalent.* A study of the structure and properties of biological macromolecules. Emphasis is placed on both the methods of investigation and interpretation of the results. Topics covered include: polymer statistics and thermodynamics, sedimentation, light scattering, spectroscopy, X-ray diffraction, and electron microscopy. Offered alternate years; offered in 1970-71. Same as Ch 132 ab. Instructors: Davidson, Dickerson, Sinsheimer, Vinograd.

Bi 133. Biophysics of Macromolecules Laboratory. *14 units (0-10-4); second and third terms.* A laboratory course designed to provide an intensive training in the techniques for the characterization of biological macromolecules. Open to selected students. Offered alternate years; offered in 1970-71. Instructor: Vinograd.

Bi 141. Selected Topics in Evolution Theory. *9 units (3-0-6); third term. Prerequisite: Bi 110 or Bi 122.* Lectures and seminars on subjects of current interest, with emphasis on genetic and molecular processes in evolution. Topics to be treated include modern experiments on the origin of life, biological aspects of planetary exploration, the evolution of protein structure, and mathematical models of evolution. Instructors: Horowitz, Dickerson.

Bi 151. Neurophysiology. *12 units (3-4-5); first term.* A lecture and laboratory course on fundamental aspects of nervous excitation and conduction, synaptic transmission, inhibition, muscle contraction, sense organ physiology, etc. May also be taken, without laboratory, for six units (3-0-3). Instructors: Strumwasser, Van Harreveld, Wiersma.

Bi 152. Behavioral Biology. *6 units (2-0-4); second term.* The behavior of organisms, including lower forms. Emphasis is placed on molecular, genetic, and developmental mechanisms. Instructor: Benzer.

Bi 153. Brain Studies of Motivated Behavior. *9 units (3-0-6); second term. Prerequisites: permission of the instructor.* A lecture course concerned with the anatomical and physiological bases of drives, arousal, rewards, and learning. Emphasis is placed on the mammalian brain, particularly the midbrain, hypothalamus, and paleocortex with reference to the effects of lesions and electric stimulation upon physiological and behavioral activity. Instructor: Olds.

Bi 155. Psychobiology. *9 units (2-3-4); third term.* An introduction to the study of neural mechanisms of behavior with emphasis on the higher functions of the nervous system and mind/brain relations. May be taken for 6 units without laboratory. The laboratory includes study of vertebrate brain structure and selected behavioral projects. Instructor: Sperry.

[B.] Subjects primarily for graduate students.

Bi 201. General Biology Seminar. *1 unit; all terms.* Meets weekly for reports on current research of general biological interest by members of the Institute staff and visiting scientists. In charge: Dreyer, Strauss, Strumwasser.

Bi 202. Biochemistry Seminar. *1 unit; all terms.* A seminar on selected topics and on recent advances in the field. In charge: Mitchell.

Bi 204. Genetics Seminar. *2 units; all terms.* Reports and discussion on special topics. In charge: Lewis.

Bi 205. Experimental Embryology Seminar. *1 unit; all terms.* Reports on special topics in the field; meets twice monthly. Not offered 1970-71.

Bi 207. Biophysics Seminar. *1 unit; all terms.* A seminar on the application of physical concepts to selected biological problems. Reports and discussions. In charge: Delbrück.

Bi 208. Selected Topics in Neurobiology. *Units to be arranged with the instructor; second and third terms.* Lectures and seminars on neurophysiology, neurochemistry, and animal behavior. In charge: Strumwasser, Van Harreveld, Wiersma, and invited lecturers.

Bi 209. Psychobiology Seminar. *Units to be arranged; all terms. Prerequisite: consent of instructor.* An advanced seminar course in brain mechanisms and behavior. In charge: Sperry.

Bi 220 abc. Developmental Biology of Animals. *6 units (2-0-4); first, second, third terms.* Lectures and discussion of biological and chemical problems and principles of embryonic development of animals, with reference to correlative studies on other organisms. Topics covered include: origin of the germ cells, maturation of the gonads, spermatogenesis and oogenesis, breeding habits, endocrinological influences, fertilization, cleavage, germ layer and organ formation, processes of embryonic determination and induction, specific protein biosynthesis, embryonic metabolism, cell-interactions and properties of cultured cells, metamorphosis, regeneration, etc. The course may be taken for 5 consecutive terms since the subject matter will be duplicated only in alternate years. Not offered 1970-71.

Bi 221. Developmental Biology Laboratory. *Units to be arranged; all terms.* A laboratory course designed to give the student first-hand experience with biological and chemical methods of study and experimentation with developing animals. Included are methods of cell isolation, transplantation, cytochemistry, protein biosynthesis, micromanipulation, metabolism, etc. Not offered 1970-71.

Bi 241. Advanced Topics in Molecular Biology. *6 units (2-0-4); third term. Prerequisite: consent of instructor.* Group discussions of new areas in molecular biology. Instructor: Dreyer.

Bi 260. Advanced Physiology. *Units to be arranged. Second and third terms.* A project laboratory using advanced techniques of physiology. Instructors: Strumwasser, Van Harreveld, Wiersma.

Bi 270. Special Topics in Biology. *Units to be arranged. First, second, and third terms.* Students may register with permission of the responsible faculty member.

Bi 280-291. Biological Research. *Units to be arranged. First, second, and third terms.* Students may register for research in the following fields after consultation with those in charge: Animal physiology (280), biochemistry (281), bio-organic chemistry (282) embryology (283), genetics (284), immunology (285), marine zoology (286), plant physiology (287), biophysics (288), psychobiology (289), cell biology (290), physiological psychology (291).

Chemical Engineering

UNDERGRADUATE SUBJECTS

ChE 10. Chemical Engineering Systems. *9 units (3-3-3); third term.* Selected problems applicable to systems studies in chemical engineering. Topics from fields such as artificial organs, air pollution, saline water recovery, and fixation of nitrogen will be used to study principles of engineering and elucidate the relationships among engineering principles, chemistry and economics, and their application to the needs of society. Instructor: Shair, and staff.

ChE 63 abc. Chemical Engineering Thermodynamics. *9 units (3-0-6); first, second, and third terms.* Basic thermodynamic laws and relations for one-component closed systems and for simple steady-flow systems; the treatment includes imperfect substances and frictional processes. Introduction to the thermodynamics of chemical equilibria and phase equilibria; in the third quarter, applications to the equilibrium of chemical reactions under practical conditions, and to separation processes involving equilibrium staged operations. Instructor: Pings.

ChE 80. Undergraduate Research. *Units by arrangement.* Research in chemical engineering and industrial chemistry offered as an elective in any term. If ChE 80 units are to be used to fulfill elective requirements in the chemical engineering option, a thesis approved by the research director must be submitted in duplicate before May 10 of the year of graduation. The thesis must contain a statement of the problem, appropriate background material, a description of the research work, a discussion of the results, conclusions, and an abstract. The thesis need describe only the significant portion of the research.

ChE 81. Special Topics in Chemical Engineering. *Units by arrangement.* Occasional advanced work involving reading assignments and a report on special topics. Permission of the instructor is required. No more than 12 units in ChE 81 may be used to fulfill elective requirements in the chemical engineering option.

ADVANCED SUBJECTS

ChE 101 abc. Applied Chemical Kinetics. *9 units (2-0-7); first, second, and third terms.* A study of homogeneous and heterogeneous kinetics with application of combined kinetics and transport processes in the analysis and synthesis of engineering systems. Topics covered include: elementary reactions, collision and activated complex theory, catalytic and chain reactions. Principles of combustion. Analysis and design of chemical reactors, non-ideal flow and residence time distribution. Determination of kinetic parameters from experimental data. Heterogeneous, non-catalytic reactions. Catalysis, adsorption and surface reaction kinetics, diffusion and reaction in porous catalyst. Selected industrial catalytic processes. Design of catalytic reactors. Instructor: Gavalas.

ChE 103 abc. Transport Phenomena. *9 units (3-0-6); first, second, third terms. Prerequisite: AM 95 abc or AM 113 ab, or concurrent registration in either.* A study of transfer of momentum, energy, and material in situations of practical interest, particularly those including chemical reaction and those involving staged and continuous unit operations. Derivation of applicable differential equations and their solution to determine distributions of velocity, pressure, temperature, and composition, and the fluxes of momentum, energy, and material in fluid systems. Brief treatment of the molecular theory of transport phenomena. Turbulent as well as laminar flow systems are considered. Instructor: Seinfeld.

ChE 105 abc. Applied Chemical Thermodynamics. *9 units (3-0-6); first, second, third terms. Prerequisite: ChE 63 abc or equivalent.* The first term consists of a rigorous development of the concepts and formalisms of thermodynamics, while in the second and third terms these principles are applied to problems of chemical interest. They include ideal and real behavior of single and multicomponent systems and treatment of multiple phase equilibria both with and without simultaneous chemical reactions. Criteria of thermodynamic stability are discussed and applied to both homogeneous and heterogeneous systems. The dynamic response of near equilibrium systems is discussed, and the elements of statistical thermodynamics and irreversible thermodynamics are presented. Instructor: Vaughan.

ChE 107 abc. Polymer Science. *9 units (3-0-6); first, second, third terms. Prerequisite: Ch 21 or equivalent.* The first term covers polymer chemistry: the nature and classification of polymers, methods of synthesis, polymerization kinetics and molecular weight distribution, copolymerization, and cross-linking. During the second term attention is focused on the physical characterization of polymers by solution methods and by physical methods in bulk. A detailed treatment of polymer properties is the subject of the third term which includes a discussion of the principles of polymer technology.

Throughout the course the emphasis is on an understanding of polymer properties in terms of polymer structure. Not offered 1970-71. Instructors: Tschoegl and Rembaum.

ChE 110 abc. Optimal Design of Chemical Systems. *9 units (3-0-6); first, second, third terms. Prerequisites: ChE 63 ab, ChE 103 abc or equivalent, or enrolled in ChE 103 concurrently.* Applications of the principles of chemical engineering and general engineering to the study of systems involving chemical reactions. Topics of current interest will be drawn from the chemical and petroleum industries, the aerospace industry, and the biomedical engineering field. Techniques of numerical analysis and the digital computing facility will be used to simulate and optimize. Principles of transport phenomena, chemical kinetics and economics along with the elements of applied mechanics, machine design, strength and properties of materials will be employed. Instructor: Corcoran.

ChE 126 abc. Chemical Engineering Laboratory. *(ChE 126 same as ME 126). Units to be arranged; first, second, third terms.* Seniors taking this course are introduced to some of the basic techniques of laboratory measurements. Several short projects, illustrative of problems in transport phenomena, unit operations, chemical kinetics and reactor control, are performed. Master's degree students are introduced to advanced experimental techniques involving energy transport and reactor kinetics and control during the first term; during the second and third terms, each student works on an individual research project under the direction of a staff member.

Experiments in energy transport may be chosen from those available in ME 126. These include solid state and solar energy conversion, conduction, free and forced convection, radiation, nucleate and stable film boiling, free surface and supersonic flows. Experiments in chemical systems include projects in homogeneous gas-phase kinetics using a microreactor with gas chromatography, homogeneous liquid-phase kinetics and control using a stirred-tank reactor for the study of the multiplicity of steady states. Instructors: Shair, Sabersky, Zukoski.

ChE 172 abc. Control Systems Theory. *(Same as EE 172 abc) 9 units (3-0-6); first, second, third terms. Prerequisite: AM 95 abc or equivalent.* Linear feedback control systems. Frequency and time domain analysis. Stability. Synthesis using Bode diagrams, Nyquist plots, and root locus methods. Controllability and observability. Optimal control theory. Dynamic programming. The maximum principle. Distributed parameter systems. Linear and nonlinear estimation theory, Kalman filtering, nonlinear filtering. Methods of adaptive control. Applications of these methods in the analysis and synthesis of chemical, electrical, and mechanical systems will be studied. Instructors: Gavalas, Seinfeld.

ChE 203 ab. Interfacial Phenomena. *9 units (3-0-6); second, third terms. Prerequisite: ChE 103 abc, or permission of instructor.* Review of the theory of the Brownian motion and irreversible thermodynamics, structure of the interface, absorption and monomolecular layers, membrane transport, facilitated transport, active transport, convective diffusion, concentration boundary layers, current flow through electrolytic solutions, interfacial turbulence. Not offered in 1970-71. Instructor: Friedlander.

ChE 206 abc. Molecular Theory of Fluids. *9 units (3-0-6); first, second, third terms. Prerequisite: Ch 21 abc, AM 113 ab, ChE 103 abc, or their substantial equivalents.* A study of the models and mathematical theories of the liquid and gaseous states, including plasmas. Some emphasis is placed on the prediction and correlation of macroscopic properties and phenomena from molecular parameters. Rigorous kinetic theory of equilibrium and transport properties of dilute gases; statistical mechanics and kinetic theory of equilibrium and nonequilibrium behavior in dense gases and liquids; study of intermolecular forces and potentials in neutral and ionized systems; treatment of plasma, with special emphasis on problems of chemical interest. Not offered in 1970-71. Instructors: Gavalas, Pings, and Shair.

ChE 207 abc. Mechanical Behavior and Ultimate Properties of Polymers. *9 units (3-0-6); first, second, third terms. Prerequisite: ChE 107 or equivalent.* The course begins with an introduction to the theory of viscoelastic behavior. The discussion centers on material functions and their interconversion, model representation, time-temperature equivalence, and the molecular theories of polymer behavior. During the second term consideration is given to the mechanical behavior of various polymeric systems including amorphous, crystalline, and cross-linked polymers, copolymers, elastomers, filled and plasticized systems, blends and melts. The third term is devoted to a discussion of the phenomenology and the molecular and statistical theories of rupture in polymeric materials. Special attention is given to the controlling molecular parameters. Instructors: Tschoegl, Landel.

ChE 280. Chemical Engineering Research. *Offered to Ph.D. candidates in Chemical Engineering.* The main lines of research now in progress are:

Turbulent heat transfer.
Turbulent mass transfer.
Phase and thermodynamic behavior of fluids.
Measurements of transport coefficients.
Reaction kinetics and mechanisms.
Combustion.
Dynamic control and optimization of chemical systems.
Liquid-state physics.
Rheology and flow of suspensions and emulsions.
Special transport problems in biomedical systems.
Mechanical behavior and ultimate properties of polymers.
Mechanics of dispersions.
Plasma chemistry and engineering.
Interfacial transport.
Statistical mechanics of gases, liquids, and ionic solutions.
Solid-state chemistry and physics.

ChE 291 abc. Chemical Engineering Conference. *2 units (1-0-1); first, second, third terms.* Oral presentations on problems of current interest in chemical engineering and industrial chemistry with emphasis on the techniques of effective oral communication with groups. Instructors: Shair and staff.

Chemistry

UNDERGRADUATE SUBJECTS

Ch 1 abc. General and Quantitative Chemistry. *First term 12 units (3-6-3); second, third terms 6 units (3-0-3).* Lectures and recitations dealing with general principles of chemistry. Fundamental laws and theories of chemistry are discussed and illustrated by factual material. The laboratory emphasizes precise experimental technique and quantitative reasoning. Analytical and synthetic experiments involving quantitative, gravimetric, volumetric, optical, electrical, and spectroscopic measurements are provided, including application of digital computers to actual laboratory experiments. Text: *Chemical Principles,* Dickerson, Gray, and Haight. Instructors: Anson, Dickerson, and Gray.

Ch 2 abc. Advanced Placement in Chemistry. *12 units (3-6-3) first term; 6 units (3-0-3) second, third terms.* Ch 2 differs from Ch 1 chiefly in having different lectures and recitation. The one-term required laboratory is the same. Admission to the course is based on CEEB Advanced Placement and a short additional departmental examination. Competence in the following areas is assumed: (1) *elementary* theories of atomic structure and electronic theories of valence (2) chemical stoichiometry, and (3) mass action law. There is more emphasis on systematic treatment of reactions and chemical reactivity than in Ch 1. Equilibrium relationships, electrochemistry, etc., are discussed directly in terms of thermodynamics and used as examples of variations in chemical reactivity as a function of chemical structure. Not offered in 1970-71.

Ch 3 ab. Experimental Chemical Science. *3 units (0-3-0) or 6 units (0-6-0); second, third terms. Either 3 or 6 units may be elected either second or third terms or both terms. Open to all undergraduates, but the total units may not exceed 12 units.* An introductory laboratory course emphasizing basic experimental science with experiments involving qualitative and quantitative determinations, chemical dynamics, synthesis, and correlation of structure and physical properties. Many modern tools and techniques with broad application in science are employed, such as digital computers, infrared spectroscopy, spectrophotometry, radioactive tracers, gas chromatography, coulometry, electron microscopy, and stirred flow reactors. Instructors: Gordon, and other staff members and assistants.

Ch 14. Chemical Equilibrium. *10 units (2-6-2); first term. Prerequisite: Ch 1 abc or equivalent.* A lecture and laboratory course. The lectures offer a systematic treatment of the principles of ionic equilibria. Topics discussed include acid-base equilibria, complex ion formation and chelation, oxidation-reduction reactions and solubility. The laboratory work provides opportunity to apply the principles discussed in the lectures to selected problems in chemical analysis. Instructor: Anson.

Ch 21 abc. The Physical Description of Chemical Systems. *9 units (3-0-6); first, second, third terms. Prerequisites: Ch 1 abc; Ph 2 abc; Ma 2 abc.* A lecture and recitation course. The main emphasis is on atomic and molecular theory, quantum mechanics, statistical mechanics, thermodynamics, and chemical kinetics. Instructor: Chan.

Ch 24 abc. Elements of Physical Chemistry. *9 units (3-0-6); first, second, third terms. Prerequisites: Ch 1 abc; Ma 2 abc; Ph 2 abc.* The first two terms cover classical thermodynamics from the chemical point of view and its application to thermochemistry, to homogeneous and heterogeneous equilibria, to the colligative properties of solutions, and to cell potentials; chemical crystallography. The third term will consider steady-state thermodynamics and its application to electrical and material transport phenomena; chemical kinetics. Only Ch 24 c is open to undergraduates majoring in chemistry. Instructor: Hughes.

Ch 26 ab. Physical Chemistry Laboratory. *10 units (0-6-4); second, third terms. Prerequisites: Ch 1 abc and Ch 21 a are required; two terms of EE 90 or EE 9 or equivalent* *(e.g., suitable physics laboratory courses) are recommended.* Laboratory exercises which provide illustrations of the principles of physical chemistry, an introduction to problems of current interest, and techniques of contemporary research. Instructors: Beauchamp, Holtz.

Ch 41 abc. Chemistry of Covalent Compounds. *9 units (3-0-6); first, second, third terms. Prerequisite: Ch 1 abc.* The study of the chemical reactions of covalent compounds and the mechanisms of these transformations. Emphasis will be on the study of the molecules formed from the first- and second-row elements and the transition metals. Instructors: Bergman, Richards.

Ch 46 ab. Experimental Methods of Covalent Chemistry. *8 units (0-6-2); second, third terms. Prerequisite: Ch 1 abc.* Laboratory acompaniment to Ch 41 abc. Experiments stressing modern techniques for investigating the structures and dynamic behavior as well as synthesis, purification, and characterization of covalent compounds both organic and inorganic. Instructors: Bergman, Richards.

Ch 80. Chemical Research. *Offered to B.S. candidates in chemistry.* If Ch 80 units are to be used as electives in the chemistry option, a thesis describing the research, or a portion of it, must be submitted in duplicate to the research supervisor before May 10 of the year of graduation. This date is set in order to give the supervisor sufficient time to read the thesis and suggest changes, if desirable. The two final copies, with the *written* approval of the research supervisor, should be submitted to the Divisional office, 156 Crellin, not later than May 27. The thesis must contain a statement of the problem, appropriate background material, a description of the research work or a portion of the research work, a discussion of the results, conclusions, and an abstract. No more than 60 units of undergraduate research may be used as chemistry electives without special permission.

Ch 81. Special Topics in Chemistry. Occasional advanced work involving reading assignments and a report on special topics. Permission of the instructor is required. 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); first term.* Training in the technique of oral presentation of chemical topics. Practice in the effective organization and delivery of reports before groups. Instructor: Beauchamp.

ADVANCED SUBJECTS

Ch 113 abc. Advanced Inorganic Chemistry. *9 units (3-0-6); first, second, third terms. Prerequisite: Ch 21 abc or concurrent registration.* The course consists primarily of tutorial instruction in ligand field theory and other relevant theoretical aspects of structural coordination chemistry. Instructor: Gray.

Ch. 114. Chemical Equilibrium. *4 units (2-0-2); first term. Prerequisite: Ch 1 abc or equivalent.* This course is the same as Ch 14 except that no laboratory work is involved. No residence credit is given for this course to graduate students majoring in chemistry. Instructor: Anson.

Ch. 117. Introduction to Electrochemistry. *4 units (2-0-2); second term.* A discussion of the structure of the electrode-electrolyte interface, the mechanism by which charge is transferred across it, and of the experimental techniques used to study electrode reactions. The topics covered change from year to year but usually include diffusion currents, polarography, coulometry, irreversible electrode reactions, the electrical double layer, and complex electrode processes. Instructor: Anson.

Ch. 118 ab. Experimental Electrochemistry. *Units by arrangement; second, third terms.* Laboratory practice in the use of selected electrochemical instruments and techniques. The student may pursue a set of expository experiments and/or elect to carry out a research project in electrochemistry. Instructor: Anson.

Ch 122 ab. The Structure of Molecules. *6 units (2-0-4); first, second terms.* A discussion of the arrangement of atoms in molecules and crystals, of the experimental methods used to determine these arrangements, and of the various types of interatomic forces and their relationships to the chemical and physical properties of substances. Instructor: Marsh.

Ch 124 abc. Elements of Physical Chemistry. *6 units (3-0-3); first, second, third terms.* This course is the same as Ch 24 abc with reduced credit for graduate students. Instructor: Hughes.

Ch 125 abc. Introduction to Chemical Physics. *9 units (3-0-6); first, second, third terms. Prerequisite: Ch 21 abc or the equivalent.* This course provides a basic quantitative introduction to quantum mechanics and statistical mechanics. In addition to fundamental methods, applications to electronic structure of atoms and molecules, radiation theory, spectroscopy, and solid-state problems will be discussed. Most graduate courses in physical chemistry will assume a knowledge of the contents of this course. Instructors: McKoy, Kuppermann.

Ch 127 ab. Nuclear Chemistry. *9 units (3-0-6); first, second terms. Prerequisite: Consent of Instructor.* An introductory course concerned with the properties of nuclei and their application to chemical problems. Topics to be discussed include: Production and decay of radioactive nuclei; the interaction of radiation with matter; nuclear masses and energy; alpha and beta decay; emission of gamma-radiation; nuclear fission; nuclear reactions; chemical applications of radioactivity. Not offered in 1970-71. Instructor: Burnett.

Ch 129 abc. The Structure of Crystals. *9 units (3-0-6); first, second, third terms.* The nature of crystals and X-rays and their interaction. The various diffraction techniques. The theory of space groups and the use of symmetry in the determination of the structures of crystals. The detailed study of representative structure investigations. The quantitative treatment of X-ray diffraction. Fourier-series methods of structure investigation. Given in alternate years. Not offered in 1970-71. Instructor: Sturdivant.

Ch 130. Fundamentals of Photochemistry and Photobiology. *6 units (3-0-3); first term. Prerequisite: Ch 21 ab or equivalent.* A discussion of radiative and radiationless processes associated with problems in photochemistry and photobiology. Instructor: Robinson.

Ch 132 ab. Biophysics of Macromolecules. *9 units (3-0-6); first, second terms. Prerequisite: Ch 21 or the equivalent.* A study of the structure and properties of biological macromolecules. Emphasis is placed on both the methods of investigation and the results. Topics covered include: polymer statistics and thermodynamics, sedimentation, light scattering, spectroscopy, X-ray diffraction, and electron microscopy. (This course is the same as Bi 132 ab.) Given in alternate years. Offered in 1970-71. Instructors: Davidson, Dickerson, Sinsheimer, Vinograd.

Ch 133. Biophysics of Macromolecules Laboratory. *14 units (0-10-4); offered in both second and third terms.* A laboratory course designed to provide an intensive training in the techniques for the characterization of biological macromolecules. (This course is the same as Bi 133.) Open to selected students. Given in alternate years. Offered in 1970-71. Instructor: Vinograd.

Ch 135 ab. Chemical Dynamics. *9 units (3-0-6); second, third terms. Prerequisite: Ch 21 abc or equivalent required: Ch 125 a and concurrent registration in Ch 125 b recommended.* The mechanics and statistical mechanics of reactive collisions; the kinetics and mechanism of chemical reactions. Instructors: Kuppermann, Beauchamp.

Ch 140 abc. Special Topics in Organic Chemistry. *4 units (2-0-2); first, second, third terms. Prerequisite: Ch 41 abc or equivalent.* Lectures on a series of subjects of current interest at the frontiers of organic chemistry. Not offered in 1970-71. Instructors: faculty members, research fellows.

Ch 144 ab. Organic Chemistry. *9 units (3-0-6); first and second terms.* A survey of synthetic, theoretical and bio-organic chemistry with emphasis on stereochemistry. Text: *Basic Principles of Organic Chemistry,* Roberts and Caserio. Instructor: Roberts.

Ch 145 bc. Organic Chemistry Laboratory. *3 units (0-3-0), second term; 6 units (0-6-0), third term. Prerequisite: Ch 46 abc, Ch 144 a, and concurrent registration in Ch 144 b.* An organic chemistry laboratory course that includes synthetic, kinetic, and spectroscopic techniques within the framework of preparative organic chemistry. Not offered in 1970-71. Instructor: Ireland.

Ch 180. Chemical Research. *Offered to M.S. candidates in chemistry.*

Ch 223 ab. Statistical Mechanics. *9 units (3-0-6); first, second terms. Prerequisite: Ch 125 abc; or Ph 125 abc; or an introductory course in statistical mechanics; or some substantial equivalent of the preceding; or the consent of the instructor.* A course concerning advanced topics in equilibrium and non-equilibrium statistical mechanics. The content will vary somewhat from year to year, and typically may include application of information theory theorems to statistical physics, cluster expansions of dilute gases, theory of ionic solutions, spatial correlation functions, and lattice statistics. Given in alternate years. Not offered in 1970-71. Instructor: Pings.

Ch 224 abc. Special Topics in Magnetic Resonance. *4 units (2-0-2); first, second, third terms.* The principles of nuclear magnetic resonance will be discussed. Emphasis will be placed on the theoretical background behind various types of nuclear magnetic resonance experiments, the theory of interaction between nuclear spins and their dynamical coupling to lattice degrees of freedom. Novel applications of n.m.r. to current problems of interest in physics, chemistry, and biology will also receive attention. Texts: *The Principles of Magnetic Resonance,* Slichter, and *Principles of Nuclear Magnetic Resonance,* Abragam. Not offered in 1970-71. Instructor: Chan.

Ch 226 abc. Molecular Quantum Mechanics. *9 units (3-0-6); second, third, and first terms. Prerequisite: Ch 125 a and concurrent registration in Ch 125 b or equivalent.* The basic material is the electronic structure of atoms and molecules. The first term concentrates on the elements of group theory important for molecular quantum mechanics and upon the methods used to obtain *ab-initio* electronic wave functions for atoms and molecules. The foundations, properties, and applications of the Hartree-Fock method will be stressed. The second term emphasizes the use of perturbation theory in molecular quantum mechanics and the reduction of the N-body problem into a set of effective two-body equations. In addition, the formalism of second quantization with some of its applications will be discussed. This term also includes a discussion of the theory of Rayleigh and Raman scattering and optical rotation. Various advanced topics will be covered in the third term. The a and b terms are offered in the winter and spring quarters, respectively, and the c term in the fall. Instructors: Goddard, McKoy.

Ch 227 abc. Dynamics of Atomic and Molecular Energy States. *9 units (3-0-6). Prerequisite: Ch 125 or equivalent.* Topics in nonsteady state quantum mechanics comprise the basic course material first term. A summary of exact general relations and approximate methods relating to time-dependent quantum mechanics will be given. This, in addition to a semi-classical treatment of the absorption and emission of radiation will provide the basis for an examination of the processes by which transitions occur between atomic and molecular energy states. In the second term topics of current interest such as resonant and nonresonant energy and particle transfers, relaxation phenomena, optical pumping and level crossing will be examined. A formal treatment of elastic and inelastic scattering will be given in the third term, with an emphasis on applications to current research in elementary processes, including the determination of potential energy surfaces, studies of particle impact excitation processes, and chemical reactions. Not offered in 1970-71. Instructors: Beauchamp, Chan, Kuppermann.

Ch 229 abc. X-Ray Diffraction Methods. *6 units (2-0-4); first, second, third terms. Prerequisite: Ch 129 abc or equivalent.* An advanced discussion of the techniques of structure analysis by X-ray diffraction. Topics covered include protein crystallography, direct phase analysis methods, lattice vibrations, and refinement and assessment of accuracy of structure determination. Given in alternate years. Offered in 1970-71. Instructors: Dickerson, Hughes, Marsh.

Ch 242 ab. Chemical Synthesis. *4 units (2-0-2); first and second terms. Prerequisite: Ch 41 abc.* The concepts of synthetic planning will be developed through the analysis of recorded syntheses. The methodology of the organization of a complex set of reactions so as to accomplish a chosen goal will be examined with the aid of examples of bio-organic, organic, and organometallic interest. Instructor: Ireland.

Ch 244 ab. Molecular Biochemistry. *6 units (3-0-3); first, second terms.* The chemistry of enzyme reactions with special emphasis on modern methods for elucidating the mechanisms of enzyme action and the influence of enzyme structure on biological function. Enzymes with a wide variety of functions will be considered; e.g., peptidases, oxidases, reductases, phosphatases, enzymes involved in the synthesis of nucleic acids, and other important biosynthetic processes. Techniques discussed for elucidation of mechanisms will include kinetic studies, tracer techniques, studies of model systems, methods for isolation, purification, and determination of the structure of the enzyme, and the effect of structural modification on enzyme function. The molecular basis of biological control mechanisms will also be considered. Instructor: Raftery.

Ch 246 abc. Structures and Reactions of Organic Compounds. *4 units (2-0-2); first, second, third terms. Prerequisites: Ch 41 abc, Ch 21 abc.* Special methods for study of organic compounds and reactions. Topics discussed vary from year to year but usually include applications of the molecular orbital approach and nuclear magnetic resonance spectroscopy to problems of structure and reactivity. Seminar-type format. Given in alternate years. Not offered in 1970-71. Instructor: Roberts.

Ch 247 ab. Organic Reaction Mechanisms. *6 units (2-0-4); first, second terms.* Various tools for the study of organic reaction mechanisms will be discussed with major emphasis on kinetic methods. Not offered in 1970-71. Instructors: Bergman, Hammond.

Ch 254 ab. The Chemistry of Amino Acids, Peptides, and Proteins. *6 units (2-0-4); second, third terms. Prerequisite: Ch 41 abc.* A discussion of the chemical reactions, structures, and functions of amino acids, peptides, and proteins. Given in alternate years. Not offered in 1970-71. Instructor: Schroeder.

Ch 258. Immunochemistry. *8 units (0-5-3); second term. Prerequisite: Bi 114 and consent of instructor.* Essentially a laboratory course involving the basic methodology used in immunochemistry. Informal lectures and discussion will be scheduled as needed. The laboratory work will be based primarily on *Methods in Immunology,* by Campbell, Garvey, Cremer and Sussdorf, and related special selected publications. Instructors: Campbell, Garvey, and associates.

Ch 280. Chemical Research. *Offered to Ph.D. candidates in chemistry.* The main lines of research now in progress are:

In physical chemistry, chemical physics, and inorganic chemistry —

- Electronic structures of simple molecules and molecular fragments.
- Low-energy electron scattering.
- Spectroscopic studies of the chemistry of free radicals trapped at low temperatures.
- Kinetics of chemical reactions including photochemical reactions.
- Experimental and theoretical molecular kinetics.
- Reactions in crossed molecular beams.
- Determination of the structure of crystals by the diffraction of X rays.
- Application of quantum mechanics to chemical problems.
- Molecular structure by spectroscopic methods.
- Nature of the metallic bond and the structure of metals and intermetallic compounds.
- Electron spin and nuclear magnetic resonance.
- Distribution of chemical compounds between immiscible phases.
- Kinetics and mechanics of electrode reactions.
- Inorganic and analytical methods.
- Bonding in and structures of transition-metal complexes.
- Gas-phase ion chemistry.
- Nuclear spin relaxation.

In organic chemistry —

- Mechanisms of organic reactions in relation to electronic theory.
- Structural elucidation and biosynthesis of natural products.
- Total synthesis of natural products.
- Chemistry and reaction mechanisms of metallocenes.
- Isotope effects in organic and biochemical reactions.
- Chemistry of small-ring carbon compounds.
- Application of isotopic tracer and nuclear magnetic resonance techniques to problems in organic chemistry.
- Chemistry of non-benzenoid aromatic compounds.
- Relation of structure to reactivity of organic compounds.

Organic chemistry of metal chelates.
Solution photochemistry.
Reactions of free radicals in solutions.

In chemical biology —

Molecular structure of proteins by X-ray crystallography.
Chemical studies of enzyme structure and function.
Applications of n.m.r. to chemical biology: enzyme-substrate interactions, polynucleotide interactions and structure, membrane structure.
Physical chemistry of nucleic acids; studies of gene structure and function.
Sequence determination of proteins.
Genetics and chemistry of the abnormal hemoglobins.
Chemical studies of specific biological receptors.
Mechanism of antigen-antibody reactions and the structure of antibodies.
Spectroscopic studies in photobiology.
Magnetic and spectroscopic studies of iron-containing proteins.
Structure of biological membranes.
Conformation properties of oligonucleotides and polynucleotides.
Mechanisms of ion transport.

Ch 290 abc. Chemical Research Conference. *First, second, third terms.* These conferences consist of reports on investigations in progress in the chemical laboratories and on other researches which are of current interest. Seminars in the special fields (immunochemistry, analytical chemistry, crystal structure, chemical physics, organic chemistry, and inorganic chemistry) are also held.

Civil Engineering

UNDERGRADUATE SUBJECTS

CE 10 abc. Structural Analysis and Design. *9 units (3-0-6); first, second, and third terms. Prerequisites: AM 97 abc.* Analysis of lumped-parameter structural systems, including the basic concepts of relaxation. The design of structural components using such materials as steel and reinforced concrete. Instructors: Staff.

CE 17. Civil Engineering. *9 units (3-0-6); third term. Prerequisite: Senior standing.* Selected comprehensive problems of civil engineering systems involving a wide variety of interrelated factors. Instructors: Staff.

ADVANCED SUBJECTS

CE 105. Introduction to Soil Mechanics. *9 units (2-3-4); first term. Prerequisite: AM 97.* A general introduction to the physical and engineering properties of soil, including origin, classification and identification methods, permeability, seepage, consolidation, settlement, slope stability, lateral pressures and bearing capacity of footings. Standard laboratory soil tests will be performed. Text: *Principles of Soil Mechanics*, Scott. Instructor: Scott.

CE 115 ab. Soil Mechanics. *9 units (3-0-6); first term. 9 units (2-3-4); second term. Prerequisite: CE 105, or equivalent, may be taken concurrently.* A detailed study of the engineering behavior of soil through the examination of its chemical, physical and mechanical properties. Classification and identification of soils, surface chemistry of clays, inter-particle reactions, and their effect on sediment deposition and soil structure. Permeability and steady state water flow, transient flow and consolidation processes, leading to seepage and settlement analyses. In the second term, attention is given to stress-deformation behavior or soils, elastic stability, failure theories, and problems of plastic stability. Study is devoted to the mechanics of soil masses under load, including stress distributions and failure modes of footings, walls, and slopes. Laboratory tests of the shear strength of soils will be performed. Text: *Principles of Soil Mechanics,* Scott. Instructor: Scott.

CE 121. Analysis and Design of Structural Systems. *9 units (0-9-0); third term. Prerequisite: AM 112 ab.* The analysis and design of complete structural systems. In general, students will work on a single problem for the entire term. The problem may be primarily one of analysis or one of design. Instructors: Staff.

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: Housner, Jennings.

CE 130 abc. Civil Engineering Seminar. *1 unit (1-0-0); each term.* Conferences participated in by faculty and graduate students of the Civil Engineering department. The discussions cover current developments and advancements within the fields of civil engineering and related sciences, with special consideration given to the progress of research being conducted at the Institute.

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 spread and combined footings, mats, piles, caissons, retaining walls, cofferdams, and methods of underpinning. Instructor: Scott.

CE 180. Experimental Methods in Earthquake Engineering. *9 units (1-5-3); first term. Prerequisite: AM 151 abc or equivalent.* Laboratory work involving design, calibration, and performance of basic transducer and recorder types suitable for the measurement of strong earthquake ground motion, and of structural response to such motion, including a consideration of data processing techniques. Study of principal methods of dynamic tests of structures including generation of test forces and measurement of structural response. Instructors: Hudson, Iwan.

CE 181. Principles of Earthquake Engineering. *9 units (3-0-6); second term.* Characteristics of potentially destructive earthquakes from the engineering point of view. Includes a consideration of: determination of location and size of earthquakes; earthquake magnitude and intensity; frequency of occurrence of earthquakes; seismic risk maps, and techniques of seismic regionalization; engineering implications of geological earthquake phenomena, including earthquake mechanisms, faulting, fault slippage and the effects of local geology on earthquake ground motion; characteristics of ground motions; seismic sea waves and their damaging effects; socio-economic aspects of earthquakes such as cost factors in earthquake-resistant design, disaster planning; and the implications of earthquake prediction. Instructors: Hudson, Housner.

CE 182. Structural Dynamics of Earthquake Engineering. *9 units (3-0-6); third term. Prerequisite: AM 151 ab.* Response of structures to earthquake ground motion; influence of physical parameters on the response; spectrum techniques; influence of plastic deformations; earthquake excitation as a random process; nature of building code requirements and their relation to actual behavior of structures; observed effects of earthquakes on structures; earthquake behavior of special structures such as nuclear reactor containment structures, long-span suspension bridges, and fluids in tanks and reservoirs; earthquake design criteria. Instructors: Housner, Jennings.

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 212 abc. Advanced Structural Mechanics. *9 units (3-0-6); each term. Prerequisite: AM 112 abc or equivalent.* Advanced methods of structural analysis applied to problems involving space frames, plates, shells and finite element models of continuous structures. Instructors: Staff.

CE 300. Civil Engineering Research.

For courses in Environmental Engineering Science and Hydraulics see separate sections.

Computers and Machine Methods of Computation

(See courses listed under Information Science)

Economics

UNDERGRADUATE SUBJECTS

Ec 4 ab. Economic Principles and Problems. *6 units (3-0-3); first and second terms, or second and third terms.* A course in economic theory, institutions, and problems. The first half stresses analysis of money, national income, economic growth, and business fluctuations. The second half emphasizes the understanding of wages, prices, and profits in individual industrial and farm enterprises as well as international economic relations. Instructors: Staff.

Ec 13. Reading in Economics. *Units to be determined for the individual by the department. Not available for credit toward humanities-social science requirement.*

Ec 18. Industrial Organization. *7 units (3-0-4); third term.* After outlining the historical background of industry with the economic changes involved, this subject surveys the major problems facing management, especially in factory operations. The principal topics included are organization, plant layout, costs and budgets, methods, time and motion study, production control, labor relations, and wage scales. Instructor: Gray.

Ec 48. Introduction to Industrial Relations. *9 units (3-0-6).* This course stresses the personnel and industrial relations functions and responsibilities of supervisors and executives. The history, organization, and activities of unions and the provisions of current labor legislation are included. The relationships of a supervisor or executive with his employees, his associates, and his superiors are analyzed, and the services which he may receive from the personnel department are examined. The course also discusses the use of basic tools of supervision. Instructor: Gray.

Ec 98 abc. Senior Research and Thesis. Senior majors wishing to undertake a research project and to prepare a paper for presentation to interested faculty and fellow students may elect a variable number of units, not to exceed 12 in any one term, for such work under the direction of some member of the economics faculty. Consent of the instructor.

ADVANCED SUBJECTS

Ec 100 abc. Business Economics. *9 units (3-0-6); first, second, third terms. Open to graduate students.* This course endeavors to bridge the gap between engineering and business. It is primarily intended for technically trained students who wish, sooner or later, to take advantage of opportunities in industry beyond their strict technical fields. The broad assumptions in the course are that technical training is an excellent approach to positions of general responsibility in business and industry, and that technically trained men going into industry can make significant contributions to the improved functioning of the economy. The principal divisions of the subject matter of the courses are: 1) managerial accounting and information flows, 2) business finance, 3) quantitative technique and business decisions, 4) economic applications to business, and 5) systems analysis. This treatment provides a description of the industrial economy about us and of the latest management techniques. The points of most frequent difficulty are given special study. Not offered in 1970-71.

Ec 106 abc. Business Economics (Seminar). *Units by arrangement; first, second, third terms. Open to graduate students.* This seminar is intended to assist the occasional graduate student who wishes to do special work in some part of the field of business economics or industrial relations. Special permission to register for this course must be secured from the instructor. Instructor: Gray. *Not available for credit toward humanities-social sciences requirement.*

Ec 110. Industrial Relations. *9 units (3-0-6); first term. Not open to students who have taken Ec 48, Introduction to Industrial Relations.* An introductory course dealing with basic problems of employer-employee relationships and covering the internal organization of an enterprise, the organization and functions of unions, and the techniques of personnel administration with emphasis on the problems of setting wage rates. Instructor: Gray.

Ec 111. Business Cycles and Governmental Policy. *9 units (3-0-6); second term.* A study of the nature, causes, and possible control of economic fluctuations with special emphasis on the interrelationship of business cycles and such fiscal matters as national debt control, national budgetary control, and the maintenance of high levels of employment, production, and purchasing power. The course also integrates the international problems of war, reconstruction, trade, and investment with the analysis of business cycles and internal fiscal policies in order to provide a unified theory of national and international equilibrium. Not offered in 1970-71.

Ec 112. Modern Schools of Economic Thought. *9 units (3-0-6); third term.* A study of economic doctrine in transition, with particular emphasis on the American contribution. Against a background of Marshall and Keynes, a critical examination will be made of the institutional, collective, quantitative, social, experimental, and administrative schools of economics. Not offered in 1970-71.

Ec 113. Reading in Economics. *Same as Ec 13 but for graduate credit.*

Ec 115. Seminar on Population Problems. *9 units (3-0-6); third term. Prerequisite: Ec 4.* This seminar will be concerned with (1) the causes of rapid population growth, both in the West in the 18th and 19th centuries and in the less developed countries today; (2) the relation between population growth and economic development; (3) the problem of reducing the rate of growth through control of fertility. Consideration will also be given to the current situation in the United States: what is happening to the birth rate, what are the economic and social implications of continuing population growth, how birth control might contribute to the solution of the poverty problem. Instructor: Sweezy.

Ec 116. Contemporary Socioeconomic Problems. *9 units (3-0-6). Prerequisite: Ec 4 ab.* An analytical investigation of the economic aspects of certain current social issues. Topics to be discussed include the economics of education, medical care systems, urban affairs and the welfare system. Part of the instructional content of the course will be provided by field investigations and outside visitors. Instructor: Noll. Not offered in 1970-71.

Ec 117. Problems of Urban Society. *9 units: (3-0-6).* A description of some of the significant urban problems of contemporary America and an investigation of alternative policies. The problems considered include race relations, poverty, public education, crime, housing, urban planning, the public administration of cities and local politics and finance. Stress is placed on field trips and individual student research on specific problems in the Pasadena area. This course emphasizes economic theory less than does Ec 116. Instructor: Oliver. Not offered in 1970-71.

Ec 118. Environmental Economics (same as Env. 118). *9 units (3-0-6); first term. Prerequisites: Ec 4 ab and Env 1 or permission of instructor.* 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. Topics include (1) theory of externalities; (2) economic analysis of current and proposed regulatory policies to restrict pollution; (3) the application of economic planning tools such as capital budgeting, linear programming, cost-benefit analysis and input-output analysis to specific environmental management problems (such as water supply, solid waste disposal, smog control devices, health effects of air pollution, etc.); and (4) comprehensive environmental planning for coordinated use of environmental resources and for rational allocation of funds for environmental improvement. Instructor: Dohan.

Ec 120. International Economic Theory. *9 units (3-0-6); third term. Prerequisite: Ec 4 ab.* An investigation of the factors affecting the exchange of goods and services and the flow of capital between markets. Major issues include the determination of international values, the gains from trade and their division among major trading areas, the theory of economic integration, and the problems of foreign-exchange-rate and balance-of-payments adjustments. Theory is stressed in this course. Instructor: Oliver. Not offered in 1970-71.

Ec 121 ab. Price Theory and Industrial Organization. *9 units (3-0-6); first and second terms. Prerequisite: Ec 4 ab or equivalent.* A theoretical analysis of the price system, with special reference to the nature and problems of the U.S. economy. The course includes 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. The second term deals with questions of industrial organization such as economics of scale, elasticity of demand, and conditions of entry in a highly quantitative way. Instructor: Davis.

Ec 122 a. Econometrics. *9 units (3-0-6). Prerequisite: Ma 112 a.* The application of statistical techniques to the analysis of economic data. The first part of this course deals with the statistical theory and methods most useful to economists and to other social scientists. The second part is a survey of important empirical studies in the estimation of functional relationships derived from economic theory, such as supply and demand functions, the behavioral relationships determining investment and personal consumption expenditures, and relationships useful for forecasting future levels of economic activity. Instructor: Grether.

Ec 122 b. Economic Research. *Units to be determined by the instructor: maximum of 9 units. Prerequisites: Ec 122 a and consent of the instructor.* Advanced work on a tutorial basis on specific econometric problems.

Ec 123. The Russian Economy. *9 units (3-0-6); third term.* A study of the Russian soviet economic system and a comparison of the Russian economy with the economics of Western Europe and the United States.

Ec 124 a. Theory and Problems of Economic Development. *9 units (3-0-6). Prerequisites: Economics 4 a and 4 b or consent of the instructor.* A systematic survey of the theories of economic growth and of the different historical paths to development with special emphasis on the role of technological change, capital accumulation, economic planning, population growth, investment criteria, foreign aid, and educational, fiscal and monetary policies in the development process. Instructor: Frederick.

Ec 124 b. Planning for Economic Development: Theory and Case Studies. *9 units (3-0-6).* Theoretical methods of economic planning, techniques of evaluation of investment projects and foreign aid programs, critical analysis of planning methods and development policy currently used in Latin America. Case studies of the development programs in Latin America and Africa. Instructor: Frederick.

Ec 125 ab. The Economics of International Relations. *9 units (3-0-6). No prerequisite.* An examination of the economic factors which influence relations among nations. Among the topics discussed are international banking and business, the pattern of international trade, payments and investments, economic warfare, the international gold standard, the International Monetary Fund, the World Bank, the European Common Market, the General Agreement on Tariffs and Trade, the Organization for Economic Cooperation and Development, the dollar crisis and the American Foreign Aid program. The foreign economic policy of the United States is analyzed in some detail. This course emphasizes economic theory less than does Ec 120 and has no prerequisite.

Ec 126 ab. Money, Income, and Growth. *9 units (3-0-6); first and second terms.* Open to students who have taken Ec 4 ab and to other qualified students with the consent of the instructor. This course starts with an intensive study of Keynes' "General

Theory of Employment" and then goes on to post-Keynesian developments in the theory of income, consumption, investment and growth. The course also covers the theory of wages and productivity and the relation of technical progress to increases in productivity and real income. It deals with economic policy as well as economic theory, especially the application of monetary, fiscal, and other policies to problems of inflation, depression, unemployment, automation, and growth. Instructor: Sweezy.

Ec 127 abc. Problems in Economic Theory (Seminar). *Units by arrangement; first, second, third terms. Prerequisite: 126 or its equivalent.* Consideration of selected topics in economic theory. Instructors: Members of the staff and guest lecturers.

Ec 128 abc. New Technology and Economic Change. *9 units (3-0-6).* At the macro-economic level this course will be concerned with the role of new technology in economic growth and in international trade. At the micro-economic level it will be concerned with an examination of the factors making for efficient conduct of research and development activities, with the problems involved in transferring technology between firms and between countries, and with various public policy issues that arise out of the production and dissemination of technological knowledge. Instructor: Klein.

Ec 129 ab. Economic History of the United States. *9 units (3-0-6).* An examination of certain analytical and quantitative tools available to the economic historian and their application to a study of the process of American economic development. Instructor: Davis.

Ec 150. Independent Study on Population Problems. *Units to be arranged. Prerequisite: Ec 115 or its equivalent.* This course is designed to encourage study on a broad range of problems covering the technological, economic, demographic, sociological, political, and biological aspects of population growth, movement, and density. Instructors: Sweezy, H. Brown, Bonner, Scudder, and Munger. *Not available for credit towards humanities-social sciences requirement.*

Electrical Engineering

UNDERGRADUATE SUBJECTS

EE 3. Introduction to Solid State Electronics. *6 units (3-0-3); first term.* An introduction to the significant concepts of modern electronic devices such as diodes, junction and field effect transistors, etc. Topics will include: conductors, energy barriers, junctions, and rectification. The operating principles of transistors and transistor-like devices. Instructor: Humphrey.

EE 4. Introduction to Digital Electronics. *6 units (2-0-4); second term.* An introduction to the significant concepts and techniques of modern digital integrated electronic circuitry. The formulation of logical equations and their realization in hardware. Binary arithmetic and its implementation with logical functions. The course concludes with the design and construction of a simple digital computer. Instructor: Mead.

EE 5. Introduction to Linear Electronics. *6 units (2-0-4); third term.* An introduction to the significant concepts of modern linear electronic circuitry. A. C. circuit analysis; networks and their characterization in frequency and time domain. Amplifier, gain, frequency response. The use of operational amplifier to synthesize function of input variables. Power, dynamic range and the design of power output amplifiers. Instructor: Mead.

EE 9. Solid State Electronics Laboratory. *6 units (1-3-2); second and third terms. Prerequisite: EE 3. 6 units credit allowed toward freshman laboratory requirement.* An introductory laboratory designed to illustrate the principles of modern electronic devices and modern electronic instrumentation. Experiments are designed to cover the range of sophistication from the fairly simple devices such as resistors or diodes to more complicated concepts such as the Hall Effect and drift-mobility. The student is afforded the opportunity of using a wide variety of modern electronic instruments including the campus-wide Citran computer system. Instructor: McCaldin.

EE 13 abc. Linear System Theory. *9 units (3-0-6); three terms. Prerequisites: Ma 1 abc and Ph 1 abc.* Introduction to the analysis of linear systems in both the time and frequency domain. Topics presented include loop and node equations, two terminal pair networks, Fourier and Laplace transforms, convolution, autocorrelation, feedback systems, flow graphs, noise and distributed linear systems. Instructor: Langmuir.

EE 14 abc. Electronic Circuits. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 1 abc, Ph 1 abc.* A course covering the general area of active devices and their circuit applications. Transistor and vacuum tube amplifiers, biasing, gain, frequency response, class A, B and C power output circuits and their limitations. Nonlinear electronics, diodes, rectifiers, mixers, switching circuits, saturation, power converters, etc. Texts: *Transistor Circuit Analysis,* Joyce and Clarke; *Electronic Fundamentals and Applications,* Ryder. Instructor: Martel.

EE 20 abc. Physics of Electronic Devices. *9 units (3-0-6); first, second, third terms. Prerequisite: Ph 2 abc.* The application of modern physical principles to materials and devices important in present technological applications. Topics include energy bands in solids, electrical properties of semiconductors, metals and dielectrics, semiconductor devices, plasmas, gas tubes, excitation and relaxation of electronic systems and reference to luminescence and stimulated emission. Instructor: Wilts.

EE 90 abc. Laboratory in Electronics. *3 units (0-0-3); each term.* An introductory laboratory normally taken in the junior year. The experiments are designed to acquaint the student with the techniques and the equipment used in electrical measurements. The characteristics of linear passive electrical circuits, the properties of electron devices and the behavior of simple linear and nonlinear active circuits are measured and compared with theoretical models. A maximum of six units may be used in satisfying the laboratory requirement of the Division of Engineering and Applied Science (see page 209). Instructors: Staff.

EE 91 abc. Experimental Projects in Electronic Circuits. *Units by arrangement; 6 units minimum each term. Prerequisite: EE 14 abc and EE 90 or equivalent. Recommend: EE 114 abc or IS 110 (may be taken concurrently).* Open to seniors; others only with consent of instructor. A general laboratory program designed to give the student an opportunity to do original projects in electronics and electronic circuits. Emphasis is placed upon the selection of significant projects, the formulations of the engineering approach, and the demonstration of a finished product as well as the use of modern electronic techniques. The use of integrated circuit elements, digital and analogue, is encouraged. Printed circuit board facilities are available. Text: Literature References. Instructor: Humphrey.

ADVANCED SUBJECTS*

EE 113 abc. Modern Optics. *9 units (3-0-6); first, second, third terms. Prerequisite: AM 95 abc.* The analysis of optical systems based on electromagnetic theory. Mode theory and functions for optical resonators and transmission structures, image formation and spatial filtering with coherent light, partial coherence and partial polarization, theory of dielectrics, theory and applications of holography and selected topics of research importance. Text: *Class notes and selected references.* Instructor: George.

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. Instructor: Middlebrook.

EE 131 abc. Physics of Semiconductors and Semiconductor Devices. *9 units (3-0-6); three terms.* Introduction to the concepts of semiconductor devices. Includes topics such as the solid state, electric properties of solids, Boltzmann and Fermi statistics, properties of regular arrays, band theory of crystals, electrons, holes, semiconductors, theory of p-n junctions and of semiconductor devices. Instructors: Mayer, McCaldin, and Mead.

EE 133 abc. Interaction of Radiation and Matter. *9 units (3-0-6); first, second and third terms. Prerequisite: Ph 125, its equivalent, or instructor's permission.* The interactions of coherent electromagnetic fields with a variety of atomic systems are considered. Topics discussed include: electron paramagnetic resonance of free ions and of ions in crystals, spin-lattice and spin-spin relaxation, quantization of EM fields and of lattice vibrations, photon-phonon scattering and stimulated Brillouin scattering, the theory of one and two-photon absorption, laser oscillators, non-linear optics and multifrequency interactions in crystals, spontaneous and stimulated Raman scattering, absorption and emission of radiation in semiconductors, selected applications. Instructor: Yariv.

EE 135 abc. Ferromagnetism. *9 units (3-0-6); first, second, and third terms. Prerequisites: EE 20 or Ph 113.* Review of current theories of ferromagnetism. Phenomenological treatment of magnetization using the Landau-Lifschitz equation to treat flux reversal, spin wave resonance and micromagnetics. Relaxation mechanisms. Applications of magnetic materials in modern technology. Ferromagnetism in all materials will be considered with the greatest attention being given to ferromagnetism in metals. Instructor: Wilts.

EE 151 abc. Electromagnetism. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 2 abc; AM 95 abc.* A course in theoretical electricity and magnetism, primarily for electrical engineering students. Topics covered include electrostatics, magnetostatics, Maxwell's equations, waveguides, cavity resonators, and antennas. EE 151 c will include topics on propagation in the ionosphere, propagation over the earth's surface, and modern microwave tubes. Text: *Electromagnetic Fields and Waves*, Langmuir. Instructor: Harp.

EE 155 abc. Electromagnetic Fields. *9 units (3-0-6); first, second, third terms. Prerequisite: EE 151 abc.* An advanced course in classical electromagnetic theory and its applica-

* See also Ge 152, page 348.

tion to guided waves, cavity resonators, antennas, artificial dielectrics, propagation in ionized media, propagation in anisotropic media, magnetohydrodynamics, and to other selected topics of research importance. Text: Course notes. Instructor: Papas.

EE 172 abc. Control Systems Theory. (Same as ChE 172 abc.) *9 units (3-0-6); first, second, third terms. Prerequisite: AM 95 abc or equivalent.* Linear feedback control systems. Frequency and time domain analysis. Stability. Synthesis using Bode diagrams, Nyquist plots, and root locus methods. Controllability and observability. Optimal control theory. Dynamic programming. The maximum principle. Distributed parameter systems. Linear and nonlinear estimation theory, Kalman filtering, nonlinear filtering. Methods of adaptive control. Applications of these methods in the analysis and synthesis of chemical, electrical, and mechanical systems will be studied. Instructors: Gavalas, Seinfeld.

EE 191. Advanced Work in Electrical Engineering. Special problems relating to electrical engineering will be arranged to meet the needs of students wishing to do advanced work. Primarily for undergraduates. Students should consult with their advisers before registering for this course.

EE 194. Microwave Laboratory. *9 units (1-4-4); third term. Prerequisite: EE 151 abc or Ph 106 abc, may be taken concurrently.* Selected laboratory experiments and related theory on microwave generation and amplification; measurements of impedance, frequency and power; properties of microwave cavities, waveguides, junctions, and irises. Open to undergraduates. Instructor: Harp.

EE 221 abc. Topics in Physical Electronics. *4 units (1-0-3); first, second, third terms.* Principles of electromagnetic interaction with solids and ionized gases and current applications. Content to vary from year to year. Typical topics are: microwave noise in electron beams, magnetic resonance and relaxation, cyclotron resonance, oscillations and waves in plasmas. Not offered in 1970-71.

EE 235. Special topics in Ferromagnetism. *9 units (3-0-6); first term.* A lecture series devoted to special topics of current interest in ferromagnetism. Instructors: Staff. Not offered in 1970-71.

EE 236 abc. Seminar in Ferromagnetism. *1 unit.* Meets once a week for discussing work on ferromagnetism in progress on campus and in the current literature. Instructors: Wilts, Humphrey.

EE 243 abc. Quantum Electronics Seminar. *6 units (3-0-3).* Advanced treatment of topics in the field of quantum electronics. Each weekly seminar consists of one lecture of a series on the elements of radiation theory, partial coherence, dispersion, nonlinear optics, laser media, and spectroscopy, followed by a discussion of a current research paper. Text: Class notes and selected references. Instructor: Yariv.

EE 255 abc. Boundary-Value Problems of Electromagnetic Theory. *9 units (3-0-6); first, second, third terms. Prerequisite: EE 155 abc, or equivalent.* This course presents the mathematical techniques (Fourier-Lamé method, integral equation method, variational principles) that are available for the solution of boundary-value problems arising from the study of antennas, waveguides, and wave propagation. Text: *Randwertprobleme Der Mikrowellenphysik,* Borgnis and Papas; also class notes. Instructor: Papas.

EE 291. Advanced Work in Electrical Engineering. Special problems relating to electrical engineering will be arranged to meet the needs of students wishing to do advanced work. Primarily for graduate students. Students should consult with their advisers before registering for this course.

Engineering

E 5. Laboratory Research Methods in Engineering and Applied Science. *6 units (1-3-2); second term; third term by special arrangement. 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. The experiments will be selected from such fields as fluid mechanics, elasticity and plasticity, dynamics and vibration, heat transfer, gasdynamics, combustion, materials science, environmental health, solid state electronics, biomedical engineering, information science, chemical engineering, etc. The student is given some choice in selecting experiments of particular interest to him. Instructors: Sturtevant and staff.

E 10 ab. Technical Presentations. *2 units (1-0-1); first and second terms.* A course concerned with oral presentations of technical material. Instructors: Clark, Burhans.

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. Instructor: Clark.

Engineering Graphics

Gr 1. Basic Graphics. *3 units (1-2-0); first term.* This course deals with the fundamental aspects of projective geometry and graphical techniques used by the scientist and engineer as an aid in spatial visualization, communication and in creative design. Emphasis is placed on the effective use of freehand sketching in perspective, orthographic projection and other useful forms of representation. The student's ability to visualize three-dimensional forms and spatial relationships is logically developed through a series of freehand problems followed by basic descriptive geometry solutions analyzing some of the general relationships which exist among points, lines and planes. Accuracy, neatness and clarity of presentation are encouraged throughout the course. Instructor: Welch.

Gr 7. Advanced Graphics. *Maximum of 6 units. Elective; second and third terms. Prerequisite: Gr 1.* Further study in the field of graphics as applied to engineering problem analysis and in design for production. Through a coordinated series of discussions, laboratory problems, and field trips the student is introduced to work in various branches of engineering as well as to some of the broad aspects of human engineering, aesthetics, and various economic factors as they affect design. Instructor: Welch.

Engineering Science

ADVANCED SUBJECTS

ES 101 abc. Nuclear Reactor Theory. *9 units (3-0-6); first, second, and third terms. Prerequisite: AM 95 abc or equivalent.* Fission and fusion systems; steady-state and transient chain reactions; the criticality condition; slowing down and diffusion of neutrons in multiplying and non-multiplying systems; effects of lattice structure; and reflectors; theory of control rods; elements of the rigorous theory of neutron transport.

ES 102 abc. Applied Modern Physics. *9 units (3-0-6); first, second, and third terms. Prerequisite: AM 95 abc or equivalent.* A comprehensive introduction to modern physics for engineering students. Topics covered include: atomic physics; introductory quantum mechanics; statistical mechanics; solid state physics; interaction of charged particles, neutrons and gamma rays with matter; nuclear stability; nuclear reactions; and nuclear fission. Applications such as lasers, semiconductors, and radiation shielding will also be discussed.

ES 103. Nuclear Radiation Measurements Laboratory. *9 units (1-4-4); second term. Prerequisite: Ph 2 abc.* A one-term laboratory course designed to familiarize students with basic nuclear detecting and measuring techniques. The instruments are used to determine the properties of various types of radiation and to observe the nature of their interaction with matter.

ES 104. Nuclear Energy Laboratory. *9 units (1-4-4); third term. Prerequisites: ES 103 a, ES 101 (may be taken concurrently).* Measurements associated with nuclear reactor parameters are made. Steady state neutron flux distributions in moderators and in a subcritical assembly are analysed. Dynamic techniques are also employed with the use of a pulsed neutron generator. Instructor: Shapiro.

ES 130 abc. Introduction to Classical Theoretical Physics I. *9 units (3-0-6); first, second, and third terms. Prerequisite: AM 95 abc, or equivalent.* Analytical mechanics (first term); electrodynamics (second and third terms). Instructor: Plesset.

ES 131 abc. Introduction to Classical Theoretical Physics II. *9 units (3-0-6); first, second, and third terms. Prerequisite: AM 95 abc, or equivalent.* Thermodynamics (first term); kinetic theory and classical statistical mechanics (second term); quantum statistical mechanics (third term). Not offered in 1970-71.

ES 200. Special Problems in Engineering Science. *By arrangement with members of the staff properly qualified graduate students are directed in independent studies in Engineering Science. Hours and units by arrangement.*

ES 201 abc. Neutron Transport Theory. *9 units (3-0-6); first, second, and third terms. Prerequisites: ES 101 abc and ES 102 abc, or equivalent.* Systematic treatment of the linear Boltzmann equation. Mono-energetic transport in purely absorbing media. Applications of the theory of singular integral equations to transport in scattering media. Neutron thermalization: classical theory of scattering, the Wigner-Wilkins kernel; quantum theory of thermal neutron scattering by atomic systems. Topics in resonance escape and reactor kinetics. Energy-dependent theory of pulsed neutron, neutron wave propagation, and diffusion length experiments. Instructors: Corngold, E. Cohen.

ES 204 abc. Hydrodynamics of Free Surface Flows. *9 units (3-0-6); first, second, and third terms. Prerequisites: Hy 101 abc, AM 113 abc and AM 125 abc, or equivalent.* Theory of surface waves in a dispersive medium. Infinitesimal waves and wave resistance of floating or submerged bodies. Ship hydrodynamics. Theory of planing surface and hydrofoil. Scattering and diffraction of surface waves. Geometrical wave approximation. Hydrodynamic stability. Nonlinear waves and existence theorems. Shallow-water waves. Open-channel flows and river waves. Flows with shear and stratification of density and entropy. Free streamline theory for jets, wakes, and cavities. General theory for curved obstacles; existence and uniqueness. Unsteady flows with jets and cavities. Instructor: Wu.

ES 205 abc. Theory of Solids. *9 units (3-0-6); first, second, and third terms. Prerequisite: Ph 125 abc or equivalent.* This course is mostly concerned with the theory of the thermal and electrical properties of solids at low temperatures. The theory of lattice dynamics, electronic states, and dynamics of electrons will be presented. Specific heat, thermal conductivity, thermoelectric effects, electrical conductivity, and superconductivity of metals and alloys will be treated in terms of the interactions of electrons, phonons, and magnons. Instructor: Tsuei.

ES 206 abc. Special Problems in Biological Engineering Science. *Renumbered Env 206 abc.*

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

UNDERGRADUATE SUBJECTS

En 1 abc. Literature of the Modern World. *9 units (3-0-6); first, second, third terms.* A study of literature relevant to interests which are contemporary as well as traditional, chosen from the Renaissance to the present. The course will emphasize literature as an experience, while at the same time considering the dynamic relation between ideas, conceptions of man, social movements and their literary expression and aesthetic formulation. Included will be such topics as Renaissance science and its effect on traditional values, eighteenth-century rationalism, the romantic reaction, the nineteenth-century hero, the impact of science on religion and literature, effects of reform and revolution, romantic theories of art, the movement toward "realism," the growth of relativism, the problems of engagement and identity, the anti-hero, and the modern concern with war and peace. The study will also involve a consideration of the principal literary forms: poetry, drama, narrative prose, and literary criticism. Frequent analytical and critical papers are assigned.

En 7 abc. Advanced Literature. *9 units (3-0-6); first, second, third terms.* A sequence of courses dealing with Western man's attitudes toward his experience as expressed in satire and comedy (first term), realism and idealism (second term), and in major works concerned with the conflicts of the individual and society (third term). Material for these courses is drawn from acknowledged literary classics of the Graeco-Roman world, the Renaissance, the Age of Enlightenment, the Romantic Age, and the contemporary world. Frequent critical papers are assigned. Cannot be taken for credit by students who have taken En 1 abc; required of all others.

En 11. Literature of the Bible. *9 units (3-0-6). Prerequisite: En 7.* A study of the Old and New Testaments, and the Apocrypha, exclusively from the point of view of literary interest. The history of the English Bible is reviewed, and attention is brought to new translations. Opportunity is offered for reading modern fiction, poetry, and drama dealing with Biblical subjects.

En 12 abc. Debating. *4 units (2-0-2).* A study of the principles of argumentation; systematic practice in debating; preparation for intercollegiate debates. Instructor: Wright. *Not available for credit toward humanities-social science requirement.*

En 13. Reading in English. *Units to be determined for the individual by the department. Prerequisite: En 1 or En 7.* Collateral reading in literature and related subjects, done in connection with regular courses in English or history, or independently of any course, but under the direction of members of the department. *Not available for credit toward humanities-social science requirement.*

En 15 abc. Journalism. *3 units (1-0-2); first, second, third terms.* A study of the elementary principles of newspaper writing and editing, with special attention to student publications at the Institute. Instructor: Hutchings. *Not available for credit toward humanities-social science requirement.*

En 18. Modern Poetry. *9 units (3-0-6). Prerequisite: En 1 or En 7.* A study of three or four major poets of the twentieth century, such as Yeats, T. S. Eliot, and W. H. Auden. Modern attitudes toward the world and the problem of belief. Some consideration of recent theories of poetry as knowledge. Instructor: Clark.

En 20. Summer Reading. *Units to be determined for the individual by the department. Maximum 8 units. Elective.* Reading in literature, history, and other fields during summer vacation, books to be selected from a recommended reading list, or in consultation with a member of the staff. Critical essays on reading will be required. *Not available for credit toward humanities-social science requirement.*

En 21. Introduction to the Visual Arts. *9 units (3-0-6).* The vocabularies of analysis for the study of painting, sculpture and architecture. Approaches to study of art history, and case studies of selected art forms. Instructor: Wark.

En 50 a. Shakespeare. *9 units (3-0-6); second term. Prerequisite: En 1 or En 7.* A study of some of the principal plays of Shakespeare. The course will concentrate upon the great tragedies, along with significant examples of the other dramatic genres. (Cannot be taken for credit by students who have credit for En 7 b before 1968.)

En 50 b. Shakespeare. *9 units (3-0-6); second term. Prerequisite: En 50 a.* Further study of plays of Shakespeare. The emphasis of this course will be upon types of comedy and representative chronicles, with consideration of some of the tragedies not covered in En 50 a.

ADVANCED SUBJECTS

En 100 abc. Seminar in Literature. *9 units (2-0-7); first, second, third terms. Prerequisite: En 1 or En 7.* The novels and novelists, European and English, of the late 19th and 20th centuries. A background to the modern novel will be provided and such topics as symbolism and decadence, realism and experiment will be investigated. While surveying the development of the modern novel, the course will tend to concentrate on such major figures as Joyce, Conrad, Kafka, Mann, and Lawrence. Instructors: Mayhew, D. R. Smith.

En 102 ab. Linguistics. *9 units (2-1-6); first, second terms.* An intensive introduction to the fundamental concepts and methods of current structural study of natural language (exemplified largely through English). Primary focus on three levels of linguistic analysis: (1) phonology, (2) morphology, and (3) syntax as descriptive and theoretical levels for the study, respectively, of (1) sound systems, (2) internal structure of words, (3) inter- and intra-phrase and sentence structure and relations, including transformational grammar. Emphasis on current models of linguistic structure and implications of linguistic study for understanding human mental behavior, involving review of current work in semantics and psycholinguistics. Discussion of fields of application (linguistics and the computer, language in society, pedagogical linguistics). Instructor: Dostert.

En 102 c. Topics in Linguistics. *9 units (1-2-6). Prerequisite: En 102 ab or equivalent.* A seminar-type course focusing on major aspects of language structure, models of linguistic description and functions of language. Problems in syntax, semantics, psycholinguistics (including experiments) and sociological and biological aspects of language. Participants are expected to concentrate on individual or small-group research projects. Instructor: Dostert.

En 110 abc. Development of the Modern Drama. *9 units (3-0-6); first, second, third terms. Prerequisite: En 1 or En 7.* En 110 a will trace the development of English and Continental drama from its medieval and Renaissance origin through French Classical Drama. En 110 b will include the 18th century "Age of Elegance," the Romantic Age and the 19th century to Ibsen. En 110 c will deal with leading British and Continental dramatists from Ibsen to the present. Special attention will be given to dramatic technique and to philosophical content. The three terms may be taken as a sequence or independently of each other. Instructor: Mandel.

En 119. Classical Literature in Translation. *9 units (3-0-6); first term. Prerequisite: En 1 or En 7.* Readings in English of outstanding Greek authors. The course will include a study of the major classical genres, emphasizing the development of comedy, tragedy, lyric poetry, and history, philosophy, and religion.

En 120. Medieval Continental Literature. *9 units (3-0-6); second term. Prerequisite: En 1 or En 7.* The Roman classics, the *Divine Comedy* of Dante, and the lyric poetry of the Middle Ages, will be considered in the light of the humane and religious traditions of Europe. Instructors: Zeigel, Cozart.

En 121. The Medieval Imagination in England. *9 units (3-0-6); spring term. Prerequisite: En 1 or En 7.* A course designed to examine the major literary and cultural developments in England before and after the Norman Conquest, with special attention to Chaucer and the fourteenth century. The major forms — epic, romance, lyric, and drama — will be studied against their backgrounds in history, philosophy, painting and architecture. (Replaces En 124b. Credit for both is not allowed.) Instructor: Cozart.

En 122 abc. Senior Seminar. *9 units (2-0-7); first, second, third terms. For English majors or by special permission.* An examination of some major movements in literary history and criticism. These include neoclassicism (first term), romanticism (second term), and modern critical theories (third term).

En 125 ab. Sixteenth and Seventeenth Centuries. *9 units (3-0-6); first and second terms. Prerequisite: En 1 or En 7.* A course designed to acquaint the student with the principal figures and genres of the period from the Reformation to the Restoration. It includes the Humanists, Elizabethan poetry, non-Shakespearian drama, seventeenth century prose writers, metaphysical and cavalier poets, Dryden, and Milton. Instructor: H. D. Smith.

En 126. Eighteenth Century. *9 units (3-0-6). Prerequisite: En 1 or En 7.* Study of dominating figures of the eighteenth century, particularly Pope, Swift, and Johnson, and of the Restoration and eighteenth century drama.

En 127. Earlier English Novel. *9 units (3-0-6). Prerequisite: En 1 or En 7.* The novel from Richardson and Fielding to Scott and Jane Austen.

En 128. Victorian Novel. *9 units (3-0-6). Prerequisite: En 1 or En 7.* Critical study of chief Victorian novelists, in the context of their age. Social, political, and literary influences.

En 130. American Renaissance. *9 units (3-0-6); first term. Prerequisite: En 1 or En 7.* Study of the emergence of distinctively American literature and culmination in Emerson, Thoreau, Melville, and Hawthorne. Their influence on subsequent American writing.

En 131. The Gilded Age. *9 units (3-0-6); second term. Prerequisites: En 1 or En 7.* A survey of American literature from the post-Civil-War period to World War I. The course will illustrate the change and development of sensibilities, attitudes, and techniques in the works of authors rooted in the "genteel tradition" who are under exposure to the social and intellectual forces that predominate in the twentieth century. Emphasis will be placed on the writings of Mark Twain, Henry James, W. D. Howells, Henry Adams, Willa Cather, Stephen Crane, and Theodore Dreiser.

En 132. Hemingway and Faulkner. *9 units (3-0-6). Prerequisite: En 1 or En 7.* An investigation of the American novel since World War I which focuses on the polarities of attitude, theme, and technique represented by Hemingway and Faulkner. Instructor: Langston.

En 142. Black Literature and Culture. *9 units (3-0-6).* The course will begin with an introduction to the non-literary arts of American black culture (music, painting, folk-lore, rhetoric) and go on to a survey of American black literature with emphasis on those writers who have made their impact mostly since 1930: Langston Hughes, Richard Wright, Ralph Ellison, James Baldwin, Martin Luther King, Eldridge Cleaver, and LeRoi Jones. Instructor: Langston.

Environmental Engineering Science

UNDERGRADUATE SUBJECT

Env. 1. Engineering Problems of Man's Environment. *9 units (3-0-6); third term. Prerequisites: Ph 1 ab, Ch 1 ab and Ma 1 ab.* Man's physical environment includes air, water, and land, all of which are vital for survival as well as for esthetic enjoyment of life. By selected case studies, this course explores ways in which man is adversely changing his environment, ways in which these alterations are affecting him and other forms of life, and methods of engineering control. Typical problem areas are: air pollution, water pollution (ocean and inland), solid and industrial wastes, harmful trace elements, pesticides, thermal pollution, and land erosion. Instructors: Brooks, Friedlander, Morgan, Scudder and staff.

ADVANCED SUBJECTS

Env 100. Special Topics in Environmental Engineering Science. *6 or more units as arranged.* Special courses of reading, problems, or research for qualified undergraduates, or graduate students working for the M.S. degree. Instructors: Staff.

Env 112 ab. Hydrologic Transport Processes. *9 units (3-0-6); second and third terms. Prerequisites: AM 95 abc or AM 113 abc (may be taken concurrently); basic fluid mechanics; and some knowledge of elements of hydrology (may be satisfied by special reading assignments). Recommended: Hy 106.* The hydrologic cycle and its interrelations with man; statistical analysis and simulation of hydrologic data; floods; overall mass balance; physics of flow through porous media, including flow toward wells, ground-water recharge, drainage; sea water intrusion in aquifers and estuaries; transport and dispersion of solutes, sediments, and contaminants in rivers, lakes, ground water and estuaries; river morphology; heat exchange and density stratification in natural waters; thermal pollution control. Instructor: Brooks.

Env 118. Environmental Economics. *(Same as Ec 118.) 9 units (3-0-6); first term. Prerequisites: Ec 4ab and Env 1 or permission of instructor.* 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. Topics include: (1) theory of externalities; (2) economic analysis of current and proposed regulatory policies to restrict pollution; (3) the application of economic planning tools and input-output analysis to specific environmental management problems (such as water supply, solid waste disposal, smog control devices, health effects of air pollution, etc.); and (4) comprehensive environmental planning for coordinated use of environmental resources and for rational allocation of funds for environmental improvement. Instructor: Dohan.

Env 141. Applied Aqueous Solution Chemistry. *9 units (3-3-3); first term. Prerequisites: Ch 1 abc or equivalent; Ch 114 (may be taken concurrently).* Application of principles from chemical thermodynamics and kinetics and analytical chemistry to the study of the behavior of the important constituents of natural waters. The chemistry of solutions, heterogeneous processes, and oxidation-reduction reactions are applied to provide quantitative explanations for the chemical characteristics of various natural waters. Among the topics treated are metal-ion solubility controls, carbonate equilibria at ordinary temperatures and pressures, pH buffer systems in natural waters, ion-exchange and adsorption processes, mathematical and graphical treatment of chemical equilibrium data, and kinetics of some simple oxidation reactions under natural water conditions. The laboratory illustrates application of various techniques of measurement, including electrometry, spectrophotometry, and ion-exchange in the analysis of natural waters. Instructor: Morgan.

Env 142 ab. Applied Chemistry of Natural Water Systems. *9 units (2-3-4); second and third terms. Prerequisite: Env 141.* Detailed considerations of the application of chemical principles to the analysis of actual natural water systems and to the understanding and solution of specific chemical problems in areas such as water purification technology, water pollution control, and aquatic sciences. Among the topics dealt with are the chemical properties of streams, lakes, and ocean waters; colloidal phenomena in natural waters; chemical aspects of coagulation and flocculation; heterogeneous chemical processes of various kinds, such as adsorption from solution; corrosion and corrosion control processes; and the chemistry of water purification processes such as softening, ion-exchange, stabilization, and disinfection. Instructor: Morgan.

Env 144. Ecology. *6 units (2-1-3), second term.* Basic principles of ecology and ways in which human activities can influence natural populations, including the marine environment as affected by ocean waste disposal. Topics discussed include community structure, dynamics of populations, geochemical cycles, limiting factors, and microbial ecology. (May be taught in conjunction with parts of Env 145 a.) Instructor: North.

Env 145 ab. Environmental Biology. *10 units (2-4-4), second term; 9 units (3-0-6), third term. Prerequisites: Ch 41 abc or equivalent (may be taken concurrently).* An exposition of basic biological principles concerning interrelations between organisms, particularly those directly affecting man and his environment. Emphasis is placed on the influences of microorganisms as illustrative of the ways populations react on each other and condition the physical and chemical environment. Unique features of the terrestrial, freshwater, and marine environments are discussed and extensive reading is required, covering a broad scope of biological literature. Instructor: North.

Env 146 abc. Analysis and Design of Water and Wastewater Systems. *9 units (3-0-6); each term. Prerequisites: ME 17 ab, ME 19 ab, or equivalents.* A series of selected problems in the application of basic science and engineering science to water supply and treatment for municipal, industrial, and irrigation use; removal, treatment, and disposal of liquid and solid wastes; the theory of unit operations as applied to environmental systems; the designs of works; and economic aspects of projects. Instructor: McKee.

Env 150 abc. Seminar in Environmental Engineering Science. *1 unit (1-0-0).* Weekly seminar on current developments and research within the field of environmental engineering science, with special consideration to work at the Institute.

Env 155. Special Problems in Waste Management. *9 units (2-3-4); second term. Prerequisite: permission of the instructor.* Investigation of environmental pollution related to nuclear energy; the siting of steam-electric power plants; solid wastes from municipalities, industries, and agriculture; transportation of petroleum and other hazardous materials, and similar special situations, including detailed case studies of specific problems. Field trips to illustrative examples in Southern California. Instructor: McKee.

Env 156. Industrial Wastes. *9 units (3-0-6); third term. Prerequisite: Env 146 ab.* A study of the industrial processes resulting in the production of liquid wastes; the characteristics of such wastes and their effects upon municipal sewage treatment plants, receiving streams, and ground waters; and the theory and methods of treating, eliminating, or reducing the wastes. Instructor: McKee.

Env 160. Biological Fluid Flows: Hemorheology. *6 units (2-0-4); second term. Prerequisites: AM 95 abc, Hy 101 abc or equivalent.* The problems of measurement of bulk rheological properties of blood; the influence of the composition of the suspending medium on blood flow properties; the influence of the particulate nature of blood on its flow in narrow tubes and small blood vessels; the influence of cell deformation on flow through capillaries. Instructor: Wayland.

Env 170 ab. Behavior of Disperse Systems in Fluids. *9 units (3-0-6); first and second terms. Prerequisites: ME 19 ab, Ch 21 abc, or equivalents.* Studies of the mechanical and physicochemical behavior of particles in fluids with applications to gas cleaning, cloud physics, emulsion stability and water treatment. The first term is concerned primarily with stochastic problems including fluctuation theories of new phase formation, the theory of the Brownian movement, and theories of coagulation and convective diffusion. The second term deals with mechanical problems including impaction and sedimentation in flow systems, theories of filtration of particles from fluids, and experimental methods for measuring particle size distributions. Instructors: Friedlander, Morgan.

Env 203. Advanced Topics in Environmental Engineering Science. *Units by arrangement.* A course to explore new approaches which bear on environmental problems. The topics covered vary from year to year, depending on interests of students and staff. Visiting professors may present portions of this course from time to time. Instructors: Staff.

Env 206 abc. Special Problems in Biological Engineering Science. *Units by arrangement. 3 terms.* Special topics relating to the interplay between the engineering sciences and biological and medical sciences can be made the subject for directed study for properly qualified graduate students on an individual basis. Each year, however, one or more topics will be chosen for group discussions between students and interested faculty with a systematic series of lectures by faculty and visiting scientists and reports by the students. For example, in 1969-70 half of the year was spent studying blood flow and exchange processes in the kidney and half on the respiratory system. Instructors: Wayland, Friedlander, Baker, Frasher, Lang, and Meiselman.

Env 214 abc. Advanced Environmental Fluid Mechanics. *9 units (3-0-6); first, second and third terms. Prerequisites: Hy 101 or Ae 101, AMa 101 or AM 125.* Large scale motions in the oceans and atmosphere, air-water interface, wind generation of waves and currents, stratified fluids, internal waves, blocking, stratified withdrawal, jets and plumes, stratified flows in porous media, turbulent diffusion, mixing in the oceans and atmosphere, dispersion in rivers and estuaries. Applications to engineering problems of pollution control in air and water environments. Instructors: Lees, List.

Env 250. Advanced Environmental Seminar. *4 units (2-0-2); every term. Prerequisite: Permission of the instructor in charge.* 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: Brooks and staff.

Env 300. Thesis Research.

Other closely related courses (listed elsewhere) are:

ChE 103 abc	Transport Phenomena
ChE 172 abc	Control Systems Theory
ChE 203 ab	Interfacial Phenomena
Hy 101 abc	Fluid Mechanics

Hy 106	Experimental Hydraulics and Similitude
Hy 111	Fluid Mechanics Laboratory
Hy 113	Coastal Engineering
Hy 121	Advanced Hydraulics Laboratory
Hy 210 ab	Hydrodynamics of Sediment Transport
Hy 211	Advanced Hydraulics Seminar
Hy 213	Advanced Coastal Engineering

French

(See under Languages)

Geological Sciences

Geology, Geobiology, Geochemistry, Geophysics, Planetary Science

UNDERGRADUATE SUBJECTS

Ge 1. Physical Geology. *9 units (3-3-3); first term.* An introduction to the basic principles of the earth sciences, geology, geochemistry and geophysics in relation to materials and processes acting upon and within the earth. Consideration is given to: rocks and minerals; structure and deformation of the earth's crust; earthquakes; volcanism; and the work of wind, running water, ground water, the oceans, and glaciers upon the earth's surface with the aim of stimulating the student's interest in the geological aspects of the environment in which he will spend his life. Text: *Principles of Geology,* Gilluly, Waters, and Woodford. Instructors: Sharp and Teaching Fellows.

Ge 2. Geophysics. *9 units (3-0-6); second term. Prerequisites: Ge 1, Ma 2 a, Ph 2 a.* A selection of topics in the field of geophysics using, as fully as possible, the prerequisite background. Included are consideration of the earth's gravity and magnetic fields, geodesy, seismology, and the deformation of solids, tides, thermal properties, radioactivity, age determinations, the continents, the oceans, and the atmosphere. Observations followed by their analysis in terms of physical principles. Instructor to be named.

Ge 4. Introduction to Cosmochemistry and Nuclear Geophysics. *6 units (3-0-3); third term. Prerequisite: Consent of instructor.* An introductory course focusing on the information obtained by the laboratory study of natural samples, both terrestrial and extraterrestrial, using the techniques of modern chemistry and physics. Topics discussed include: the synthesis and abundances of elements; ages of the earth, the moon and the solar system; formation and chemical differentiation of objects in the early solar system; the chemical composition of lunar, terrestrial, and meteoritic material; the recent history of the moon and the meteorites as inferred by the study of the products of cosmic ray induced nuclear reactions. Instructor: Wasserburg.

Ge 5. Geobiology. *9 units (3-0-6); third term. Prerequisites: Ge 1, Ch 1, Bi 1, or consult instructor.* An examination, chiefly in biological terms, of processes and environments governing the origin and differentiation of secondary materials in the crust throughout the span of earth history. Consideration is given to the environmental influence of the change from a reducing to an oxidizing atmosphere upon the evolution of life processes and to the subsequent progression of organisms and organic activity throughout the oxidizing era as recorded in the sedimentary rocks of the earth's crust. Special attention is devoted to organic progression and differentiation in time and space in terms of environment. Instructor: Lowenstam.

Ge 40. Special Problems for Undergraduates. *Units to be arranged, any term.* This course provides a mechanism for undergraduates, other than freshmen, to undertake honors-type work in geologic sciences. By arrangement with individual members of the staff.

Ge 41 abc. Senior Thesis. *Units to be arranged.* Senior majors wishing to undertake some research and prepare a *suitable professional report* on some topic may elect a variable number of units, not to exceed 12 in any one term, for such work under the direction of some member of the Division faculty.

ADVANCED SUBJECTS

Courses given in alternate years are so indicated. Courses in which the enrollment is less than five may, at the discretion of the instructor, not be offered.

Ge 100. Geology Club. *1 unit (1-0-0); all terms.* Presentation of papers on research in geological science by the students and staff of the Division of the Geological Sciences and by guest speakers. Generally required of all senior and graduate students in the Division; optional for sophomores and juniors. Instructor: Albee.

Ge 102. Oral Presentation. *2 units (1-0-1); first, second, or third term.* Training in the technique of oral presentation. 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. The number of terms taken will be determined by the proficiency shown in the first term's work. Instructors: Burhans, Murray.

Ge 104 abc. Advanced General Geology. *9 units (4-2-3). Prerequisites: Ch 1 or 2, Ma 2, Ph 2.*

104 a. Mineralogy and Igneous Petrology. *First term.* Basic atomistic theory in the chemistry and physics of the crystalline state. Bonding forces in solids. Elements of crystallography. Solid state transformations. Systematics of silicate, oxide, carbonate minerals in terms of crystal structures, chemical composition and physical properties. Igneous phenomena and processes. Classification of igneous rocks. Phase equilibria in rock systems and the genesis of igneous rocks.

104 b. Sedimentary Rocks and Structural Geology. *Second term.* Sedimentary processes and environments. Sedimentary minerals and rocks. Principles of physical stratigraphy. Principles of paleontology and animal stratigraphy. Elements of structural geology. Instructors: Albee, Lowenstam, Allen.

104 c. Tectonics, Metamorphism, and Earth History. *Third term.* Major structural features and tectonic processes of the earth's crust. Metamorphic processes and rocks. Elements of the Phanerozoic history of the earth with emphasis on both faunal and physical history. Outlines and problems of the Precambrian history of the earth. Instructors: Allen, Albee, Silver.

Ge 105 abc. Geological Field Training and Problems. *6 units (0-6-0); first, second, and third terms. Prerequisite: Ge 104 abc should be taken concurrently.* Elementary field mapping techniques in stratigraphy and structural geology. Selected field problems designed to develop techniques and to establish an understanding of basic geologic relationships. Field trips to important examples of the local and regional geologic setting. Instructors: See Ge 104 abc.

Ge 111 ab. Invertebrate Paleontology. *10 units (2-6-2); second and third terms. Prerequisite: Ge 1.* Morphology and geologic history of the common groups of the lower invertebrates, with emphasis on their evolution and adaptive modifications. Second term: consideration of the higher invertebrate groups; preparation of fossils and problems of invertebrate paleontology. Instructor: Lowenstam.

Ge 114. Optical and X-ray Mineralogy. *10 units (3-6-1); second term. Prerequisite: Ge 104 a-105 a.* Methods of optical crystallography. Measurement of optical constants with the polarizing microscope. X-ray determination of lattice parameters and space symmetry. Characterization and identification of minerals by optical and X-ray methods. Systematic application of these methods to the study of important mineral groups, including feldspars, chain silicates, and sheet silicates. Instructor: Kamb.

Ge 115. Petrology and Petrography. Systematic study of rocks and rock-forming minerals with emphasis both upon the use of the petrographic microscope and megascopic identification; interpretation of mineral assemblages, textures, and structures; problems of genesis. Field trips will supplement laboratory study.

115 a. Igneous Petrology and Petrography. *10 units (3-6-1); third term. Prerequisites: Ge 114, Ch 24 b or 124 b or Ch 21 b.* 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 feldspar, pyroxene, amphibole, olivine, and feldspathoid mineral groups. Instructor: Albee.

115 b. Sedimentary Petrology and Petrography. *10 units (3-4-3); second term. Prerequisite: Ge 115 a.* The mineralogic and chemical composition, occurrence, and classification of sedimentary rocks; consideration of the chemical, physical, and biological processes involved in the origin, transport, and deposition of sediments and their subsequent diagenesis. Detailed consideration of structure, phase relations, composition and identification of clay minerals, carbonates, and Fe-Mn oxides. Laboratory study will include identification of clay minerals by X-ray diffraction. Instructor to be named.

115 c. Metamorphic Petrology and Petrography. *10 units (3-4-3); first term. Prerequisite: Ge 115 a.* The mineralogic and chemical composition, occurrence, and classification of metamorphic rocks; interpretation of mineral assemblages in light of chemical equilibrium and experimental studies. Detailed consideration of structure, phase relations, composition, and determination of the major metamorphic minerals. Instructor: Taylor.

Ge 121 abc. Advanced Field Geology. *10 units (0-8-2); first term; 10 units (0-8-2); second term; 10 units (0-8-2), third term. Prerequisites: Ge 104 abc, Ge 105 abc.* Interpretation of geologic features in the field, with emphasis on problems of the type encountered in professional geologic work. Advanced techniques of investigation are discussed. The student investigates limited but complex field problems in igneous, sedimentary, and metamorphic terranes. Individual initiative is developed, principles of research are acquired, and practice gained in field techniques, including the use of the plane table in geologic mapping. The student prepares reports interpreting the results of his investigations. Instructors: Staff.

Ge 122. Geophysical Field Studies. *10 units (3-5-2); first term. Prerequisite: Ge 105 (may be taken concurrently).* This course is a field program in an area of particular geological interest, using seismic refraction, gravity, and magnetic field measurements. Students participate in all phases of the program, e.g., station surveying, geophysical equipment operation, and interpretation of data. A final report, embodying calculations and interpretations is required. Instructor: Dix.

Ge 123. Summer Field Geology. *30 units (6 weeks); 40 units (8 weeks). Prerequisites: Ge 104 abc, Ge 105 abc.* Intensive field study of a 10-15 square mile area from a centrally located, temporary camp. Emphasis is placed on stratigraphic and structural interpretation, and on detailed mapping techniques, including the use of aerial photographs. Each student prepares a geologic map, stratigraphic and structural sections, and a complete geologic report. The work is performed under close supervision of regular staff members. The area chosen generally lies in a part of the Rocky Mountains, or the Basin and Range Province. The course is designed to complement the field training in southern California afforded by the regular school year courses, Ge 105 and Ge 121. The course begins the Monday following commencement (about June 15) and lasts for six-eight weeks. It is required at the end of the junior year of candidates for the bachelor's degree in the geology and geochemistry options; and, at the discretion of the staff, of candidates for other advanced degrees in the Division of Geological Sciences. Registration is limited to students regularly enrolled in the California Institute of Technology or to those entering the following term. Text: *Suggestions to Authors,* Fifth Edition. Instructors: To be designated.

Ge 126. Geomorphology. *9 units (3-0-6); second term.* Primarily a consideration of dynamic processes acting on the surface of the earth, and the genesis of land-forms. Instructor: Sharp. Offered in alternate years (1971-72).

Ge 130. Introduction to Geochemistry. *6 units (2-0-4); second term. Prerequisites: Ch 14, Ch 21 abc or Ch 24 ab, Ma 2 abc, Ph 2 abc, Ge 1.* A lecture and problem course on the application of chemical principles to earth problems, involving topics in stable isotopic geochemistry. Instructor: Epstein.

Ge 132. Chemistry of the Earth and Planets. *9 units (3-0-6); first term. Prerequisite: Permission of instructor.* A critical evaluation of what is known about the chemical composition of the planetary bodies in the solar system and the processes and time scales required for evolution into their present states. Topics include: survey of mechanisms of nucleosynthesis; solar system elemental abundances; formation times of planetary bodies; the chemical composition and evolution of the earth and moon; speculations on the compositions of other planets; composition and origin of planetary atmospheres. Instructor: Burnett. Offered in alternate years (1970-71).

Ge 135. Regional Geology of Southern California (Seminar). *5 units (2-0-3); second term. Prerequisites: Ge 104 abc, Ge 105 abc 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 137 ab. Laboratory Techniques in the Geological Sciences. *9 units (1-4-4); second and third terms. Prerequisite: Consent of instructors.* A series of laboratory experiments covering the important types of laboratory measurements made in modern geological and geochemical research. The emphasis will be placed on understanding the physical and chemical principles on which the measurements are based. X-ray, mass spectrometric, and counting techniques will be treated in detail. Instructors: Patterson, Burnett, and Epstein. Offered in alternate years (1970-71).

Ge 150. The Nature and Evolution of the Earth. *6 units (3-0-3).* Discussions at an advanced level of problems of current interest in the earth sciences. The course is designed to give graduate students in the geological sciences and scientists from other fields a broad sampling of data and thought concerning current problems. Students may enroll for any or all terms of this course without regard to sequence. Instructors: The staff and visitors. Offered by announcement only.

Ge 152. Radar Astronomy. *9 units (3-0-6) second term. Permission of the instructor.* This course covers techniques of radar astronomy and interpretations of observational results in terms of the physics of the target planet. Radar studies of Mercury, Venus, and Mars will also be described. Additionally it will provide an introduction to the design of radar experiments. Instructor: Goldstein.

Ge 153. Planetary Radio Astronomy. *9 units (3-0-6); third term. Permission of the instructor.* The interpretation of radio astronomy observations of the Moon, Mercury, Venus, Mars, and Jupiter in terms of the planets' surface properties and atmospheric characteristics. Thermal and non-thermal emission mechanisms in planetary atmospheres and surfaces will be discussed with particular emphasis toward the construction of mathematical planetary models which can be tested by all possible observational techniques including radio interferometry, planetary occultation, and radar astronomy. Instructor: Muhleman.

Ge 154. Atmospheric Physics. *9 units (3-0-6); second term.* Basic processes affecting the structure and composition of planetary atmospheres. Scattering, absorption, radiative transfer, convection, diffusion, thermal escape, atmospheric tides, geostropic motion. Observations of the earth, observations of the planets, theoretical models of planetary atmospheres. Instructor: Ingersoll.

Ge 155. Introduction to Planetary Science. *9 units (4-0-5); first term.* A broad survey course for undergraduates and graduates. The planets: their probable composition, physical state and dynamical behavior. Ground-based observations: spectroscopy, photometry, radio interferometry, radar mapping, observations from spacecraft. Theories of atmospheric structure, surface processes, internal history. Speculations on the origin and evolution of bodies in the solar system. Instructors: Ingersoll and staff.

Ge 160. Introduction to Modern Geophysics. *2 units (2-0-0).* Seminar on current topics in geophysics with emphasis on active research programs within the department. The course is designed to acquaint new graduate students with outstanding problems in geophysics and with current methods of investigation. Instructors: Staff, Anderson in charge.

Ge 166 a. Physics of the Earth's Interior. *9 units (3-0-6); second term. Prerequisite: AM 95 abc or AM 113 abc, or permission of instructor.* A study of current knowledge concerning the interior of the Earth using information from various earth-science disciplines. Interpretation of the fundamental data of seismology, gravity and heat flow using available high pressure laboratory data and equations of state with the aim of understanding the structure, composition and phase of the Earth's deep interior. Thermal history of the Earth. Internal constitution of the terrestrial planets.

Suitable for students in geology and as an elective in physics, astronomy and engineering. Instructor: Anderson.

Ge 166 b. Planetary Physics. *9 units (3-0-6); third term. Prerequisites: Ph 106 abc, AM 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 to be discussed include tidal friction, resonant orbits and rotation rates, gravitational fields of planets and satellites, dynamics of polar wandering and continental drift. Instructor: Goldreich. Not offered in 1970-71.

Ge 176. Elementary Seismology. *6 units (3-0-3); third term. Prerequisites: Ge 1, Ma 2 ab.* A survey of the geology and physics of earthquakes. Text: *Elementary Seismology,* Richter. Instructor to be named.

Ge 212 ab. Thermodynamics of Geological Systems. *10 units each term (3-0-7); first and second terms.*

212 a. *Prerequisites: Ch 124 ab or Ch 21 abc.* An advanced treatment of chemical thermodynamics using the methods of Gibbs, with emphasis on applications to geologic problems. Topics to be covered include heat flow and heat sources, high pressure 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. Instructor: Wasserburg. Offered in alternate years (1970-71).

212 b. *Prerequisite: 212 a.* Lectures and problems on the chemical and physical properties of aqueous solutions, with emphasis on the thermodynamic behavior of those electrolyte solutions important in nature. Topics to be covered include the effects of solution composition on mineral equilibria, Eh-pH diagrams, Debye Huckel theory, extension of thermodynamic data to high temperatures and pressures, nonideality in mixed-gas systems, and reaction kinetics in systems involving water. Results will be applied to problems of metamorphic pore fluids, the magmatic gas phase, and hydrothermal vein deposits. Text: *Thermodynamics,* Lewis, Randall, and Brewer. Instructor: Taylor. Offered in alternate years (1970-71).

Ge 213. Seminar, to be offered at pleasure of the staff on special topics and problems of current interest in the fields listed below. *5 units. Prerequisites dependent upon topics.* Offered by announcement only.

Ge 213 a—Mineralogy Seminar.
Ge 213 b—Petrology Seminar.
Ge 213 c—Geochemistry Seminar.
Ge 213 d—Geochronology Seminar.
Ge 213 e—Planetary Science Seminar.

Ge 214. Advanced Mineralogy. *10 units (3-3-4); offered in accordance with student interest. Prerequisite: Ge 115 abc.* Principles of optical and X-ray crystallography, developed on a fundamental basis. Study of modern optical and X-ray methods for determining and interpreting the crystallography, space symmetry, structure, and composition of the rock-forming minerals and mineral groups. Instructor: Kamb.

Ge 215 abc. Topics in Advanced Petrology. *Prerequisites: Ge 115, Ch 124.* (Alternate years.) Integrated lecture, laboratory, and seminar study of sedimentary, igneous, and metamorphic processes and their products. Laboratory and field studies will be pursued in close association with the classwork. Consideration of petrologic problems in terms of basic principles and modern approaches will be emphasized.

215 a. Advanced Sedimentary Petrology. *10 units (3-4-3); first term.* Not offered in 1970-71.

215 b. Advanced Igneous Petrology. *12 units (3-6-3); third term.* Instructor: Silver. Offered in alternate years (1971-72).

215 c. Advanced Metamorphic Petrology. *12 units (3-6-3); second term.* Instructor: Albee. Offered in alternate years (1971-72).

Ge 216. Nuclear Problems in Geology. *10 units (3-0-7); third term. Permission of instructor.* This course will cover a variety of topical material relating to nuclear processes which are of geologic importance. Topics to be covered include introductory discussion of theories of nucleosynthesis, naturally occurring and extinct radio-activities and their daughter products, isotopic anomalies, heat generation in the earth, cosmic ray induced nuclides, methods of absolute age dating, age determinations on meteorites and rocks, the geologic time scale, element redistribution in radioactive parent-daughter systems, and residence times and mixing processes for some model systems. Instructor: Wasserburg.

Ge 220 ab. Lunar and Planetary Surfaces. *9 units (4-0-5); second and third terms. Prerequisite: Consult with instructor.* Observational evidence pertaining to the surface geology and geophysics of the Moon, Mars, Mercury, and the Galilean satellites is covered at an advanced level along with brief consideration of the probable surface conditions on other planets. The interpretation of visible, infrared, and microwave observations is considered in the context of: (1) the surface processes likely to have been operative in the past as well as present, and (2) the likely optical properties of silicate mineral aggregates in extraterrestrial surface environments. Instructors: Murray, Shoemaker. Offered in alternate years (1971-72).

Ge 221. Shock Metamorphism. *3 units (0-2-1); third term. Prerequisite: Ge 115 a.* A series of laboratory lecture demonstrations are used to present to the student the terminal effects of shock waves in rock forming and meteoritic minerals such as produced by meteorite impact on planetary surfaces. Sample materials taken from terrestrial impact structures and laboratory shock experiments are examined by petrographic and X-ray techniques. Special emphasis is placed on relating the formation of shock-induced deformation structures and high pressure phases to a thermodynamic description of the shock process and the equilibrium phase diagram of the mineral system. Instructors: Ahrens, Shoemaker.

Ge 225 abc. Current Research in Planetary Science. Required attendance for all Planetary Science graduate students. Others welcome.

> **225 a. Student/Faculty Research Conference.** *1 unit (1-0-0); first term.* One hour per week informal review of current research by staff and students. Instructor: Ingersoll.
>
> **225 b. Selected Topics in Planetary Science.** *1 unit (1-0-0); second term.* Review of current research in selected area of chemistry, physics, or geology of moon, planets, or meteorites. Instructor: Muhleman.
>
> **225 c. Planetary Research with Spacecraft.** *1 unit (1-0-0); third term.* Review of

potential or recently-completed scientific exploration of the moon or planets by means of spacecraft. Instructor: Murray.

Ge 226. Observational Planetary Astronomy. *9 units (3-0-6): first term.* Observational papers in the planetary astronomy literature will be critically analysed to introduce the use of telescopes and other optical instruments for measurement of the physical and chemical properties of the solar system. The nature of 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. Instructor: Westphal.

Ge 229. Glaciology. *9 units (3-0-6); second term.* Origin and behavior of the North American ice sheet, physical conditions and structures of existing glaciers, glacier flow, erosional and depositional processes and products. Instructor: Sharp. Offered in alternate years (1970-71).

Ge 230. Geomorphology (Seminar). *5 units; third term.* Review and critical analysis of current research and literature in geomorphology. On occasion, activities are devoted wholly to field excursions within southwestern U.S. Instructor: Sharp.

Ge 244 ab. Paleoecology (Seminar). *5 units; second and third terms.* Critical review of classic investigations and current research in paleoecology and biogeochemistry. Instructor: Lowenstam.

Ge 245. Biostratigraphy (Seminar). *5 units; first, second and third terms.* A consideration of problems and principles of biostratigraphy, including regional, inter-regional, and world-wide correlations by means of fossils, and the problems arising from the consideration of animal geography. Not offered in 1970-71.

Ge 247 a. Tectonics. *10 units (3-0-7); third term. Prerequisite: Ge 105 abc.* Structure and geophysical features of continents, ocean basins, geosynclines, mountain ranges, and island arcs. Structural histories of selected mountain systems in relation to theories of orogenesis. Instructors: Allen, Kamb. Offered in alternate years (1970-71).

Ge 247 b. Tectonophysics. *10 units (4-0-6); third term. Prerequisites: Ge 104 abc, AM 95 abc or equivalent.* Analysis of stress and deformation in tectonic processes. Brittle failure of rocks in relation to faulting. Elastic stress distributions and fault patterns. Dislocation theory of faulting, and analysis of stress distribution around strike-slip faults. Brittle-ductile transition. Plasticity of mineral crystals and rocks in relation to structure. Non-hydrostatic thermodynamics, recrystallization, origin, and significance of structural anisotropy in rocks. Theories of plasticity and non-linear creep, with application to stress analysis in tectonic problems. Viscous buckling of layered media: theory of folding. Rheological properties of rocks at high temperatures and pressures. Viscosity of earth materials from post-glacial rebound and other evidence. Convective instability and mantle convection. Tectonic models. Instructors: Kamb, Allen. Offered in alternate years (1971-72).

Ge 260. Behavior of Geologic Materials under High Pressure. *8 units (3-1-4); first term. Prerequisite: Familiarity with basic concepts of thermodynamics and mineralogy. See instructor.* This course deals with the application of high-pressure physics to geologic problems. Topics to be covered include: concepts of elastic and shock propagation in single and polycrystalline solids and in fluids, and their relation to various thermodynamic processes; phase changes, dynamic yielding, shock metamorphism, and high-pressure electrical properties of minerals and application of shock and ultrasonic equation-of-state data to earth and planetary interiors. The student is introduced to current laboratory methods used in measuring the properties of earth materials under static and dynamic high pressure. Instructor: Ahrens.

Ge 261. Advanced Seismology. *9 units (3-0-6); first term. Prerequisite: AM 95 abc or AM 113 abc.* Essential material in modern seismology: seismograph theory, elastic wave propagation, ray theory, normal mode theory, dispersion, free oscillations, applications to determination of earth structure and earthquake source mechanism, interpretation of seismograms. Instructor to be named.

Ge 264 abc. Theoretical Geophysics. *9 units (3-0-6); Prerequisite: Ph 129 abc or equivalent. Ge 264 c may be taken independently of Ge 264 ab.*

First term. A systematic presentation of basic continuum theory relevant to planetary geophysics. Topics from: hydrodynamics, electromagnetics, hydromagnetics, shock wave theory, elasticity, thermodynamics and the basic solid state theory related to mechanical properties of solids.

Second term: Applications to planetary dynamics and thermal properties. Topics include: Convection and diffusion processes, heat transport processes, phase changes, discussion of the hydromagnetic dynamo problem, geophysical evidence and dynamical model calculations related to mass transport and planetary evolution. The final part of the term will be devoted to an introduction to stress wave propagation. Topics include: Reflection, refraction and scattering of waves in fluid media, waves in random media, waves in multiphase media, statistical continuum methods.

Third term. Theory of wave propagation in elastic and anelastic media, structure of the earth. Topics include: representation theorems in elastic wave propagation, dislocation and relaxation sources, free and forced oscillations of a radially inhomogeneous planet, wave propagation in layered media, inversion theory, perturbations of the free oscillation spectra due to rotation and lateral variations in earth properties, physics of anelastic processes and absorption, asymptotic wave theory, elastic-anelastic structure of the earth. Instructor: Archambeau. Offered in alternate years (1970-71).

Ge 265 ab. Advanced General Geophysics. *9 units (3-0-6); Prerequisite: Ph 129 abc.* A discussion of a range of problems of current geophysical importance selected from among the general categories of: planetary magnetic and gravity fields, thermal history and evolution, mass transport processes in the earth and tectonics, high temperature-pressure geophysics, anelastic processes, wave propagation theory and solid state geophysics. Instructors: Staff; Archambeau in charge. Offered in alternate years (1971-72).

Ge 268 ab. Selected Topics in Theoretical Geophysics. *4 units (2-0-2), first term; 8 units (3-0-5), second term. Prerequisite: Ph 129 abc or equivalent.* Discussion of seismic wave propagation, general thermodynamics and dynamics as applied to earth processes, gravitational and magnetic fields, and stress systems in the rotating earth. Course content is altered in emphasis from year to year depending mainly on student needs. Instructor: Dix.

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

Ge 295. Master's Thesis Research. *Units to be assigned. Listed as to field according to the letter system under Ge 299.*

Ge 297. Advanced Study. Students may register for 12 units or less of advanced study in fields listed under Ge 299. Occasional conferences.

Ge 299. Research. Original investigation, designed to give training in methods of research, to serve as theses for higher degrees, and to yield contribution to scientific knowledge. These may be carried on in the following fields:

Geology:

- (A) Economic Geology
- (B) Field Geology
- (C) Geomorphology
- (D) Glaciology
- (E) Invertebrate Paleontology
- (F) Mineralogy
- (G) Paleoecology
- (H) Petrology
- (I) Sedimentation
- (J) Stratigraphy
- (K) Structural Geology

Geochemistry:

- (L) General Geochemistry
- (M) Geochronology
- (N) Isotopic Geochemistry
- (O) Meteorites

Geophysics:

- (P) Applied Geophysics
- (Q) General Geophysics
- (R) Geophysical Instruments
- (S) Seismology
- (T) Theoretical Geophysics

Planetary Science:

- (U) Planetary Surfaces
- (V) Planetary Dynamics
- (W) Planetary Atmospheres
- (X) Radar Observations
- (Y) Radio Emissions

German

(See under Languages)

History

UNDERGRADUATE SUBJECTS

H 1 abc. An Introduction to Modern Europe. *9 units (3-0-6); first, second, third terms.* Modern Europe, its background, development, and relations with other parts of the world. The particular topics covered may vary from instructor to instructor but will include feudalism, absolute monarchy, 17th century English revolution, the Enlightenment, the French Revolution and Napoleon, the industrial revolution, the rise of nationalism, the growth of liberal democracy, Marxism, European overseas expansion and contraction, the two world wars, the Russian Revolution, fascism, and major world developments since 1945.

H 2 abc. Major Themes in United States History. *9 units (3-0-6); first, second, third terms.* Not a survey, the course will focus on several major themes within the context of American history. Each instructor will explore some question such as the rise of cities, the growth of the Presidency, the pursuit of equality, or the place of the individual in American society. Students will have an opportunity to examine a wide variety of materials, employ different approaches, and pursue their special interests in small discussion classes and written work.

H 3. Europe in the 17th and 18th Centuries. *9 units (3-0-6). Not open to students who have already completed H 1 a, H 1 b, or H 110.* A survey of Europe in this period, with special attention to the English revolutions, Louis XIV, the Enlightenment, and the French Revolution. Instructor: Fay

H 4. Europe in the 19th and 20th Centuries. *9 units (3-0-6). Not open to students who have already completed H 1 b, H 1 c, H 110, or H 112.* A survey of Europe in this period, with special attention to the industrial revolution, liberal revolutions and reforms, the formation of Germany, the two World Wars, the Russian Revolution, and Hitler. Instructor: Fay.

H 40. Reading in History. *Units to be determined for the individual by the department. Elective, in any term.* Reading in history and related subjects, done either in connection with the regular courses or independently of any course, but under the direction of members of the department. A brief written report will usually be required. *Not available for credit toward humanities-social science requirement.*

H 41. Summer Reading. *Units to be determined for the individual by the department. Maximum, 8 units. Elective.* Reading in history and related subjects during summer vacation. Topics and books to be selected in consultation with members of the department. A brief written report will usually be required. *Not available for credit toward humanities-social science requirement.*

H 97 ab. Junior Tutorial. *9 units (2-0-7); second and third terms.* Designed primarily for students majoring in history. Consent of the instructor required. Normally taken in the junior year. Instructors: Members of the staff.

H 98 ab. Senior Tutorial. *9 units (2-0-7); first and second terms.* Designed primarily for students majoring in history. Consent of instructor required. Normally taken in the senior year. Instructors: Members of the staff.

H 99 abc. Research Tutorial. *9 (1-0-8); first, second, third terms.* Designed primarily for students majoring in history. Consent of the instructor required. Preparation of a research paper and for an oral examination based upon it. Instructors: Members of the staff.

ADVANCED SUBJECTS

H 105 ab. Medieval Civilization. *9 units (3-0-6). 105 a is not a prerequisite for b.* a. Economic development of medieval Europe; b. History of love and marriage. Instructor: Benton.

H 106 ab. Topics in Medieval and Renaissance History. *9 units (3-0-6). 106 a is not a prerequisite for b.* Seminar investigation of selected topics. a. Political theory and practice; b. Renaissance and renascences. Instructor: Benton.

H 110. Revolution and Reaction: Britain and France, 1789-1848. *9 units (3-0-6).* An inquiry into the political, social, and economic accidents and developments which permitted

Britain to take France's place at the center of the European stage and from that vantage point to dominate the world. Instructor: Fay.

H 112. Europe Since 1914. *9 units (3-0-6).* Since 1914 the world has felt the impact of two great wars and powerful revolutionary ideas. This course will analyze the upheavals of the twentieth century and their effect on domestic and international organization. Instructor: Fay.

H 116. Germany *9 units (3-0-6).* Principal historical developments in Germany from the Reformation to the present day. Emphasis on the evolution of social and political institutions and attitudes. Instructor: Ellersieck.

H 117. Russia. *9 units (3-0-6).* An attempt to discover and interpret the major recurring characteristics of Russian history and society, with attention particularly to developments in the Soviet period. Instructor: Ellersieck.

H 118. Britain. *9 units (3-0-6).* Main elements in the political life of modern Britain. Attention will be concentrated primarily on events since 1832, and emphasis will be placed on economic and social trends, on political and constitutional development, and on the lives of important statesmen. Instructor: Elliot.

H 120. The British Empire and Commonwealth. *9 units (3-0-6).* The growth of the imperial idea and the institutional development of the Empire and the Commonwealth with particular reference to Africa and Asia. Instructor: Huttenback.

H 121. India and Pakistan. *9 units (3-0-6).* The growth of Indian nationalism in the years before independence, and developments in India and Pakistan since partition. Special emphasis will be placed on the philosophical conflict between British and indigenous Indian attitudes and the consequent effect on contemporary India and Pakistan. Instructor: Huttenback.

H 130. History of War. *9 units (3-0-6).* An examination of instructive episodes in the evolution of warfare. Emphasis upon the role of political, economic and social factors in influencing the choice of organization, armament, tactics and the timing of conflict. Instructor: Ellersieck.

H 147. The Far West and the Great Plains. *9 units (3-0-6).* The exploration and development of the great regions of western America. Especial attention will be paid to the influence of the natural environment, and the exploitation of it by such industries as the fur trade, mining, cattle ranching, farming, and oil. Instructor: Paul.

H 151. The Shaping of Modern America, 1890-1917. *9 units (3-0-6).* An examination of the consolidation and expansion of economic, political, and social control by regional and national power elites. Instructor: Kousser.

H 152. The 1920's and the New Deal, 1919-1941. *9 units (3-0-6).* The economics and politics of the boom years and the Great Depression.

H 153. America since 1940. *9 units (3-0-6).* The foreign and domestic politics of an emerging affluent society, with emphasis on the minority group revolution, the new conservatism, and the modification of American liberalism. Instructors: Kevles, Rosenstone.

H 154. American Foreign Policy in the Twentieth Century. *9 units (3-0-6).* How American foreign policy has been formed and administered in recent times: the respective roles of the State Department, Congress, and the President, of public opinion and pressure groups, of national needs and local politics. Instructor: Paul.

H 157 a. Science in America, 1865-present. *9 units (3-0-6).* A study of the social and political history of American science, emphasizing the relationship of the research community to universities, industry, and government. Instructor: Kevles.

H 157 b. Science in America, 1865-present. *9 units (3-0-6). H 157 a is a prerequisite.* A seminar on selected topics, concentrating on the writing of an original research paper. Instructor: Kevles.

H 158. Main Themes in American Intellectual History. *9 units (3-0-6).* Patterns of American thought in the 19th and 20th centuries, focused on how American ideas evolved as the nation grew, industry burgeoned, and science proclaimed new theories about the nature of the world. Instructor: Rosenstone.

H 159. American Radicalism. *9 units (3-0-6).* An examination of the nature and sources of dissident American social and political movements in the 19th and 20th centuries, with emphasis on their critiques of American life, their role in a society and their contributions. Instructor: Rosenstone.

H 160. The History of Black People in America. *9 units (3-0-6).* This course will focus primarily on actions taken and ideas expressed by Negroes themselves rather than by whites. Themes will include accommodation and resistance before and after the Civil War; the development of racism and segregation; the migration from black belt to ghetto; and the roles of certain black leaders and ideologies. Instructor: Kousser.

H 161. Selected Topics in History. *9 units (3-0-6).* Instructors: Members of the staff and visiting lecturers.

H 201. Reading and research for graduate students. Units to be determined for the individual by the staff.

Hydraulics

ADVANCED SUBJECTS

Hy 100. Hydraulics Problems. *Units to be based upon work done, any term.* Special problems or courses arranged to meet the needs of first-year graduate students or qualified undergraduate students.

Hy 101 abc. Fluid Mechanics. *9 units; first, second, third terms. Prerequisites: ME 19 ab and Hy 111 or equivalent.* General equations of fluid motion; two- and three-dimensional steady and non-steady potential motion; cavity and wake flow; surface waves, linear and nonlinear shallow-water waves, layered media, stability; acoustic fields, sound radiation and scattering, acoustic energy transport; one-dimensional steady gasdynamics, expansion fans, shock waves; two- and three-dimensional flow fields; laminar flow, Stokes and Oseen problems, laminar boundary layer; laminar instability, turbulence shear flow; introduction to problems in heterogeneous flow, chemically reacting flow, sediment transport, flow through porous media. Instructor: Zukoski.

Hy 103 ab. Advanced Hydraulics and Hydraulic Structures. *9 units (3-0-6); first and second terms. Prerequisites: ME 19 ab and Hy 111 or equivalent.* Steady and unsteady flow in open channels; high-velocity flow in open channels; theory and design of some hydraulic structures such as chutes, energy dissipators, manifolds, and canals; unsteady flow in closed systems, e.g., surge and waterhammer. Instructor: Raichlen.

Hy 105. Analysis and Design of Hydraulic Projects. *6 or more units as arranged; any term.* The detailed analysis or design of a complex hydraulic structure or 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 the instructor. Among possible problems or projects are multipurpose river storage projects, spillways, waterpower developments, pipelines, pumping stations, distribution and collection systems, flood control systems, ocean outfalls, water and sewage treatment plants, irrigation systems, navigation locks and harbors. Instructors: Vanoni, Brooks, Raichlen.

Hy 106. Experimental Hydraulics and Similitude. *9 units (3-1-5); first term. Prerequisites: ME 19 abc and Hy 111 or equivalent. (One hour per week for laboratory demonstration.)* Equations of motion and dynamic similitude; dimensional analysis; experimental techniques and hydraulic measurements; turbulent incompressible flows in open channels and pipes; similarity for turbulent flows including submerged jets; similarity numbers for diffusion processes, flow in pumps, cavitation, and motion of solids or bubbles in liquids; similitude for flow in porous media and the Hele-Shaw analogue; hydraulic models for various types of hydraulic structures used in hydraulic and coastal engineering; model scales and distortions. Instructors: Brooks, Raichlen.

Hy 111. Fluid Mechanics Laboratory. *6-9 units as arranged with instructor; second or third term. Prerequisite: ME 19 ab.* A laboratory course illustrating the basic mechanics of incompressible fluid flow, and complementing the lecture course ME 19 abc. Students will usually select 4 or 5 regular experiments, but with the permission of the instructor they may propose special investigations of brief research projects of their own in place of some of the regular experiments. Objectives also include giving students experience in making engineering reports. Although the course is primarily for seniors, it is also open to first-year graduate students who have not had an equivalent course. Instructor: Raichlen.

Hy 112 ab. Hydrologic Transport Processes. *Renumbered Env 112 ab.*

Hy 113. Coastal Engineering. *9 units (3-0-6); third term. Prerequisites: ME 19 ab and Hy 111 or equivalent; AM 95 abc.* Engineering application of the theory of small and finite amplitude water waves; diffraction, reflection, refraction; tides and their interaction with the coastline; some aspects of the interaction of waves and structures; coastal processes. Instructor: Raichlen.

Hy 121. Advanced Hydraulics Laboratory. *6 or more units as arranged; any term. Prerequisite: Consent of instructor.* 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, depending on their needs and interests. Instructors: Staff.

Hy 200. Advanced Work in Hydrodynamics or Hydraulic Engineering. *Units to be based upon work done; any term.* Special courses to meet the needs of advanced graduate students.

Hy 201 abc. Fluid Machinery. *6 units (2-0-4); first, second, third terms. Prerequisite: Hy 101 or permission of instructor.* A study of the characteristics of hydraulic and aerodynamic machines including pumps, turbines, fans, propellers, etc. Energy relationships, similarity parameters, radial and axial cascade theory, axisymmetric flow and cavitation with some consideration to applications. Not offered every year. Instructor: Acosta.

Hy 203. Cavitation Phenomena. *6 units (2-0-4). Prerequisite: Graduate standing.* A study of the occurrence and effects of cavitation on the flow past bodies and through machines; material damage caused by cavitation will also be covered. Instructors: Staff.

Hy 210 ab. Hydrodynamics of Sediment Transportation. *9 units (3-0-6). Prerequisites: AM 95 abc, Env 112 ab, and Hy 101 abc.* A study of the mechanics of the entrainment, transportation, and deposition of solid particles by flowing fluids. This will include discussion and interpretation of results of laboratory and field studies of alluvial streams, and wind erosion. Instructor: Vanoni.

Hy 211. Advanced Hydraulics Seminar. *4 units (2-0-2); every term.* A seminar course for advanced graduate students to discuss and review the recent technical literature in hydraulics and fluid mechanics. Emphasis will be on topics related to civil engineering which are not already available in courses offered by the Division of Engineering and Applied Science. The subject matter will be variable depending upon the needs and interests of the students. It may be taken any number of times with permission of the instructor. Instructor: Brooks.

Hy 212. Topics in Turbulent Diffusion and Stratified Flow. *Renumbered Env 212.*

Hy 213. Advanced Coastal Engineering. *9 units (3-0-6); third term. Prerequisites: Hy 101 abc and Hy 113.* Wind-generated waves and wave prediction procedures; wave spectra; effect of waves on coastal structures such as breakwaters and pile supported structures; harbor resonance; impulsively generated waves; mooring of ships in waves; coastal sediment transport. Instructor: Raichlen.

Hy 300. Thesis Research.

Information Science*

ADVANCED SUBJECTS

Several classes of courses are offered on the basic principles of information processing and machine computation. There are a number of non-credit coding courses given every term that are frequently prerequisites to certain credit courses and to the uses of the computers in the Booth Computing Center. The office of the Computing Center should be contacted concerning these.

Accredited Courses

IS 10 a. Introduction to the Use of Computers. *6 units (1-2-3); one term course offered second and third terms.* The purpose of this course is to introduce to the students the use of computers for solving mathematical problems arising in engineering and science. By solving a variety of sample problems, the student will learn basic techniques of computational mathematics. Algebraic computer languages will be employed in batch processing and in conversational time-sharing. Instructor: McCann.

100 series courses open to juniors and seniors or by special permission of instructors.

IS 110 abc. Principles of Digital Information Processing. *9 units (3-3-3).* This course presents the principles and concepts of digital information processing systems with emphasis on the stored program synchronous computer. This includes switching theory and its application to the design of systems. The organization of digital processors at the machine language level is covered together with the basic concepts of formal algebraic languages, their uses and the translation between them and machine languages. The laboratory permits direct experimentation with a variety of systems ranging from basic subsystems to complete computers. Instructor: Ray.

IS 121 abc. Biosystems Analysis. *6 units (2-0-4). Same as Bi 121 abc. Prerequisite: Bi 118 or concurrently.* This course presents a systematic consideration and application of the methods of systems analysis, information theory and computer logic to problems in neurobiology. The subjects to be considered include the mechanical properties of striated muscle, the analysis of neuronal integrative mechanisms and reflex behavior in terms of logical net theory. The course will seek to describe some aspects of human cortical activity in terms of information theory and conceptual modeling. The course will be conducted as a research seminar and the detailed subject matter will change from year to year. Instructor: Fender.

IS 129 abc. Introduction to Programming Systems. *9 units (3-0-6).* Introduction to the concepts of systems synthesis and the design of programming systems. Topics include scanning, text encoding, list processing and dynamic storage allocations. The design and implementation of assemblers, compilers and loaders are treated in detail. Operating systems and I/O supervision are covered primarily as they relate to language processor design. The student is required to supplement the lecture material by participating in several design and implementation projects. Instructor: Caine.

IS 170 abc. Computability Theory. *9 units (3-0-6). Prerequisite: Ma 5 or equivalent.* Alternative formulations of the notion of "effective procedure" and proof of their equivalence. Classes of recursive functions of natural numbers. Considerations on the notion of "complexity of an algorithm." Degrees of unsolvability and the arithmetical hierarchy. Recursive functions of ordinals. Relations with mathematical logic. Some applications to mathematical problems. Instructor: Ingargiola. Taught in alternate years. Not offered in 1970-71.

IS 203 ab. Data Acquisition, Analysis and Modeling for Living Systems Research. *9 units (3-3-3); second and third terms.* The development of adequate theories for complex living systems requires the extensive integration of computer aided strategies for data acquisition, analysis and modeling. Since the proper development of such theories requires a rich data base, supplementary material is presented on the physiology of systems used as examples. A laboratory is provided to test and extend the integrated use of computer concepts in such research. Instructors: Ingargiola with Fender, McCann, Naka, Nye.

IS 220 a. Theories of Visual Nervous Systems. *9 units (3-0-6); third term. Prerequisites: IS 121 abc and IS 203 a.* Strategies for the correlation of experimental techniques for studying nervous systems with computer instrumented methods of examining experimental results by data analysis and modeling. Comparisons will be made between models based upon formal mathematics and new computer instrumented strategies that provide more complete and detailed correlations with experimental results. Instructor: McCann.

IS 230 abc. Advanced Programming Systems. *9 units (3-0-6). Prerequisite: IS 129.* A treatment of advanced topics in the field of systems synthesis and programming systems design. Subjects include the design of compilers for complex languages, compiler optimization and sophisticated compilers for small machines. Advanced operating systems are discussed, including time sharing, multi-tasking, dynamic resource management and multi-computer systems. While the emphasis in the course is on system architecture and design, students will have the opportunity to test their ideas by participating in implementation projects. Instructor: Caine. Offered in alternate years. Not offered in 1970-71.

IS 250 abc. Mathematical Linguistics. *9 units (3-0-6); Prerequisite: Ma 116 abc.* This course presents a systematic development of the syntactic and semantic properties of languages. This includes the natural languages as well as the formal languages of symbolic logic and information processing. The philosophical aspects of language will be stressed together with the formalization of language structures suitable for computer simulation. Instructor: Thompson. Taught in alternate years. Not offered in 1970-71.

IS 270 abc. Automata Theory. *9 units (3-0-6). Prerequisite: IS 170 or Ma 116.* Algebraic theory of finite state machines. Automata as acceptors and generators of languages. Hierarchies of automata and of classes of automata. Global models: automata that construct other automata. Instructor: Ingargiola. Taught in alternate years. Offered in 1970-71.

IS 280. Research in Information Science. *Units in accordance with work accomplished. Approval of student's research adviser and his department adviser must be obtained before registering.*

IS 281. Seminar in Information Science. *2 units. All terms.* Meets once a week for discussion of new research in the information sciences and biological systems analysis. Meetings are devoted to topics in language theory, information system synthesis, computational mathematics, and topics related to information processing in living nervous systems. In charge: Staff.

The following courses cover related basic mathematics and applied mathematics:

AMa 104. Matrix Algebra. See Applied Mathematics Section.

AMa 105 ab. Introduction to Numerical Analysis. See Applied Mathematics Section.

Ma 116 abc. Mathematical Logic and Axiomatic Set Theory. See Mathematics Section.

Ma 121 abc. Combinatorial Analysis. See Mathematics Section.

Ma 205 abc. Numerical Analysis. See Mathematics Section.

Ma 216 abc. Advanced Mathematical Logic. See Mathematics Section.

*For linguistics, En 102, see page 339.

Jet Propulsion

ADVANCED SUBJECTS

JP 120 abc. Thermodynamics of Propulsion Systems. *9 units (3-0-6); each term. Open to all graduate students and to seniors with permission of the instructor.* Application of thermodynamics, chemical equilibrium, and molecular structure to properties of propellants and evolution of performance; equilibrium and transport properties of propellant materials at high temperatures; phenomenological chemical kinetics, introduction to laminar flame theory, combustion of solid propellants, nonequilibrium molecular processes. Approximately one term will be devoted to molecular gas lasers. Instructor: Culick.

JP 121 abc. Jet Propulsion Systems and Trajectories. *9 units (3-0-6); each term. Open to all graduate students and to seniors with permission of the instructor.* Modern aspects of rocket, turbine, electrical, and nuclear propulsion systems and the principles of their application to lifting, ballistic, and space flight trajectories. Combustion thermodynamics, equilibrium and nonequilibrium nozzle flow, propellant evaluation. Combustion and burning characteristics of solid and liquid propellants, liquid propellant fuel systems, combustion instability. Subsonic and supersonic compressor and turbines, basic gas turbine propulsion cycle and its variations, inlets and diffusers. Ion and colloidal engines, plasma thrustors, crossed field and wave MHD propulsion systems. Nuclear rockets, nuclear air breathing cycles, radio-isotope propulsion. Instructor: Marble.

JP 170. Jet Propulsion Laboratory. *9 units (0-9-0); third term.* Laboratory experiments related to propulsion problems. Instructor: Zukoski.

JP 201. Physical Mechanics. *9 units (3-0-6); any term. Prerequisite: JP 120 abc or equivalent.* Introduction to quantum mechanical and statistical mechanical methods for calculating thermodynamic properties, in particular properties of materials at high temperatures; transport theory.

JP 213 abc. Gas Dynamics and Combustion in Propulsion Systems. *6 units (2-0-4). Prerequisites: JP 120 abc, JP 121 abc, Ae 101 abc or Hy 101 abc, or equivalent.* Topics from theory of real gases; gas dynamics of reacting mixtures; theory of combustion of solid, liquid, and gaseous fuels. Inlet diffusers for supersonic and hypersonic air-breathing engines; effects of real gases, rarefied gas and low Reynolds number flow; diffuser stability. Review of laminar and turbulent flame theory; combustion of solid and liquid propellants; combustion in boundary layers, wakes, and mixing regions; flame stability. Nozzles for rockets and air-breathing engines; one-dimensional and axially symmetric nozzle flow with chemical reactions, characteristic theory, integral methods, two-phase flow. Instructor: Marble.

JP 230 abc. Power Generation and Electric Propulsion for Space Vehicles. *6 units (2-0-4). Prerequisite: JP 120 abc or equivalent.* The purpose of this course is to provide a background for understanding the current status and problems of energy conversion in space vehicles. Portions of the course will change from year to year. Particular emphasis is placed on analysis of the behavior of relevant materials, such as ionized gases, electrons in metals, semiconductors, and their use in special systems. Devices treated include magnetohydrodynamic generators, fuel cells, thermionic converters, solar cells, Rankine cycles, thermoelectric generators, ion and plasma rockets. Limited discussion will be devoted to existing examples and energy sources now available. Not offered in 1970-71. Instructor: Culick.

JP 240. Heat Transfer in Propulsion Systems—Radiative Heat Transfer. *9 units (3-0-6); any term. Prerequisite: AM 95 ab.* Black body radiation laws; spectral absorption coefficients; spectral emissivities and absorptivities for gases, liquids, and solids. The fundamental equations for radiative transfer. Mean absorption coefficients. Methods of solution of representative integro-differential equations arising in radiative transfer calculations. Non-dimensional parameters in transfer processes involving radiative exchange. Radiative transfer in shock waves, solid propellant burning, etc.

JP 250 abc. Fluid Mechanics of Turbomachines. *6 units (2-0-4). Prerequisite: Hy 101 abc or equivalent.* Cascade theory, potential flow through two-dimensional cascades, real fluid effects, and evaluation of performance; axisymmetric flow through an actuator disc in an annular duct, linearized perturbations of strong vorticity fields, single and multiple blade rows of finite axial extent, transonic and supersonic blading; effects of varying duct height; three-dimensional real fluid effects, secondary flows, propagating stall, blade tip clearance flow. Instructor: Rannie.

JP 270. Special Topics in Propulsion *6 units (2-0-4).* The topics covered will vary from year to year. Instructors: Staff.

JP 280. Research in Jet Propulsion. *Units to be arranged.* Theoretical and experimental investigations of problems associated with propulsion and related fields. Instructors: Staff.

JP 290 abc. Advanced Seminar in Jet Propulsion. *1 unit (1-0-1); each term.* Seminar on current research problems in propulsion and related fields. Instructors: Staff.

Languages*

UNDERGRADUATE SUBJECTS

L 32 abc. Elementary Scientific German. *10 units; first term (3-1-6), second term (3-1-6); third term (4-0-6).* A course in grammar, pronunciation, and reading that will provide the student with the ability to read scientific literature of average difficulty. In the first two terms, the essentials of grammar are covered, supplemented by a weekly drill in the language laboratory and selections from an elementary scientific reader. The third term is devoted to the reading of scientific literature of graduated difficulty. Students who have had German in the secondary school or junior college should not register for this course without consulting the staff in languages. Does not qualify as prerequisite for L 131 abc or L 132 abc. *Not available for credit toward humanities-social science requirement.* Instructor: Allswang.

L 39. Reading in French, German or Russian. *Units to be determined for the individual by the department.* Reading in scientific or literary French, German or Russian under the direction of the department. *Not available for credit toward humanities-social science requirement.*

L 50 abc. Elementary Scientific Russian. *10 units (3-1-6); first, second, third terms.* A course in pronunciation, grammar, and reading that is intended to enable a beginner to read technical prose in his field of study. One session in the language laboratory will be scheduled each week. *Does not qualify as prerequisite for L 153. Not available for credit toward humanities-social science requirement.* Instructor: M. Zirin.

L 51 abc. Intermediate Russian. *10 units (4-0-6); first, second, third terms. Prerequisite: L 50 abc or the equivalent.* A continued study of the Russian language with increased emphasis on conversation. The reading of selected classical and modern literature. Discussions in Russian. Continuation of reading and translation of scientific material. Not offered after 1970-71 school year. Instructor: M. Zirin.

ADVANCED SUBJECTS

L 102 abc. Elementary French. *10 units (3-1-6); first, second, third terms.* A course taught by the conversational method, aimed at giving a student a superior reading knowledge of French and the ability to understand the contents of a lecture in his general field and to discuss the subject matter in French, as well as competence in general conversation. This is the first course of a two-year sequence, but enrollment is not restricted to students intending to complete the two-year program. Instructor: L. Rosenstone. *Not available for credit toward humanities-social science requirement.*

L 103 abc. Intermediate French. *10 units (3-1-6); first, second, third terms. Prerequisite: L 102 abc or equivalent.* Continuation of L 102 abc, includes a review of grammar, conversational practice principally on scientific subjects and an introduction to contemporary French culture and politics. Instructor: A. Smith.

L 105 abc. French Literature. *9 units (3-0-6); first, second, third terms. Prerequisite L 103 abc or equivalent. Courses need not be taken in sequence.* Open to undergraduates and graduates. Credit in this course may be applied towards a subject minor in French. The Writer and the Establishment as seen through a selection of French authors from Molière to Boris Vian. Conducted in French. Instructor: A. Smith.

L 130 abc. Elementary German. *10 units (3-1-6); first, second, third terms.* The course provides the basis for developing a broad knowledge of the German language, covering aural comprehension, speaking, reading, and writing. Classroom work is supplemented by language laboratory drill. Open to graduate and undergraduate students. This course also constitutes the first year of the two-year intensive program in German for graduate students. Students who have had German in the secondary school or junior college should not register for this course without consulting the staff in languages. Instructors: Wayne, Huber. *Not available for credit toward humanities-social science requirement.*

L 131 abc. Intermediate German: Science and Civilization. *10 units (3-1-6); first, second, third terms. Prerequisite: L 130 abc, or equivalent.* Second year of intensive program in German for graduate students. Open to a limited number of undergraduate students. The purpose of this course is to acquaint the student with the major aspects of contemporary Germany and to enable him to acquire German language competence in his general field. Written and oral reports will be required in the student's major area of study Instructor: Huber.

L 132 abc. Intermediate German: Readings in German Literature. *9 units (3-0-6); first, second, third terms. Prerequisite: L 130 abc, or equivalent.* The reading of selected short contemporary stories and plays of intermediate difficulty with emphasis on the development of communication skills. Open to undergraduate students, and to graduate students who are not taking the two-year intensive program in German. Students who wish to offer German study elsewhere as basis for admittance to the course should consult with the instructor. Instructor: Wayne.

L 139. Independent Reading in French, German, or Russian Literature. For graduate students who have completed at least one year of literature in the foreign language. Credit in this course may be applied towards a subject minor in language. Units to be determined for the individual by the department.

L 140 abc. German Literature. *9 units (2-0-7); first, second, third terms. Courses need not be taken in sequence. Prerequisite: L 131 abc or L 132 abc or equivalent.* The reading and discussion of representative works by selected authors of the nineteenth and twentieth centuries. Conducted in German. Open to undergraduates and graduates. Credit in this course may be applied towards a subject minor in German. Instructors: Frey, Wayne, Huber.

L 152 abc. Elementary Russian. *10 units (3-1-6); first, second, third terms.* A course taught by the conversational method aimed at giving a student a superior reading knowledge of Russian and the ability to understand the contents of a lecture in his general field and to discuss the subject matter in Russian, as well as competence in general conversation. The first course of a two-year sequence; enrollment not restricted to students intending to complete the two-year program. *Not available for credit toward humanities-social science requirement.* Instructor: Novins.

L 153 abc. Intermediate Russian. *10 units (3-1-6); first, second, third terms. Prerequisite: L 152 abc or equivalent.* The continuation of L 152 abc. Instructor: Novins.

L 154 abc. Russian Literature. *9 units (3-0-6); first, second, third terms.* Students are advised to take these courses in sequence. Prerequisite: L 153 or equivalent. Reading and discussion of representative works of selected nineteenth- and twentieth-century Russian authors. Conducted in Russian. Open to undergraduates and graduates. Credit in this course may be applied towards a subject minor in Russian. Instructor: M. Zirin.

*For linguistics, see En 102, En 103 in this catalog, page 339.

Materials Science

UNDERGRADUATE SUBJECTS

MS 5 abc. Structure and Properties of Solids. *9 units (3-0-6); first, second, and third terms. Prerequisites: Ch 1 abc, Ph 2 abc, AM 97 a.* The purpose of this course is to acquaint the student with the principles underlying the properties of solid materials. The electronic structure of atoms, the types of bonds between atoms in molecules and crystals, crystal structure and its determination by X-ray diffraction, and the band theory of crystalline solids are discussed. Topics in the physical properties of solids include: Electrical and thermal conductivity; the dielectric properties of insulators; diamagnetism, paramagnetism, ferromagnetism, and antiferromagnetism; specific heat; thermoelectric effects. An introduction to statistical thermodynamics is given. Rate processes such as diffusion and phase transformations in solids are discussed briefly. Elastic and plastic deformation of crystals, the concept of dislocations, properties, and interactions of dislocations are studied and applied to discussions of mechanical properties of polycrystalline aggregates, influence of grain size, alloying and phase dispersion, and high temperature creep and fracture. Instructors: Buffington (MS 5 b), Wood (MS 5 a, c).

MS 10. Engineering Physical Metallurgy. *9 units (2-1-6); first term. Prerequisite: MS 5 ab, or ME 3.* A study of the properties of ferrous and non-ferrous metals and alloys with respect to their application in engineering; the principles of the treatment of ferrous and non-ferrous alloys for a proper understanding by engineers for application of alloys in fabrication and design. Four laboratory sessions during the term correlate properties and heat treatment with the microstructures of alloys. Text: *Physical Metallurgy for Engineers,* Clark and Varney. Instructors: Clark, Buffington.

MS 11. Metallography Laboratory. *9 units (0-6-3); second term. Prerequisite: MS 10.* The technique of metallographic laboratory practice including microscopy, preparation of specimens, etching reagents and their use, photomicrography. The study of the microstructure of ferrous and non-ferrous metals and alloys for different conditions of treatment. Text: *Principles of Metallographic Laboratory Practice,* Kehl. Instructor: Clark.

ADVANCED SUBJECTS

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.

MS 101 abc. Physical Metallurgy. *9 units (3-0-6); first, second, and third terms. Prerequisite: AM 97 a, or equivalent.* The purpose of this course is to provide the student with a comprehensive coverage of the basic aspects of the field of physical metallurgy. The first term deals with the crystal structure of solids and X-ray diffraction. The first term also includes a discussion of crystal imperfections, including dislocations associated with basic concepts of the mechanical behavior of metallic materials. The second term consists of a discussion of phase equilibria in binary and ternary systems approached from thermodynamic principles; diffusion in solids will be considered from a fundamental point of view. The third term is devoted to a discussion of nucleation and growth and phase transformations in one and two component systems. Instructors: *first term,* Duwez, Wood; *second term,* Buffington; *third term,* Villagrana.

MS 103 ab. Physical Metallurgy Laboratory. *9 units (0-6-3); second term; 6 units (0-6-0); third term. Prerequisite: MS 11.* Experimental studies concerned with the structures and properties of metals and alloys associated with heat treatment and recrystallization phenomena. Studies of hardenability characteristics of steel with respect to prediction by thermodynamic considerations. The determination of grain size of metals and alloys in relation to properties. Instructor: Clark.

MS 104 abc. Materials Science Laboratory. *9 units (0-6-3); first, second, and third terms. Prerequisite: For second term, AM 97 a, or equivalent.* The purpose of this course is to familiarize graduate students in Materials Science with the basic techniques and equipment which the student is likely to need in subsequent research work. A graduate student in Materials Science will be required to take all three terms unless he has had the equivalent work elsewhere. Any one term may be taken independently of the others. The course is open to undergraduate students to satisfy the laboratory requirement in engineering. The first term is concerned with the techniques of optical metallography and photomicrography, temperature measurements, and cooling curves. The second term is concerned with experiments selected from such topics as: stress-strain behavior, rate effects in plastic flow and discontinuous yielding, internal friction, wave propagation, brittle and ductile fracture, fatigue, and dislocation studies using etching and X-ray micrography. The third term is concerned with X-ray metallography involving the determination of crystal structures, use of the X-ray spectrometer, and the application of X-ray diffraction methods to the study of phase diagrams. Instructors: *First term,* Clark, Wood; *second term,* Vreeland; *third term,* Duwez.

MS 105. Mechanical Behavior of Metals. *9 units (3-0-6); second term. Prerequisites: AM 97 abc, MS 5 abc.* A study of the mechanical behavior of metals for engineering applications. Elastic behavior of anisotropic materials and polycrystalline aggregates. Yielding, plastic flow, and strengthening mechanisms, the influence of temperature and rate of loading on plastic deformation. Fracture of metals by ductile flow, brittle cracking, fatigue, and creep. Behavior under impact loading. Instructor: Wood.

MS 110. Special Topics in Physical Metallurgy. *9 units (3-0-6); third term. Prerequisite: MS 10 or MS 101 abc.* The emphasis is on recent developments, so topics will vary from year to year. Both metals and nonmetals are considered. Areas of interest include: the influence of special environments, such as nuclear reactors and high temperatures; the development of specific physical properties, such as magnetic and electrical properties; the study of special systems and procedures, such as transformations in titanium-base alloys, ultra-high strength steels, and fiber reinforcement of metals. Instructor: Buffington.

MS 115. Crystal Structure of Metals and Alloys. *9 units (3-0-6); second term. Prerequisite: MS 5.* Physics of X-rays, elementary crystal structure, symmetry operations, symmetry classes, space groups. Stereographic projections. Reciprocal lattice. Von Laue and Debye-Scherrer methods of crystal structure analysis. Use of the diffractometer and intensity measurements. The texture of plastically deformed metals. Electron and neutron diffraction. Relationships between the structure of metals, solid solutions and intermetallic compounds and their physical properties. Text: *Elements of X-ray Diffraction,* Cullity and *Atomic Theory for Students in Metallurgy,* Hume-Rothery. Instructor: Duwez.

MS 120. Physics of Solids. *9 units (3-0-6); first term. Prerequisite: AM 95 ab or equivalent.* Introduction to wave mechanics; band theory of solids; physical properties of solids. Those who have received credit for MS 5 ab cannot receive credit for MS 120, since there exists some duplication of material. Additional study in physics of solids can be arranged under MS 100. Instructor: Buffington.

MS 125. Transmission Electron Microscopy of Crystals. *9 units (3-0-6); first term. Prerequisite: Ph 125 abc or equivalent.* The theoretical aspects of image contrast and diffraction analysis in transmission electron microscopy of thin crystals are treated. The dynamical theory of image contrast is developed from the principles of wave mechanics. The two-beam and many-beam theories are developed, including inelastic scattering. The theory is applied to electron channeling, contrast and diffraction effects from: planar and line defects, polyphase crystals, and ferromagnetic crystals. Instructor: Villagrana.

MS 126. Transmission Electron Microscopy Laboratory. *9 units (0-3-6); second term. Prerequisite: MS 125.* The principles of transmission electron microscope operation are presented. The principle methods of thin foil preparation are applied to various materials. Contrast experiments are performed and the results compared to theoretical calculations. Specialized experimental techniques, e.g., direct lattice resolution, hot and cold stage microscopy are demonstrated. Instructor: Villagrana.

MS 200. Advanced Work in Physical Metallurgy. The staff in physical metallurgy will arrange special courses or problems to meet the needs of advanced graduate students.

MS 205 a. Theory of Crystal Dislocations. *9 units (3-0-6); second term. Prerequisites: Ae 102 a or AM 135 a, MS 115 (may be taken concurrently).* The concept of a dislocation, special types and general dislocations. Dislocation motion and plastic deformation. The force on a dislocation, and the stress field and energy of a dislocation. Interactions of a dislocation with the crystal lattice, other dislocations, surfaces, and point defects. Text: *Theory of Dislocations*, Hirth and Lothe. Instructor: Wood.

MS 205 b. Dislocations and the Mechanical Properties of Crystalline Solids. *9 units (3-0-6); third term. Prerequisite: MS 205 a.* Current theories of plastic yielding, strain hardening, alloy hardening, anelasticity, twinning, fracture, creep, and fatigue are discussed. Experimental techniques used for the observation of crystalline defects are discussed including etch pitting, X-ray diffraction, electron transmission and diffraction, and field ion microscopy. Instructor: Vreeland.

MS 217. X-Ray Metallography Laboratory. *9 units (0-6-3); any term. Prerequisite: MS 104 c.* An advanced laboratory course for students carrying out research involving the use of X-ray diffraction techniques. Methods of X-ray diffraction requiring the use of single crystals, rotating crystal and Weisenberg methods. Accurate measurements of diffracted intensities. Quantitative analysis of phases in alloys. Special problems are assigned, depending on the student's field of interest. Instructor: Duwez.

MS 250 abc. Advanced Topics in Materials Science. *6 units (2-0-4); first, second, and third terms.* The content of this course will vary from year to year. Topics of current interest will be chosen according to the interests of students and staff. Visiting professors may present portions of this course from time to time. Instructors: Staff.

MS 300. Thesis Research.

Other courses related to Materials Science include:

Ae 210 abc	Advanced Solid Mechanics (See Aeronautics Section)
Ae 213	Fracture Mechanics (See Aeronautics Section)
Ae 221	Theory of Viscoelasticity (See Aeronautics Section)
AM 135 abc	Mathematical Elasticity Theory (See Applied Mechanics Section)
AM 140 abc	Plasticity (See Applied Mechanics Section)
AM 141 abc	Wave Propagation in Solids (See Applied Mechanics Section)
ChE 107 abc	Polymer Science (See Chemical Engineering Section)
ChE 207 abc	Mechanical Behavior and Ultimate Properties of Polymers (See Chemical Engineering Section)
Ch 21 abc	The Physical Description of Chemical Systems (See Chemistry Section)
Ch 24 abc	Elements of Physical Chemistry (See Chemistry Section)
Ch 122 ab	The Structure of Molecules (See Chemistry Section)
Ch 124 abc	Elements of Physical Chemistry (See Chemistry Section)
Ch 129 abc	The Structure of Crystals (See Chemistry Section)
Ch 223 ab	Statistical Mechanics (See Chemistry Section)
EE 20 abc	Physics of Electronic Devices (See Electrical Engineering Section)
ES 205 abc	Theory of Solids (See Engineering Science Section)

Ph 125 abc	Quantum Mechanics (See Physics Section)
Ph 214 ab	Solid State Physics (See Physics Section)
Ph 221	Topics in Solid State Physics (See Physics Section)

Mathematics

UNDERGRADUATE SUBJECTS

Ma 1 abc. Freshman Mathematics. *9 units (4-0-5); first, second, third terms. Prerequisites: High school algebra and trigonometry.* Topics covered: The calculus of functions of one variable and an introduction to differential equations; vector algebra; analytic geometry in two and three dimensions; infinite series. The course work consists of two general lectures each week in which the mathematical notions of the calculus and the other topics listed above are presented and two class recitations which provide active practice in applications of the corresponding mathematical techniques. Instructor in charge: Bohnenblust.

Ma 1.5 abc. Advanced Placement Freshman Mathematics. *9 units (4-0-5); first term. 12 units (5-0-7); second and third terms.* This course is intended for entering freshmen who are given advanced placement in mathematics but who do not qualify for Ma 2. The course covers the material for Ma 2 together with certain topics from Ma 1. Students who complete this course will have satisfied the Institute requirement for Ma 1 abc and Ma 2 abc. Instructors: Glasner, Schmidt.

Ma 2 abc. Sophomore Mathematics. *9 units (4-0-5); first, second, third terms.* A continuation of the freshman mathematics course including: linear algebra; matrices and determinants; differential equations; an extension of the calculus to functions of several variables. Instructors in charge: Apostol, Crawley.

Ma 5 abc. Introduction to Abstract Algebra. *9 units (3-0-6); three terms.* Groups, rings, fields, and vector spaces are presented as axiomatic systems. The structure of these systems is studied, making use of the techniques of automorphisms, homomorphisms, linear transformations, subsystems, direct products, and representation theory. Many examples are treated in detail. Instructors: Aschbacher, Dean, McKay.

Ma 31. Introduction to the Constructive Theory of Functions. *9 units (3-0-6); third term. Prerequisite: Ma 1 abc.* Polynomial approximation. The Weierstrass theorem and the Bernstein polynomials. Extremal properties of the Chebyshev polynomials. Markov's theorems. Classical orthogonal polynomials. Applications to interpolation and approximation integration. Not offered in 1970-71.

Ma 91. Special Course. *9 units (3-0-6).* In 1970-71 three special courses will be given, as follows:

Ma 91 a. *First term.* Introduction to Potential Theory. Instructor: Glasner.

Ma 91 b. *Second term.* Introduction to Probability Theory. Instructor: Lorden.

Ma 91 c. *Third term.* Basic Numerical Mathematics. Instructor: J. Todd.

Ma 92 abc. Senior Thesis. *9 units (0-0-9); three 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 term and will be supervised by a member of the staff. Students will consult periodically with their supervisor, and will submit a thesis at the end of the year.

Ma 98. Reading. *3 units or more by arrangement.* Occasionally a reading course under the supervision of an instructor will be offered. Topics, hours, and units by arrangement. Only qualified students will be admitted after consultation with the instructor in charge of the course.

ADVANCED SUBJECTS

[A] The following courses are open to undergraduate and graduate students. Notice that some courses are given on an alternating basis.

Ma 102. Differential Geometry. *9 units (3-0-6).* Selected topics in metrical differential geometry. Not offered in 1970-71.

Ma 103. Algebraic Geometry. *9 units (3-0-6). Prerequisite: Ma 5 abc.* A study of the relations between geometric objects (varieties) and the algebraic structures attached to them. Not offered in 1970-71.

Ma 104. Projective Geometry. *9 units (3-0-6). Prerequisite: Ma 5 abc.* Foundations of projective geometry. Theorems of Desargues and Pappus. Introduction of coordinates. Selected topics on properties of incidence and order, and various systems of coordinates. Not offered in 1970-71.

Ma 108 abc. Advanced Calculus. *12 units (4-0-8); three terms. Prerequisite: Ma 2.* In this course, a sequel to Ma 2, more advanced techniques and applications of the theory of real and complex analysis are treated. An introduction to metric spaces is the point of departure for the theory of convergence, and applications are made to infinite series and infinite products of real and complex numbers. The theory of the Lebesque integral of functions of one or more variables is considered. Other topics include: functions defined by integrals; Fourier series and integrals; Poisson summation formula. Instructors: Luxemburg, Sampson.

Ma 109. Delta Functions and Generalized Functions. *9 units (3-0-6).* Introduction to operational calculus and to delta functions. Applications to ordinary and partial differential equations. Not offered in 1970-71.

Ma 112 ab. Elementary Statistics. *9 units (3-0-6). Ma 112 a. First term and repeated in second. Ma 112 b. Third term.* This course is intended for anyone interested in the application of statistics to science and engineering. Ma 112 a covers the fundamental concepts of probability and statistics, curve fitting and least squares, and hypothesis testing, including x^2-tests, t-tests, and analysis of variance. Ma 112 b is devoted to more intensive study of selected topics, including nonparametric methods, sequential tests and confidence intervals, and point estimation. Instructors: Dean, Lorden.

Ma 116 abc. Mathematical Logic and Axiomatic Set Theory. *9 units (3-0-6); three terms. Prerequisite: Ma 5 abc or equivalent.* The predicate calculus and functional calculi of first order are presented and problems in the foundations of mathematics are studied. Included are Boolean algebra, theorems of Gödel, axiomatic set theory, and theory of cardinal and ordinal numbers. Instructor: Thompson.

Ma 118 abc. Functions of a Complex Variable. *9 units (3-0-6); three terms. Prerequisite: Ma 108 or equivalent.* Review of the basic concepts of the theory of analytic functions (Cauchy's theorem, singularities, residues, contour integration, analytic continuation). Further topics selected from: entire functions, conformal mapping, differential equations, special functions, applications of complex variable analysis. Instructor: Gaier.

Ma 120 abc. Abstract Algebra. *9 units (3-0-6); three terms. Prerequisite: Ma 5.* Abstract development of the basic structure theorems of groups, commutative and non-commutative rings, lattices, and fields. Instructor: Wales.

Ma 121 abc. Combinatorial Analysis. *9 units (3-0-6); three terms. Prerequisite: Ma 5.* Elementary and advanced theory of permutations and combinations. Theory of partitions. Theorems on choice including Ramsey's theorem, the Hall-König theorem. Existence and construction of block designs with reference to statistical design of experiments, linear programming, and finite geometries. Instructors: Ryser, van Lint.

Ma 125 abc. Analysis of Algorithms. *9 units (3-0-6); three terms.* Mathematical theory associated with algorithms for information processing; expected time and space requirements of algorithms, comparison of algorithms, construction of optimal algorithms, theory underlying particular algorithms. Instructor: Liang.

Ma 137 abc. Real Variable Theory. *9 units (3-0-6); three terms. Prerequisite: Ma 108 or equivalent.* Point set topology, measure theory and integration theory. The theory of the Lebesque L^p-spaces of measurable functions. Functions of bounded variation and the theory of differentiation of functions of a real variable. Introduction to Fourier analysis, ergodic theory and the theory of integral equations. Instructor: DePrima.

Ma 141 abc. Ordinary Differential Equations. *9 units (3-0-6); three terms. Prerequisite: Ma 108 or equivalent.* Existence, uniqueness, continuous dependence on parameters of solutions of differential equations. Singular points, periodic solutions, stability, boundary value problems, eigenvalues. Instructor: Fenichel.

Ma 142 abc. Introduction to Partial Differential Equations. *9 units (3-0-6); three terms. Prerequisite: Ma 108 or equivalent.* Topics will include the following: Equations of the first order. Linear equations of the second order. Boundary value and eigenvalue problems for elliptic equations. Initial value and initial boundary value problems for parabolic and hyperbolic equations. Applications to problems of mathematical physics. Not offered in 1970-71.

Ma 143 abc. Introduction to Functional Analysis. *9 units (3-0-6); three terms. Prerequisite: Ma 108 or equivalent.* General theory of Hilbert and Banach spaces. Hahn-Banach extension principle, Banach-Steinhaus uniform boundedness principle, closed graph theorem, Krein-Milman theorem. Weak topologies. Separable and reflexive Banach spaces. Spectral analysis in Hilbert space. Operational calculus of operators on Banach spaces. Riesz-Schauder theory of compact operators. Instructor: Boyd.

Ma 144 ab. Probability. *9 units (3-0-6); first and second terms. Prerequisite: Ma 108 or equivalent.* Either term may be taken without the other, e.g. in combination with Ma 112 a. The first term is an introduction to stochastic processes and includes Markov chains, birth and death processes, compound Poisson processes and Brownian motion with applications. The second term is designed to provide a foundation for more advanced study and covers the basic concepts and tools of modern probability theory, including random variables and distributions, expectation, characteristic functions, and the fundamental limit theorems. Not offered in 1970-71.

Ma 150 abc. Combinatorial Topology. *9 units (3-0-6); three terms.* Introduction to combinatorial topology. The course covers homology and cohomology theory with applications to fixed point theorems and homotopy theory. Selected topics from the theory of fiber bundles. Instructor: Fuller.

Ma 160 abc. Number Theory. *9 units (3-0-6); three terms. Prerequisite: Ma 108 abc or equivalent.* The first term, Ma 160 a, is a review of the elementary theory of numbers including congruences, numerical functions, elementary theory of primes, quadratic residues. The second and third terms, Ma 160 bc, include topics selected from: zeta functions, distribution of primes, elliptic modular functions, asymptotic theory of partitions, geometry of numbers, foundation of ideal theory in algebraic number fields, theory of units, valuations and local theory, discriminants, differents. Instructors: O. Todd, Kisilevsky.

Ma 165. Diophantine Analysis. *9 units (3-0-6); third term. Prerequisite: Ma 5.* The study of rational or integral solutions of equations. Theory of rational approximations to irrational numbers, and theory of continued fractions. The theorems of Thue-Siegel and Roth will be included. Instructor: Kisilevsky.

Ma 190 abc. Elementary Seminar. *9 units; three terms.* This seminar is restricted to first year graduate students and is combined with independent reading. The topics will vary from year to year. Instructors: Dilworth, Lorden.

[B] The following courses are open primarily to graduate students. Notice that some courses are given on an alternating basis.

Ma 205 abc. Advanced Numerical Analysis. *9 units (3-0-6); three terms. Prerequisite: AMa 105 or equivalent.* Discussion of areas of current interest in numerical analysis and related mathematics, such as: matrix inversion and decomposition, ordinary differential equations, partial differential equations, integral equations, conformal mapping, discrete problems, linear programming and game theory, approximation theory, applications of functional analysis, theory of machines, theory of programming, theory of context-free languages, estimates for characteristic values of matrices.

Each quarter will be treated as a separate unit. Where appropriate, accompanying laboratory periods will be arranged as a separate reading course. Instructors: J. Todd, O. Todd.

Ma 216 abc. Advanced Mathematical Logic. *9 units (3-0-6); three terms.* The propositional and predicate calculus. Gödel's completeness theorem. Recursive function theory and applications: Gödel's incompleteness theorem, undecidability. A treatment of the von Neumann-Bernays-Gödel set theory. Discussion of the axiom of choice, continuum hypothesis and inaccessible sets. Not offered in 1970-71.

Ma 222 abc. Group Theory. *9 units (3-0-6); three terms. Prerequisite: Ma 120 or permission of instructor.* An introduction to the basic properties of finite and infinite groups. Theorems on homomorphisms, the theory of abelian groups, permutation groups, free groups, automorphisms. The Sylow theorems. Study of solvable, supersolvable, and nilpotent groups. A large part of the second term will be devoted to the theory of group representation, and will include applications to theoretical physics. Not offered in 1970-71.

Ma 223 ab. Matrix Theory. *9 units (3-0-6). Prerequisite: Ma 120 or equivalent.* Algebraic, arithmetic and analytic aspects of matrix theory. Not offered in 1970-71.

Ma 224 abc. Lattice Theory. *9 units (3-0-6); three terms. Prerequisite: Ma 120 or permission of instructor.* Systematic development of the theory of Boolean algebras, distributive, modular, and semi-modular lattices. Includes the study of lattice congruences, decomposition theory, and the structure of free lattices. Instructor: Dilworth.

Ma 226 ab. Ring Theory. *9 units (3-0-6); second and third terms. Prerequisite: Ma 120 or equivalent.* Selected topics in the structure of rings leading from classical theorems to areas of current research. Topics covered will include the role of the radical, decomposition theory, representation theory, group rings, polynomial identity rings, algebras, and commutative ideal theory. Instructors: Crawley, Wales.

Ma 238 abc. Advanced Complex Variable Theory. *9 units (3-0-6); three terms. Prerequisite: Ma 118 or equivalent.* In this course the knowledge of basic parts of the classical theory of analytic functions is assumed, and special topics are presented introducing topological and group-theoretical considerations, and relations to functional analysis. The topics will be selected from: linear spaces of analytic functions, conformal mapping, algebraic functions, Riemann surfaces, functions of several complex variables, singular integral equations. Not offered in 1970-71.

Ma 243 abc. Functional Analysis. *9 units (3-0-6); three terms. Prerequisite: Ma 143 or equivalent.* Discussion of the theory of normed linear spaces; the closed graph theorem; the Riesz-Schauder theory; topics in Hilbert space; Banach algebras. Not offered in 1970-71.

Ma 244 ab. Advanced Probability. *9 units (3-0-6); first and second terms. Prerequisite: Ma 144 or equivalent.* An exposition of probability theory in general sample spaces. Topics will include the following: modes of convergence of random variables, sequences of independent random variables, the central limit theorem, infinitely divisible distributions, conditional expectation, ergodic theory and the role of entropy in ergodic theory (and information theory). Not offered in 1970-71.

Ma 290. Reading. Occasionally advanced work is given by a reading course under the direction of an instructor. Hours and units by arrangement.

[C] The following courses and seminars are intended for advanced graduate students. They are research courses and seminars, offered according to demand, and covering selected topics of current interest. The courses offered, and the topics covered will be announced at the beginning of each term.

Ma 305 abc. Seminar in Numerical Analysis. *6 units. Three terms.*

Ma 320 ab. Special topics in Algebra. *9 units. First term.* Instructor: van Lint.

Ma 324 abc. Seminar in Matrix Theory. *Units to be arranged. Three terms.*

Ma 325 abc. Seminar in Algebra. *6 units. Three terms.*

Ma 340 abc. Special topics in Analysis. *9 units. Three terms.*

Ma 345 abc. Seminar in Analysis. *6 units. Three terms.*

Ma 350 ab. Special topics in Geometry. *9 units. First and second terms.*

Ma 355 abc. Seminar in Geometry. *6 units. Three terms.*

Ma 360 abc. Special topics in Number Theory. *9 units. Three terms.*

Ma 365 abc. Seminar in Number Theory. *6 units. Three terms.*

Ma 390. Research. *Units by arrangement.*

Ma 392. Research Conference. *2 units.*

For courses in Applied Mathematics see separate section.

Mechanical Engineering

UNDERGRADUATE SUBJECTS

ME 1 ab. Introduction to Design. *9 units (2-6-1); second and third terms. Prerequisite: Gr 1.* Essentials of machine drawing are covered in conjunction with the study of machine elements and mechanisms. Useful graphical and analytical techniques are developed as effective tools for rapid engineering approximations in preliminary design. Elements of kinematic and dynamic analysis of machines are treated along with other design criteria such as selection of materials, manufacturing methods, cost estimates, etc. Emphasis is placed on the rational approach and basic simplicity in formulating design concepts. Instructors: Morelli, Welch.

ME 3. Materials and Processes. *9 units (3-0-6); second term. Prerequisites: Ph 1 ab, Ch 1 abc.* A study of the materials of engineering and of the processes by which these materials are made and fabricated. The fields of usefulness and the limitations of alloys and other engineering materials are studied, and also the fields of usefulness and limitations of the various methods of fabrication and of processing machines. The student is not only made acquainted with the technique of processes but with their relative importance industrially and with the competition for survival which these materials and processes continually undergo. Text: *Engineering Materials and Processes,* Clark. Instructors: Buffington, Clark.

ME 5 abc. Design. *9 units (2-6-1); first, second, and third terms. Prerequisite: AM 95 ab or concurrently.* The purpose of this course is to develop creative ability and engineering judgment through work in design and engineering analysis. Existing devices are analyzed to determine their characteristics and the possibilities for improving their performance or economy and to evaluate them in comparison with competitive devices. Practice in the creation or synthesis of new devices is given by problems in the design of machines to perform specified functions. The fundamental principles of scientific and engineering knowledge and appropriate mathematical techniques are employed to accomplish the analysis and designs. Text: *Design and Production,* Kent. Instructors: Morelli, Welch.

ME 17 abc. Thermodynamics. *9 units (3-0-6); first, second, and third terms. Prerequisites: Ma 1 abc, Ph 1 abc.* An introduction to the laws governing the properties of matter in equilibrium and some aspects of nonequilibrium behavior. Definition and scales of temperature. The laws of classical thermodynamics. Thermodynamic potentials, Maxwell's relations, calculation of thermal properties and applications to various homogeneous systems. First order changes of phase and the Clausius-Clapeyron equation. Analyses of energy conversion cycles. General conditions for thermodynamic equilibrium, extremum properties of the thermodynamic potentials, and the thermodynamic inequalities. Chemical potential, mixtures of gases and vapors, solutions, basic chemical thermodynamics. Elementary statistical mechanics, ensembles, and statistical thermodynamics. Introduction to non-equilibrium thermodynamics, thermoelectric effects, and problems of heat conduction in solids. Thermodynamics of fluid flow. Some aspects of the kinetic theory of gases, calculation of transport properties by mean-free-path methods and simplified forms of the Boltzmann equation. Instructor: Rannie.

ME 19 abc. Fluid Mechanics and Gas Dynamics. *9 units (3-0-6); first, second, and third terms. Prerequisites: Ma 2 abc, Ph 1 abc.* Basic equations of fluid mechanics, theorems of energy, linear and angular momentum, potential flow, elements of airfoil theory. Flow of real fluids, similarity parameters, flow in closed ducts. Boundary layer theory in laminar and turbulent flow. Introduction to compressible flow. Flow and wave phenomena in open conduits. Theory and practice of some turbomachines such as fans, pumps, compressors, and turbines. Convective transfer of heat. Brief discussion of availability of mechanical, chemical, nuclear, and solar energy sources. Brief discussion and comparison of some types of power conversion systems. Instructor: Sabersky.

ADVANCED SUBJECTS

ME 100. Advanced Work in Mechanical Engineering. The staff in mechanical engineering will arrange special courses or problems to meet the needs of students working toward the M.S. degree or of qualified undergraduate students.

ME 101 abc. Advanced Design. *9 units (1-6-2); first, second, and third terms. Prerequisite: ME 5 abc or equivalent.* Creative design and analysis of machines and engineering systems are developed at an advanced level. Laboratory problems are given in terms of the need for accomplishing specified end results in the presence of broadly defined environments. Investigations are made of environmental conditions to develop quantitative specifications for the required designs. Searches are made for the possible alternate designs and these are compared and evaluated. Preferred designs are developed in sufficient detail to determine operational characteristics, material specifications, general manufacturing requirements and costs. Instructors: Morelli, Welch.

ME 118 abc. Advanced Thermodynamics and Energy Transfer. *9 units (3-0-6); first, second, and third terms. Prerequisites: ME 17 abc, ME 19 abc, or equivalent.* Equilibrium of chemical systems including dilute solutions, elements of non-equilibrium thermodynamics, basic concepts of statistical mechanics. Special problems in heat conduction involving non-isotropic media, moving sources, and changes of phase. Exact solutions of heat transfer problems in laminar flow for compressible and incompressible fluids. Problems in turbulent flow and the application of Reynolds analogy. Principles of mass transfer and problems involving the simultaneous transfer of heat and mass. Theory of black body radiation and radiation characteristics of solids and gases. Instructor: Acosta.

ME 126. Fluid Mechanics and Heat Transfer Laboratory. *(Same as ChE 126.) 9 units (0-6-3); third term. Prerequisites: ME 17 abc, ME 19 ab, or equivalent.* Students with other background shall obtain instructor's permission prior to registration. Introduction to some of the basic measurement techniques and phenomena in the fields of heat transfer, fluid mechanics, chemical kinetics, and unit operations. The student may select several short projects from a rather wide list of possible experiments. The selection will be based on the individual needs and interests of the student. The course is generally taken by first-year graduate students and seniors. Specific areas from which experiments may be selected include free and forced convection, boiling heat transfer, combustion, solid state energy conversion, free surface flows, supersonic flows, homogeneous gas phase kinetics, homogeneous gas-solid interaction, homogeneous liquid phase kinetics and control. Instructors: Sabersky, Shair, Welch, Zukoski.

ME 200. Advanced Work in Mechanical Engineering. The staff in mechanical engineering will arrange special courses on problems to meet the needs of advanced graduate students.

ME 300. Thesis Research.

Many advanced courses in the field of Mechanical Engineering may be found listed in other engineering options such as:

Applied Mechanics, page 305.

Hydraulics, page 356.

Jet Propulsion, page 361.

Materials Science, page 364.

Music

Mu 1. Fundamentals of Music. *5 units (2-0-3); first term.* Course content: Notation, music reading, chord structures, keys, elementary ear training, basic keyboard harmony. For students with little or no previous music study. Offered the first term of each year. Instructor: Ochse. *Not available for credit toward humanities-social science requirement.*

Mu 7. Music History and Music Theory. *9 units (3-0-6); second term. Prerequisite: Mu 1, or successful completion of the Music Fundamentals Test.* Course content, second term of alternate years, beginning in January, 1968: history of music during the Renaissance and Baroque periods; analysis of forms and styles. Course content, second term of alternate years, beginning in January, 1969: music theory, including diatonic chord progressions, common chord modulations, non-harmonic tones, composition in 2, 3, and 4 parts, harmonic analysis. Instructor: Ochse.

Mu 8. Music History and Music Theory. *9 units (3-0-6); third term. Prerequisite: Mu 7.* Course content, third term of alternate years, beginning in March, 1968: history of music from 1750 to the present; analysis of forms and styles. Course content, third term of alternate years, beginning in March, 1969: music theory, including chromatic progressions and modulations, altered chords, composition in more advanced forms, introduction to counterpoint. Instructor: Ochse.

Philosophy and Psychology

UNDERGRADUATE SUBJECTS

Pl 1. Introduction to Philosophy. *9 units (2-0-7).* A study of a selected number of major historical philosophical systems by way of readings in the sources. Priority is given to philosophical traditions which are still existent and influential in the contemporary world. Instructor: Jones.

Pl 3. Existentialism and Modern Man. *9 units (3-0-6).* A critical study of the development of Existentialism in France and Germany. The course will explore literary manifestations of the movement. Alienation in Existentialism and alienation in contemporary counter cultures will be compared. Instructor: Hertz.

Pl 4. Human Nature and Ethics. *9 units (3-0-6).* A study of ethical values in relation to human nature and culture. Conceptions of human nature provide bases for study of human value systems. All phases of human inquiry which bear on human nature are considered. Instructor: Bures.

Pl 6 a. The Psychology of Behavorial Processes. *9 units (3-0-6); first term.* A study of the individual, social and cultural factors that contribute to the development of human behavior and human interaction. Both theoretical and empirical formulations will be used in the analysis of the content and process of behavior, especially as it occurs within the student's experiential field. Instructor: Breger.

Pl 6 b. The Psychology of Personality Development. *9 units (3-0-6); second term.* A study of psychological development from birth to maturity. Attention is paid to stages of development, roles, emotional and motivational patterns. A positive conception of growth and creativity and factors inhibiting growth are emphasized in terms of a basic vocabulary. Instructor: Bures.

Pl 7. Human Relations. *7 units (3-0-4); third term.* An introduction to the principles and practices of interpersonal relationships. Individual and group interactions are analyzed using current theories of personality organization, motivation and group dynamics. Lectures, laboratory and field trips are employed to investigate the nature of social sensitivity, leadership, communication and group development. *Not available for credit toward humanities-social science requirement.*

Pl 9. Theory of Knowledge. *9 units (3-0-6).* The theory of knowledge both classical and modern, with emphasis on contemporary views. Topics to be discussed will include: the problem of perception and the status of our knowledge concerning the external world, other minds, the past and the future; theories of truth; the concept of rationality; the concept of a person. Instructor: Hertz.

Pl 11. Classical and Modern Approaches to Self. *9 units (3-0-6).* An examination of philosophical views, both occidental and oriental, classical and contemporary, on the problem of self-identity. Included will be representative views from idealism, rationalism, pragmatism, existentialism, mysticism, esotericism and modern psychology. Instructor: Bures.

Pl 12. Induction. *9 units (3-0-6).* Inductive logic and the foundations of probability. Investigation of the inductive basis of scientific theories. The course will be built around readings in the contemporary literature. Instructor: Thompson.

Pl 13. Reading in Philosophy and Psychology. Elective in any term or for summer reading with consent of specific instructor. Units to be determined by consultation with the instructor. Reading in philosophy or psychology, supplementary to, but not substituted for, courses listed; supervised by members of the department. *Not available for credit toward humanities-social science requirement.*

Pl 14. Introduction to Theory of Value. *9 units (3-0-6).* An exploration of some of the important normative questions facing modern man. Topics to be discussed will include the validation of value-judgments, the search for goals and principles to guide personal decision-making, and the just society. Instructor: Hertz.

ADVANCED SUBJECTS

Pl 100 abc. Philosphy of Science. *9 units (2-0-7). A full-year sequence.* A study of the relationships between science and philosophy. The three terms respectively concentrate on: language and logic, logical analysis of some basic problems in the philosophy of science such as measurement, causality, probability, induction, space, time, reality; human nature, science and society. Not open to new registrants second and third terms. Instructor: Bures.

Pl 101 abc. History of Thought. *9 units (2-0-7). A full-year sequence.* A study of the basic ideas of Western Civilization in their historical development. The making of the modern mind as revealed in the development of philosophy and in the relations between philosophy and science, art and religion. The history of ideas in relation to the social and political backgrounds from which they came. Instructor: Hertz.

Pl 103. World Views. *9 units (2-0-7).* A study of world views and of the ways in which they are reflected in the literature, art, philosophy and science of different cultures. Several contrasting views will be selected for detailed study. Instructor: Jones.

Pl 113. Reading in Philosophy and Psychology. Same as Pl 13 but for graduate credit.

IS 250 abc. Mathematical Linguistics. *9 units (3-0-6).* (See page 360.)

Physics

UNDERGRADUATE SUBJECTS

Ph 1 abc. Kinematics, Particle Mechanics, and Electric Forces. *9 units (4-0-5); first, second, and third terms. Prerequisites: High school physics, algebra, and trigonometry.* The first year of a two-year course in Introductory Classical and Modern Physics. The course work consists of one general lecture each week, in which the main topics of the course are presented, and three class recitations in which more specific questions are treated, largely through the solution of problems. Topics covered in the first year include kinematics, the Lorentz transformation, nonrelativistic and relativistic particle mechanics, electric and magnetic forces, planetary motion, harmonic motion, geometrical optics, interference, diffraction, and scattering of radiation, kinetic theory, thermodynamics, and black body radiation. Instructors: Walker, Garmire, Lauritsen and Assistants.

Ph 2 abc. Electricity, Fields, and Quantum Mechanics. *9 units (4-0-5); first, second, and third terms. Prerequisites: Ph 1 abc, Ma 1 abc, or their equivalent.* The second year of a two-year course in Introductory Classical and Modern Physics. The course is organized along similar lines to Ph 1 abc. Topics covered in the second year include electricity and magnetism (with emphasis upon the field concept), Maxwell's equations, electromagnetic potentials, free waves and cavity resonators; quantum mechanics. Instructors: Vogt, Sciulli, Kavanagh and Assistants.

Ph 3. Physics Laboratory. *6 units; first, second and third terms.* Normally not offered to freshmen the first term. The six units cover a three-hour laboratory session per week, and three hours per week in preparation, library work and writing of reports. This introductory laboratory course emphasizes the treatment of errors entering into physical measurements, the nature of probability and graphical analysis. It also contains experiments in direct current circuits and in the application of Newton's laws of motion to the behavior of masses moving on nearly frictionless surfaces. There is also an introduction to the use of computers through the campus-wide system known as CITRAN. Instructors: Stone, Pine and Assistants.

Ph 4. Physics Laboratory. *6 units; third term only. Prerequisite: Ph 3 or equivalent.* This course is an extension of Ph 3 laboratory. It involves experiments in classical physics such as the harmonic oscillator, which is studied in both the mechanical and electrical forms. Other experiments are concerned with the properties of wave motion in various media and with some of the fundamental properties of gases. Instructors: Stone, Pine and Assistants.

Ph 5. Physics Laboratory. *6 units; first term. Prerequisites: Ph 1 abc, Ph 2 a (or taken concurrently) and Ph 3 or equivalent.* This is a continuation of Ph 3 laboratory. Measurements of physical quantities, their analysis and assignment of errors are stressed. Most of the experiments are concerned with topics in the theoretical course, Ph 2 a. These include experiments in electrostatics and direct currents. Instructors: Stone, Pine and Assistants.

Ph 6. Physics Laboratory. *6 units; second term. Prerequisites: Ph 1 abc, Ph 2 b (or taken concurrently) and Ph 3 or equivalent.* This laboratory course involves experiments in electromagnetic phenomena such as electromagnetic induction, properties of magnetic materials and high frequency circuits. The mobility of ions in gases is studied and a precise measurement of the value of e/m of the electron may be found. Instructors: Stone, Pine and Assistants.

Ph 7. Physics Laboratory. *6 units; third term. Prerequisites: Ph 5 or Ph 6.* In this laboratory course, experiments are performed in atomic and nuclear physics. These include 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: Stone, Pine and Assistants.

Ph 10 ab. Special Topics in Introductory Physics. *6 units (2-0-4); second and third terms.* An elective course for first year students, based upon material covered in Ph 1 abc. The purpose of the course is to provide interested students an opportunity to penetrate more deeply into some of the topics covered earlier in Ph 1. Emphasis will be given to the analysis of problems of broad scientific and technical interest. Topics to be covered will be selected partly on the basis of class preference. Not offered in 1970-71.

Ph 77 ab. Advanced Physics Laboratory. *6 units; first, second, or third terms.* A two-term laboratory course open to junior and senior physics majors. The purpose of the course is to familiarize the student with laboratory equipment and procedures that are used in the research laboratory. The experiments are designed to illustrate fundamental physical phenomena, such as Compton scattering, nuclear and paramagnetic resonance, the photoelectric effect, the interaction of charged particles with matter, etc. Instructors: Whaling, Persson, Mercereau.

Ph 78 abc. Senior Thesis Experimental. *9 units; first, second, and third terms. Prerequisite: Consent of instructor.* This course is intended to provide supervised experimental research experience for seniors in physics. Requirements will be set by individual faculty members, but will include a term paper based upon actual laboratory experience. The selection of topics and the final report must be approved by the Physics Undergraduate Committee. Not offered on Pass/Fail basis. Instructors: Physics Staff.

Ph 79 abc. Senior Thesis Theoretical. *9 units; first, second, and third terms. Prerequisite: Consent of instructor.* This course is intended to provide supervised theoretical research experience for seniors in physics. Requirements will be set by individual faculty members, but will include a term paper based on the work performed. The selection of topics and the final report must be approved by the Physics Undergraduate Committee. Not offered on Pass/Fail basis. Instructors: Physics Staff.

Ph 87 abc. Experimental Projects in Applied Physics. *Units by arrangement. 6 unit minimum each term. Prerequisite: Ph 7 or EE 90 abc or equivalent; open to seniors with consent of instructor.* A general program designed to give the student an opportunity to do original experiments in applied physics. Emphasis is placed upon the selection of significant projects, the formulation of the experimental approach and the interpretation of data as well as upon the use of modern laboratory techniques. Facilities are available for experiments in cryogenics, lasers, quantum electronics, ferromagnetism, optics, microwaves, plasma physics, and semiconducting solid state. Text: Literature references. Instructor: Humphrey.

Ph 93 abc. Topics in Contemporary Physics. *9 units (3-0-6); first, second, and third terms. Prerequisites: Ph 102 abc or Ph 125 abc.* A series of introductory one-term courses on topics in contemporary physics. In general, students may register for any particular term. In 1970-71 the topics will be (a) an introduction to nuclear physics, (b) elementary particle physics, (c) low temperature physics. Instructors: Tombrello, Pine and Goodstein.

ADVANCED SUBJECTS

Ph 102 abc. Modern Physics. *9 units (3-0-6); first, second, and third terms. Prerequisites: Ph 2 abc, Ma 2 abc, or equivalents; Ph 106 abc concurrently.* Applications of quantum mechanics to atomic and nuclear phenomena. The one-electron atom, the periodic table, atomic spectra, and quantum statistics will be studied. In addition there will be an introduction to nuclear physics and to some of the interactions of radiation with matter. Additional selected topics will be studied, depending upon the instructor and the interests of the students. These might, for example, be chosen from the fields of solid state physics, low temperature physics, cosmic rays, elementary particles, nuclear physics, quantum optics, or astrophysics. Text: *Principles of Modern Physics,* Leighton. Instructors: Peck, Neugebauer.

Ph 106 abc. Topics in Classical Physics. *9 units (3-0-6); first, second, and third terms. Prerequisites: Ph 2 abc, Ma 2 abc.* An intermediate course in the application of the basic principles of classical physics to a wide variety of subjects. It is intended that roughly half of the year will be devoted to mechanics, and half to electromagnetism. Topics to be covered include the Lagrangian and Hamiltonian formulations of mechanics, small oscillations and normal modes, boundary value problems, multipole expansions, and various applications of electromagnetic theory. Graduate students majoring in physics or astronomy will be given only 6 units credit for this course. Instructors: Mathews, Plesset.

Ph 112 abc. Modern Physics. *9 units (3-0-6); first, second, and third terms. Prerequisites: Ph 106, Ph 125 abc, or equivalents. Not open to students who have taken Ph 102.* A lecture and problem course on the physics of atoms, nuclei, and elementary particles. Among the topics discussed are: quantum mechanics, atomic and molecular structure, electromagnetic interactions, quantum statistical mechanics, superfluidity and superconductivity, selected topics from solid state physics, nuclear structure physics, and elementary particle physics. Text: *Principles of Modern Physics,* Leighton. Instructor: Barnes.

Ph 113 abc. Solid State Physics. *9 units (3-0-6); first, second, and third terms. Prerequisite: Ph 102 abc or equivalent.* A lecture and problem course dealing on an introductory level with experimental and theoretical problems in solid state physics. The topics to be discussed include: crystal structure, lattice vibrations, Fermi electron gas, semiconductors, superconductivity, magnetic resonance, ferroelectricity, linear and nonlinear optical phenomena in insulators. Instructors: Goodstein, Mercereau.

Ph 125 abc. Quantum Mechanics. *9 units (3-0-6); first, second, and third terms. Prerequisite: Ph 2 abc. Recommended: Ph 102 abc, and either AM 95 abc or Ma 108 abc. Available to juniors only by permission of instructor.* A fundamental course in quantum mechanics aimed at understanding the mathematical structure of the theory and its application to physical phenomena at the atomic and nuclear levels. The subject matter will include the various formulations of quantum mechanics; the classical limit; angular momentum and spin; scattering theory; stationary and time dependent perturbation theory; the variational method; quantum statistics; atomic and molecular structure. Text: *Quantum Mechanics,* Dicke and Wittke. Instructors: Cowan, Tollestrup, Boehm.

Ph 129 abc. Methods of Mathematical Physics. *9 units (3-0-6); first, second, and third terms. Prerequisites: Ph 106 abc or the equivalent. Recommended: Either AM 95 abc or Ma 108 abc.* Aimed at developing familiarity with the mathematical tools useful in physics, the course discusses practical methods of summing series, integrating, and solving differential equations, including numerical methods. The special functions (Bessel, Elliptic, Gamma, etc.) arising in physics are described, as well as Fourier series and transforms, partial differential equations, orthogonal functions, eigenvalues, calculus of variations, integral equations, matrices and tensors, and group theory. The emphasis is toward applications, with special attention to approximate methods of solution. Instructors: Barish, Davis.

Ph 171. Reading and Independent Study. Occasionally, advanced work involving reading, special problems, or independent study is carried out under the supervision of an instructor. Units in accordance with work accomplished. Approval of the instructor and of the student's Departmental Adviser or Registration Representative must be obtained before registering.

Ph 172. Experimental Research in Physics. *Units in accordance with the work accomplished.* Approval of the student's research supervisor and of his Departmental Adviser or Registration Representative must be obtained before registering.

Ph 173. Theoretical Research in Physics. *Units in accordance with the work accomplished.* Approval of the student's research supervisor and of his Departmental Adviser or Registration Representative must be obtained before registering.

Ph 203 ab. Nuclear Physics. *9 units (3-0-6); second and third terms. Prerequisites: Ph 102 abc or Ph 93 a and Ph 125 abc or equivalents.* A problem and lecture course in nuclear physics concerning experimental and theoretical methods for the study of nuclear structure. Topics include: Properties of Nuclei: size, mass, charge, static electromagnetic moments; two-body interactions; deuteron, low-energy scattering, medium energy scattering; Nuclear Models: liquid drop, independent particle shell model, intermediate coupling, collective model; Nuclear Reactions: compound nucleus, resonance reactions, direct interactions; Electromagnetic transitions and beta decay. The level will be approximately that of Preston, *Physics of the Nucleus.* Instructor: Tombrello.

Ph 204. Low Temperature Physics. *9 units (3-0-6); third term. Prerequisite: Ph 102 abc.* Introductory exposition of the subject of cryogenics. General coverage of topics includes (1) liquid helium II, (2) superconductivity, and (3) adiabatic demagnetization and nuclear alignment. Emphasis to be based on correlating behavior of matter at low temperatures with existing theoretical interpretations. Not offered in 1970-71.

Ph 205 abc. Advanced Quantum Mechanics. *9 units (3-0-6); first, second, and third terms. Prerequisites: Ph 125 abc, Ph 102 abc.* The course will cover advanced nonrelativistic quantum mechanics and relativistic quantum mechanics with an introduction to field theory. Topics covered include angular momentum, transition probabilities, scattering theory, Dirac equation, Feynman diagrams, quantum electrodynamics, and other applications of field theory. Instructor: Mandula.

Ph 209 abc. Electromagnetism and Electron Theory. *9 units (3-0-6); first, second, and third terms. Prerequisite: Ph 106 abc.* Electromagnetic fields in vacuum and in matter; classical electron theory, retarded potentials, radiation, dispersion, and absorption; theories of the electric and magnetic properties of materials; selected topics in wave propagation; special relativity. Some topics of astrophysical interest will be studied in detail. Instructor: Bahcall.

Ph 213 ab. Nuclear Astrophysics. *9 units (3-0-6); first and second terms.* A lecture or reading course in the applications of nuclear physics to astronomy. The first term reviews the fundamental properties and structure of nuclei. The experimental evidence on nuclear cross sections is extensively analyzed in terms of current theories of nuclear reactions. The second term covers energy generation and element synthesis in stars, supernovae, and the massive condensations in quasars and extended radio sources. Nuclear evidence on the origin of the solar system is also discussed. Instructor: Fowler.

Ph 214 abc. Solid State Physics. *9 units (3-0-6); first, second, and third terms. Prerequisite: Ph 125 abc. Recommended: Ph 113 abc.* An introductory problem and lecture course in the experimental and theoretical aspects of modern solid state physics. Topics to be presented will include: Crystal structures and classification of solids; lattice dynamics; thermal and electric properties of metals, insulators and semiconductors; an introduction to the magnetic properties of solids; superconductivity, modern developments. Instructor: Tsuei.

Ph 216 abc. Plasma Physics. *9 units (3-0-6); first, second, and third terms. Prerequisite: Ph 106 abc or equivalent.* An introduction to the principles of plasma physics. Topics presented will include: Orbits of charged particles in electric, magnetic, and gravitational fields; elementary processes in the production and decay of ionized gases; continuum magnetohydrodynamics and elementary stability theory; transport processes such as conductivity and diffusion; waves, oscillations, and radiation in plasmas. Examples from physics, engineering, and astrophysics will be discussed. Not offered in 1970-71.

Ph 218 ab. Electronic Circuits and their Application to Physical Research. *9 units (3-0-6); first and second terms. Permission of the instructor is required in order to register for this course.* A course on electronic circuits with primary emphasis on basic factors entering into the design and use of electronic instruments for physical research. Topics considered will include the theory of response of linear networks to transient signals, linear and nonlinear properties of electron tubes and practical circuit components, basic passive and active circuit combinations, cascade systems, amplifiers, feedback in linear and nonlinear systems, statistical signals, noise, and practical construction. Particular examples will be taken from commonly used research instruments. Given in alternate years. Not offered in 1970-71.

Ph 221. Topics in Solid State Physics. *9 units (3-0-6); third term. Prerequisite: Ph 214 ab.* A course on selected topics in solid state physics, with different subjects being presented each year. Not offered in 1970-71.

Ph 224 abc. Topics in Space Physics. *9 units (3-0-6); first, second and third terms. Prerequisites: Ph 102, Ph 106.* Topics will be selected from: Applications of plasma physics in space physics; the solar wind, the interplanetary magnetic field, and related solar and planetary phenomena. Galactic cosmic rays; characteristics and interaction with the interstellar medium; theories of origin; solar modulation. Origin and propagation of solar cosmic rays. Trapped radiation. Basic principles of cosmic ray, plasma, and magnetic field measurements. Not offered in 1970-71.

Ph 227 abc. Statistical Physics. *9 units (3-0-6); first, second, and third terms. Prerequisites: Ph 102 abc, Ph 106 abc.* This course will present a thorough introduction to problems in physics which are fundamentally statistical. Topics covered will be: The fundamental laws and concepts of thermodynamics. Kinetic theory and transport phenomena. Statistical mechanics and the connection between macroscopic and atomic laws. Random functions and statistical continuum theories. Instructor: Jokipii.

Ph 230 abc. Elementary Particle Theory. *9 units (3-0-6); first, second, and third terms. Prerequisite: Ph 205 abc (may be taken concurrently).* A course in advanced techniques of elementary particle theory, including field theory, renormalization, dispersion theory, groups and symmetries, and other approaches of current interest. Instructor: Frautschi.

Ph 231 abc. High Energy Physics. *9 units (3-0-6); first, second, and third terms. Prerequisites: Ph 125 abc or equivalent, Ph 205 abc (may be taken concurrently).* A course covering the properties of the elementary particles and their interactions, especially at high energies. Topics discussed include the classification of the particles and their properties, strangeness theory, pion-nucleon and nucleon-nucleon interactions, photoproduction of pions, high energy electron scattering, high energy electromagnetic interactions, production of strange particles, hyperfragments. Instructor: Feynman.

Ph 234 abc. Topics in Theoretical Physics. *9 units (3-0-6); first, second, and third terms. Prerequisites: Ph 205 abc and Ph 231 abc, or permission of instructor.* In 1970-71 current topics of research in high energy physics will be presented. Independent study and research will be encouraged. The detailed content of this course may vary from quarter to quarter. Instructor: Zweig.

Ph 236 abc. Relativity. *9 units (3-0-6); first, second, and third terms. Prerequisite: A mastery of special relativity at the level of* Goldstein, *Classical Mechanics, or of* Leighton, *Principles of Modern Physics.* A systematic exposition of Einstein's general theory of relativity, with particular emphasis on applications to astrophysical and cosmological problems. Topics covered include a review of special relativity; accelerated observers in special relativity; modern differential geometry; the foundations of general relativity and of other geometric theories of gravity; past and future experimental tests of general relativity; relativistic stars; gravitational collapse; black holes; gravitational radiation; cosmology; singularities and singularity theorems. Instructor: Thorne.

Ph 237 abc. Theoretical Nuclear Physics. *6 units (2-0-4); first, second, and third terms. Prerequisite: Ph 205 or equivalent.* The course covers an introduction to the theory of nuclear structure, with emphasis on nuclear models such as the shell and unified models. Inelastic nuclear processes at low energies will also be discussed. Not offered in 1970-71.

Ph 238 abc. Seminar on Theoretical Physics. *4 units; first, second, and third terms.* Recent developments in theoretical physics for specialists in particle physics. In charge: Frautschi, Gell-Mann, Zweig.

Ph 240 abc. Current Theoretical Problems in Particle Physics. *6 units (2-0-4); first, second, and third terms. Prerequisite: Ph 230 abc or equivalent.* Emphasis on symmetries and broken symmetries. Discussion and argument are encouraged. Instructor: Gell-Mann.

Ph 241. Research Conference in Physics. *4 units; first, second, and third terms.* Meets once a week for a report and discussion of the work appearing in the literature and that in progress in the laboratory. Advanced students in physics and members of the physics staff take part.

Ph 300. Research in Physics. *Units in accordance with work accomplished.* Ph 300 is elected in place of Ph 172 when the student has progressed to the point where his research leads directly toward the thesis of the degree of Doctor of Philosophy. Approval of the student's research supervisor and of his Departmental Adviser or Registration Representative must be obtained before registering.

Political Science

PS 1 abc. An Introduction to Political Behavior. *9 units (3-0-6); first, second, and third terms.* Three major approaches to the study of political behavior. First term: political psychology. Second term: group processes. Third term: stratification. Each approach will be applied to the study of political change and the methods of each will be subjected to critical analysis. Instructors: Bates, Marvick.

ADVANCED SUBJECTS

PS 102. Black Africa 800 A.D. to the Present. *9 units (2-0-7).* Topics relating to the origins of Americans of African descent, including African empires such as Ghana and Songhai, the Slave Trade, and the emergence of independent nations. Emphasis will be given to West Africa and there will be African lecturers. Instructors: Munger, in collaboration with Scudder and Bates.

PS 110 ab. Political Modernization and Development. *9 units (3-0-6); second and third terms.* The first term is devoted to the general literature in the field; the second, to case studies of African nations; e.g., Nigeria and the Congo. Topics will include: the nature and origins of political change, the formation of new elites and pressure groups, the erosion of traditional sources of power, the integrative role of political symbols, and the role of parties and bureaucracies in managing the process of change. Instructor: Bates.

PS 115. Seminar on National Security. *9 units (2-0-7); third term.* The object of this course is to afford an opportunity to study some of the problems faced by the U.S. Government in the world today. Consideration will be given to such matters as the process of policy formation within the government, the relationship of disarmament and arms control to defense policy, and the role of international organizations in the development of an orderly world society. Instructor: Elliot.

PS 135 abc. Political Geography of Developing Countries. *9 units (2-0-7).* The swift transition from colonialism or an undeveloped state to the present includes the growth of one-party states; the role of the military; tribal, religious, and class pressures; the internal and external role of boundaries; and new foreign policies including such regional groupings as the OAU and OAS. Emphasis on Africa with outside lecturers, including AUFS associates, on Latin America and Southeast Asia. Instructor: Munger.

PS 136 abc. Science and Technology in Developing Areas. *9 units (2-0-7); first term required for those who wish to take the second and third terms.* This course examines the impact of science and technology on the societies of developing areas with special attention paid to Africa. While science and technology present an extraordinary opportunity for raising living standards. its impact on human behavior and values also poses significant problems. An attempt will be made to isolate and analyze a number of these as well as to consider the best use of science in terms of meaningful economic and social development. This course can be taken as an economics elective. Instructors: Huttenback, Munger, Oliver, and Scudder.

PS 140. Seminar in Foreign Area Problems. *9 units (3-0-6); second term.* The object of this course is to give students an opportunity to study in some detail problems current in certain selected foreign areas. Three or four areas will be considered each time the course is given, and the selection will normally vary from year to year. Instruction will be given mainly by area specialists of the American Universities Field Staff. Instructors: Munger, and members of AUFS.

PS 141 abc. African Studies. *9 units (2-0-7).* Problems of transition from colonial status to independence in countries south of the Sahara. Racial and cultural tensions in the Republic of South Africa. Instructor: Munger.

Psychology

(See under Philosophy)

Russian

(See under Languages)

GENERAL INDEX